

Alberta Health

Environmental public health indoor air quality manual

A guide for environmental public health
professionals

Environmental Public Health

August 31, 2012

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Chapter I

Introduction to indoor air quality

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I. Introduction to indoor air quality

I.A. Purpose and scope of the manual

This manual describes a general framework and provides a menu of tools to empower Alberta Environmental Public Health professionals (EPHPs) in their investigations and management of indoor air quality matters. The manual does not intend to be a definitive nor a comprehensive prescriptive work; rather, it offers a concise and up-to-date collection of methodologies and approaches that are useful in problem identification, risk intervention and harm reduction. In addition to providing practical tools useful in field applications, this manual re-acquaints practitioners with toxicological, risk assessment and risk management principles that are also useful in other Environmental Public Health fields. The manual consists of four chapters and nine appendices.

- **Chapter I Introduction to indoor air quality**

The first chapter introduces health concepts, general information on IAQ-related illnesses and specific health concerns associated with different indoor environments. An overview on indoor air quality concerns and problems in Alberta and Canada is also presented. Many illnesses are associated with contaminated indoor air; this manual discusses the more common illnesses. Specific health concerns associated with various indoor environments, such as residential, commercial, educational, industrial and other specialized facilities, are also presented. Finally, mandates, authority and interventions of Environmental Public Health professionals (EPHPs) in IAQ are discussed.

- **Chapter II Toxicology, risk management and indoor air quality**

The second chapter outlines the general principles of toxicology and risk assessment, and their applications to indoor air quality. “Health determinants” related to the environment and their roles in affecting the general health status of individuals, populations and communities are discussed. A separate sub-section on vulnerable populations discusses the biological basis for their increased susceptibility and the level of needed health protection geared for sensitive individuals. The section on

toxicological principles primarily focuses on different toxic effects of contaminants on human physiological systems. It reviews the human health risk assessment process; qualitative and quantitative approaches to risk assessment are discussed under the risk characterization sub-section.

- **Chapter III Investigation of indoor air quality**

The third chapter provides guidance on investigating indoor air quality complaints. The investigation approach focuses on methods allowing EPHPs to effectively carry out IAQ investigations. IAQ investigation protocols are also described. Flow charts help practitioners to follow a step-by-step investigation procedure during inspections. Questionnaire samples designed to assist in the collection of general IAQ related information and also specific information related to different indoor environments, including residential, commercial, industrial, educational and recreational building, are mentioned in this chapter and presented in full in *Appendix I IAQ questionnaires*.

- **Chapter IV Management of indoor air quality investigations**

This chapter focuses on the management and control of IAQ problems. From an environmental management perspective, it is important to have a comprehensive approach to problem investigation and resolution. Therefore, an attempt has been made in this chapter to emphasize the fundamental management principles and control measures including source control, ventilation, cleaning and filtration, and personal protection associated with the resolution of IAQ problems.

- **Appendices**

The Appendices section provides background information on common contaminants and factors affecting the quality of indoor air.

- Appendix A1 Chemical factors: gases
- Appendix A2 Chemical factors: vapours
- Appendix B1 & B2 Introduction and particulate matter
- Appendix B3 Particulates: Asbestos
- Appendix B4 Particulates: man-made mineral fibres
- Appendix B5 Lead
- Appendix C Environmental tobacco smoke
- Appendix D Radon
- Appendix E Biological factors
- Appendix F Consumer products
- Appendix G Outdoor air factors
- Appendix H Built environment.
- Appendix I IAQ Questionnaires

Factors responsible for IAQ problems are categorized and discussed. Factors discussed include chemical, biological, physical & mechanical and outdoor air as a contamination source that can significantly influence the indoor air quality. Sources, symptoms, health effects, exposure guidelines and control measures related to each factor are also elaborated on in the appendices. Other indirect indoor environmental factors that could affect the perception of the indoor air quality, such as vibration and acoustics, are beyond the scope of this manual and are not included.

I.B. IAQ as a health priority

I.B.1 IAQ and health concerns

Air quality affects human health. In a 1996 survey, nearly two out of three Canadians said that their health had been affected by pollution and more than one out of two people were very concerned about air quality (Enviroics 1997). In the past, outdoor pollutants were primarily considered to be important. Recent indoor air quality research has garnered increased public and government attention as the quality of indoor air has become a significant public health issue.

Indoor air quality is vital to human health because most human activities take place in the indoor environment. According to Health Canada, Canadians spend approximately 90 per cent of their time indoors such as homes, work environments, commercial buildings, industrial settings, schools, restaurants and other specialized indoor settings including indoor stadiums, ice arenas and indoor swimming pools (Health Canada 2002). An exposure study has found that an adult Canadian spends 50 per cent of their total time at home, 43 per cent in occupational places; five per cent in transit vehicles and two per cent in the outdoor environment (Engineering Interface Ltd. 1988). Likewise, studies in the United States and other industrialized countries have found people spend in excess of 80 per cent of their time indoors at work, at schools or in an automobile travelling between these places (Robinson and Nelson 1995). As a result of these findings, IAQ health concerns have become priority a for federal, provincial and regional health authorities.

People spend a lot of time indoors, but unfortunately the built environment is increasingly filled with chemicals because of the rapid development of new building materials, furnishings and consumer products (Rudel and Perovich 2009). More than 70,000 synthetic chemicals are in use today. Several thousand synthetic chemicals are present, affecting the overall indoor air quality of residential, commercial, educational and industrial buildings. The strategy to conserve energy by decreasing the building ventilation has made the situation worse. As a result, individuals, communities and populations can face higher risk in the indoor environment than in the past (Godish 2000).

Indoor household chemicals are associated with persistent wheezing in pre-school age children (Sherriff et al. 2005, Ponsonby et al. 2000), respiratory hypersensitivity (Becher et al. 1996) and childhood asthma (Ponsonby et al. 2000). Unfortunately, our knowledge of synthetic chemicals is limited; among the identifiable 70,000 chemicals, 44 per cent of them have no toxicity information (Magos 1988). The mechanisms of action, adverse effects and dose–response relationship for many of these chemicals are poorly understood (Rudel and Perovich 2009).

Biological agents are responsible for some of the airborne infections, such as tuberculosis and the Legionnaires' disease. While there is limited or suggestive evidence of causal relationships, there is sufficient evidence to associate indoor exposure to mould with upper respiratory tract symptoms, cough and wheeze in otherwise healthy people; with asthma symptoms in people with asthma; and with hypersensitivity pneumonitis in individuals susceptible to that immune-mediated condition (IOM 2004). Exposure to airborne fungi may lead to fungal infections and systemic mycoses. However, serious infections are rare and usually limited to people with immune deficiencies (Shelton and Leslie 2008).

After more than a century of decline, tuberculosis is now increasing in some developed countries (Davis 2003). Poor housing conditions and inadequate ventilation have been implicated in its resurgence (Wanyeki et al. 2006, Beggs et al. 2003, and Clark et al. 2002). The primary route of infection for the Legionnaire's disease is through inhalation of aerosols from contaminated water containing *Legionella* bacteria. Several studies have reported that the fatality rate for Legionnaires' disease is close to 15 per cent (Godish 2000). 25 per cent of the reported cases of Legionnaires' disease occur among hospital patients and 75 per cent occur in communities. Legionnaires' disease is discussed in more detail in the *Appendix E Biological factors* of this manual.

The energy crisis in the seventies further compounded the indoor air quality problems. Buildings became "tighter" with decreased ventilation to conserve energy. Hence, the terms, "tight buildings" and "tight building syndrome" were coined in the late 1970s and early 1980s when it was considered that "Sick Building Syndromes" arose because of new energy-efficiency measures related to the construction and design of buildings, and ventilation systems (Godish 2000). However, causes for poor indoor air quality are many and sometimes the term "tight building" is wrongly applied when the real cause of an indoor air problem is something else, such as cigarette smoke. It has been suggested that a more general term, "problem building", may more accurately describe the concerns and problems associated with these buildings and their occupants (Godish 2000).

Public awareness of indoor air quality concerns has increased. The following factors are attributed to the increased attention and awareness to IAQ concerns among the public and regulatory agencies.

- Significant proportion of time in indoors by sensitive population groups, such as the infirmed, populations with multiple chemical sensitivities and the young
- Public health and safety concerns increased in the early 1970s regarding the presence of friable (easily crumbled and reduced to powder) asbestos in buildings (Godish 2000)
- Higher energy efficiency and lower ventilation rates; that is, less fresh outdoor air being brought into newer buildings because of higher heating costs
- Better-informed consumers who know about synthetic chemicals in indoor environments including chemicals from building materials, consumer goods, household materials and furnishings.
- Higher costs for central-heating systems driving homeowners to use alternative forms of heating, such as kerosene heaters and wood-burning stoves. Improper use

or improper installation of alternative heating systems increases indoor release of combustion byproducts

- Improved research on various health-related illnesses, such as allergies and asthma, related to physical, mechanical, chemical and biological factors that affect individuals, populations and communities
- Scientific assessment and evaluation of indoor air quality from a toxicological and risk assessment perspective
- Identification of hypersensitive population groups exposed to multiple contaminants in indoor environments
- Increased news media coverage on IAQ topics

I.B.1.1 IAQ problems in Alberta and Canada

Effective and efficient IAQ maintenance is particularly important in Canada and specifically in Alberta because of extreme weather patterns. Alberta has a dry continental climate with warm summers and cold winter (Government of Alberta 2008). Long winters and warm summers may drive more people to spend long periods in climate-controlled indoor environments. While low humidity is a characteristic feature, IAQ problems related to moulds remain a significant health concern to Alberta residents; long cold winter seasons are a driving force for the collection of moisture inside wall cavities of poorly constructed buildings.

On the other hand, dry summers in rural areas are associated with increased fine atmospheric particulate matter with a diameter equal to or less than 10 micrometres (PM₁₀) because of the prevalence of gravel roads and farming activities. Agricultural activities can impact both outdoor and indoor air qualities. Alberta, with more than three million head of cattle, is the largest cattle producer in Canada (Government of Alberta 2011). The province is also a significant hog producer. While some rural centres are impacted by industrial activities and pollutants, some Alberta communities, for example, Lethbridge, Brooks and Red Deer, must contend with cattle and pig manure disposal concerns that can reduce ambient air quality (DTHR 1999) and, in turn, IAQ.

I.B.1.2 IAQ health concerns

Indoor air health risks and toxicological concerns are related to the following factors:

- **Chemical factors**

Gases, volatiles and semi-volatiles, particulates, environmental tobacco smoke, pesticides, radon, building materials, household products and human activities including cooking and some hobbies can impact the chemical composition of the indoor air.

- **Outdoor air**

Outdoor air can impact the quality of indoor air through infiltration. Certain weather conditions, such as an inversion, can concentrate air pollutants and thereby affect the IAQ by increasing exposure and hence health risks. For example, continued or frequent exposure to untypically high concentrations of nitrogen dioxide (NO₂) may

decrease resistance to respiratory infections, causing increased incidences of acute respiratory illness in children (US EPA 2012).

- **Biological factors**

These factors include moulds and mycotoxins, dust mites and other biological agents, such as animal allergens and pollen.

- **Physical and mechanical factors**

This category includes heat, temperature, humidity, ventilation, construction materials, finishing materials and furnishings.

IAQ related illnesses and symptoms can be categorized based on “symptoms” and “syndromes”. These illnesses and symptoms are generally grouped into two major categories:

- Sick Building Syndrome (SBS)
- Building Related Illnesses (BRI)

- ▶ **Sick building syndrome (SBS)**

The term “Sick Building Syndrome” (SBS) has been used to describe general symptoms and illnesses associated with building occupancy (Spengler et al. 2001). A specific causative agent for illnesses and symptoms is not identified in the “Sick Building Syndrome” phenomenon (Godish 2000, Spengler et al. 2001). The World Health Organization definition (WHO 2000) focuses on a range of general symptoms and complaints from building occupants.

- ◇ Sensory irritation of the eyes, nose and throat
- ◇ Skin Irritation
- ◇ Odour and taste sensations
- ◇ Hypersensitivity reactions
- ◇ Neurotoxic and general health problems, such as headaches, trouble concentrating and fatigue.

- ▶ **Building-related illnesses (BRI)**

While symptoms for “Sick Building Syndrome” are non-specific and the causes are often unknown, the term “Building Related Illnesses” (BRI) or “Specific Building Related Illnesses” (SBRI) describes indoor air quality problems in buildings where specific causative agents are identified. BRIs are characterized by specific clinical signs, confirmed laboratory analysis and identified contaminants. Some examples of BRIs are: nosocomial infections, hypersensitive pneumonitis, humidifier fever, asthma, chronic allergic rhinitis, Legionnaires’ disease, fiberglass dermatitis and indoor carbon monoxide poisoning (Godish 2000).

I.B.1.3 Health concerns in various indoor environments

Every indoor setting is unique, as are the occupants. Occupants differ in age and health status, and they may have specific health concerns unique to one indoor setting. For the purpose of this manual, buildings are described according to their usage. Residential buildings include multiplex condos, multi-storied buildings, apartment complexes and single-family houses where the occupants may spend up to twenty-four hours each day for many years. Non-residential buildings are facilities occupied for only a portion of the day or night. Examples include schools, commercial buildings, such as shopping malls, business offices and industrial facilities, and specialized facilities including day-care centres, swimming pools and ice arenas. Although the indoor air quality principles are similar in all these buildings, the indoor air quality concerns can differ depending on the unique characteristics of the occupants, building use and building construction.

Five categories of indoor settings are presented and discussed in this manual.

- Residential buildings
- Commercial buildings
- School buildings
- Industrial settings
- Specialized indoor facilities

1. Residential buildings

Residential buildings or houses have unique indoor environmental features. Godish (2000) has characterized residential buildings according to multiple properties.

- The population they serve
- Ownership status of the building
- Building type
- Construction characteristics of the buildings
- Building heating and cooling system
- Site characteristics of the building
- Occupants and occupant behavior
- Exposure concerns directly related to health concerns

Health concerns with residential buildings are generally related to the release of volatile organic compounds (VOCs), gases and particulates from combustion sources, such as oil, natural gas, kerosene, coal and wood-burning devices, and tobacco products. Other sources include furnishings, asbestos-containing materials, damp carpets, cleaning products, personal care products, electronic products and other household products. All the VOCs from these products either as individual chemicals or complex mixtures can be responsible for health concerns among building occupants. Sensitive populations, such as toddlers, the elderly and the sick, have the highest potential of being exposed to indoor contaminants because they spend more time at home (Godish 2000).

Other contaminants of concern in residential buildings include: radon, formaldehyde, environmental tobacco smoke, pesticides and biological contaminants including moulds, animal dander, dust mites and contaminated dusts from lead-based paint. The spread of contagious diseases is also a major health concern because of overcrowding. Usually windows and doors of residential buildings are closed during winter and also in the summer if the building is air-conditioned. Exposure to indoor air contaminants and potential of spreading illnesses in residential buildings are significantly increased because of this lower ventilation rate or air exchange.

2. Commercial buildings

Commercial buildings include offices, shopping malls and business establishments. Occupants of these buildings face different indoor air quality concerns than occupants of residential buildings. Commercial places are filled with variety of office products, printers, copiers, computers and furniture. Emission of volatile and semi-volatile chemicals (VOCs and SVOCs) is a health concern in these buildings.

Common indoor air pollutants in office buildings include formaldehyde from pressed wood products, VOC emissions from carpets, office furnishings, cleaning materials, painted walls and photocopying machines as well as biological contaminants from contaminated HVAC systems, damp walls and ceilings. Environmental tobacco was a concern in public and office buildings; however, smoking in public places is now prohibited in Alberta by the Tobacco Reduction Act. On the other hand, asbestos can still be found in insulation and can become a health concern if it is damaged and not encapsulated properly.

The design of the building, workspaces and ventilation systems can affect the general health status of office workers. Inadequate and an inefficient ventilation system can interfere with the delivery of fresh outdoor air to the occupants. Generally, office workers have little or no control over indoor environmental factors. Inadequate ventilation can cause carbon dioxide and moisture to accumulate indoors because of a lack of dilution by fresh air. In addition to occupational stress such as interaction with co-workers and employers, productivity and efficiency concerns, and the type and nature of work odours and other psychological factors including mass hysteria can all affect people's perception to the indoor air quality.

Complaints and health problems among office workers have been increasing in recent years (Godish 2000, Spengler et al. 2001). Several well-identified and recognized illnesses, such as Legionnaires' disease, asthma, hypersensitivity pneumonitis and humidifier fever, have been directly related to specific building problems. However, many symptoms and complaints cannot be attributed to any specific causes.

3. School buildings

Children and young adults are common users of these buildings. This age group is particularly sensitive and prone to environmental pollutants; therefore, good IAQ in schools is of paramount importance. School buildings are a unique environmental setting as they consist of office spaces, science and computer laboratories, gymnasiums and classrooms. Swimming pools can produce disinfection-byproducts that can reduce IAQ. While older schools are more susceptible to indoor environmental problems related to mould infestations, newer schools may be prone to off-gassing from new building materials and furnishings.

There are several causes of IAQ problems in schools and educational institutions. Usually, most facilities depend on mechanical heating, ventilation and air conditioning (HVAC) systems for temperature, air and climate-control purposes. As such, inefficient HVAC systems can result in inadequate ventilation and hence poor air quality. Proper maintenance of the HVAC system is important. Poor maintenance of a HVAC system can result in the production and school-wide distribution of fungal, bacterial and other bio-contaminants. Carpets are more difficult to maintain

and carpeted floors can act as a reservoir of chemical and biological agents. Also, vacuuming using commonly available vacuum cleaners without a High-Efficiency Particulate Air (HEPA) filter can exhaust fine dust particles back to the room resulting in a significant amount of airborne dust. Meanwhile, synthetic materials, laminated furniture (a source for formaldehyde) and other manufactured materials used in schools can emit VOCs and SVOCs.

IAQ can also be affected by outdoor air. Schools are susceptible to the infiltration of outdoor air pollutants, including ozone, carbon monoxide, oxides of nitrogen and sulfur and particulate matters from idling vehicles in the parking lot.

Surprisingly, economic factors can be indirectly responsible for poor indoor air quality in schools. Over the years, scarce resources and cutbacks in educational funding have resulted in reduced school-building maintenance throughout Canada (B.C. Ministry of Education 2000). Budget constraints may also have encouraged cost-saving building management strategies through improving energy efficiency. However, these strategies are often counter-productive to indoor air quality. On one hand, energy costs are reduced through re-circulating more indoor air; on the other hand, indoor air contaminants can accumulate to higher concentrations in a school.

School building users differ in age, health status and needs. For example, very young individuals may need higher ventilated rooms because they are more susceptible to air-quality-related health and learning problems (BC Ministry of Education 2000). Other individuals are extremely allergic to biological agents, such as pollens or pets. Mammalian pets and birds can be sources of allergens from dander, urine and saliva. These animals could be housed inside the school buildings, or teachers, students and visitors may unintentionally transport allergens to schools from home.

Other significant pollutants with health concerns are lead, radon and asbestos. Older Canadian school buildings still have lead and asbestos in different building materials including paints and insulation. Lead paint and asbestos can become health concerns when disturbed, such as during renovations.

Radon, a natural radioactive soil gas, is another potential pollutant. Radon can be drawn into buildings through cracks in the basement foundation and floor slab by pressure differentials between the soil surrounding the building sub structure. Radon levels in Alberta vary throughout the province. According to Health Canada (Health Canada 2012), 9.6 per cent of the houses located in the former Aspen health region and 9.0 per cent of houses located in the Chinook health region had radon levels above the Canada guideline of 200 Bq/m³. But in the Capital Health region, only 1.4 per cent of all houses exceeded the radon guideline. The Northern Lights health region had even fewer homes above the Canadian radon guideline: 0.7 per cent (Health Canada 2009).

4. Industrial settings

Buildings in close vicinity to industrial settings can face unique problems B.C. In addition to the usual array of indoor sources, buildings in and around industrial areas are susceptible to the infiltration and ventilatory entrainment of ambient air compromised by adjacent industrial facilities. As a result, the contributory effect of ambient air quality may be an important consideration for nearby populations. Examples of industrial contaminants which may pose health concerns include but are not limited to chlorinated organic substances, pesticides, mercury, lead, nitrogen oxides, sulfur and particulate matter.

5. Specialized indoor facilities

Specialized indoor facilities including swimming pools, ice arenas and indoor stadiums have unique IAQ concerns because of their specific functions and operations. For instance, swimming pool IAQ concerns are often associated with disinfectants and disinfection byproducts, such as halogenated organic vapours. Swimmers are inevitably exposed to chlorinated compounds via inhalation, dermal and ingestion exposure pathways. A detailed discussion on specific contaminants associated with swimming pools is presented in *Chapter III Investigation of indoor air quality* of this manual.

Ice skating rinks also have their own IAQ concerns. Users of ice skating rinks can be exposed to combustion byproducts, such as carbon monoxide (CO) and nitrogen dioxide (NO₂) emitted from the carbon fuel used to power ice re-surfacing machines (Levy et al. 1998). Another chemical of concern associated with ice arenas is ammonia that is commonly used in mechanical refrigeration systems. Fugitive release of ammonia can pose a significant health risk. A detailed discussion on specific contaminants associated with the ice arenas is presented in *Chapter III Investigation of indoor air quality* of this manual.

I.C. Intervention approaches

Public health is about context: the professional judgment, discretion and tact of the practitioner are important in real-life practice.

Public Health is “the science and art of preventing disease, prolonging life and promoting health through the organized efforts and informed choices of society, organizations, public and private, communities and individuals.”

—Winslow (1920)

Our goal is to safeguard and improve the health status of individuals, populations and communities through collaboration with various stakeholders.

Traditionally, public health inspectors or environmental health officers have protected the health of the public by enforcing regulations. Now it is realized that public health problems are complex and require complex solutions; a single approach is not effective. Practitioners can be more effective in IAQ matters through source control, hazard prevention, hazard reduction, exposure reduction and effects modification.

Public Health is a complex system; therefore, a single strategy applied in isolation likely will not be successful (Jackson et al. 2007). Instead a system approach consisting of multiple strategies at multiple levels is required (Hawe et al. 2004, WHO 1986). Our health protection goal can be better achieved by combining regulatory and non-regulatory strategies at different levels along the hazard-to-harm continuum. These public health intervention strategies are many, including health promotion, advocacy, social marketing, regulatory enforcement and legal proceedings.

When attempting to fulfill mandates and responsibilities, practitioners must develop appropriate and targeted strategies tailored to the audience (Kreuter and Skinner 2000). The choice of intervention, whether a regulatory approach, a proactive health-education promotion strategy, a preventive precaution, or a combination of interventions, is more than a preference but rather a calculated decision, based on the context which is framed by the practitioner, the target population, the risk, stakeholders, the cultural or political environments and many other factors. Three main interventions are described in the following section to assist practitioners in making informed decisions and choices.

- Regulatory enforcement
- Health promotion
- Precautionary principle

I.C.1 Regulatory enforcement

Government of Alberta statutes empower and provide authority to Public Health inspectors or Environmental Health officers to prevent, investigate and mitigate public health nuisances. The following statutes describe the legal responsibilities of Environmental Public Health inspector staff:

- Public Health Act, Statutes of Alberta, RSA 2000, Chapter P-37
- Public Health Act, Housing Regulations, Alberta Regulation 173/99 (Effective September 01, 1999)
- Public Health Act, Nuisance and General Sanitation Regulation, Alberta Regulation 242/85
- Minimum Housing and Health Standards, Alberta Health, July 1999

Section 62 of the Public Health Act authorizes executive officers to investigate and mitigate nuisances in public and private places. The definition of a “nuisance” is broad. A “nuisance” is defined as a condition that is or might become injurious or dangerous to the public health or that might hinder in any manner the prevention or suppression of disease (Nuisance and General Sanitation Regulation, Public Health Act). An inspector can exercise his or her authority in a wide range of facilities. “Private places” include all privately owned dwellings or lands. The definition of “public places” is more comprehensive and open-ended. A public place is defined in Section 1(ii) as:

. . . any place in which the public has an interest arising out of the need to safeguard the public health and includes, without limitation,

- i. Public conveyances and stations and terminals used in connection with them*
- ii. Places of business and places where business activity is carried on*
- iii. Learning institutions, other institutions*
- iv. Places of entertainment and amusement*
- v. Places of assembly*
- vi. Dining facilities and licensed premises*
- vii. Accommodation facilities including all rental accommodation, recreation facilities*
- viii. Medical, health, personal and social care facilities*
- ix. Any other building, structure or place visited by or accessible to the public*

I.C.2 Health promotion

Health promotion through education, information dissemination and knowledge transfer is an important link in achieving and sustaining public health protection. Often, the reason for the inadequate quality of indoor air is poor articulation or lack of appreciation and understanding of basic principles underlying the policies and actions related to indoor air quality (Mølhave and Krzyzanowski 2003). Studies have shown that education efforts carried out by community health professionals “in combination with environmental interventions in the home, are effective in changing the indoor environment and motivating behavior change in ways that promote healthier home environments” (Carter et al. 2001, Krieger et al. 2005, and Morgan et al. 2004).

Proactively, environmental public health professionals can fulfill their mandate and responsibilities, at least in part, through education and dissemination of information (Morgan 1993).

Lack of information and lack of access to information are ... problems. Often, people do not know where to turn if they experience problems with their indoor environments and which information sources they can trust. People may be unaware of the link between ... indoor environments and ... adverse health symptoms or diseases.

—Wu and coworkers (Wu et al. 2007)

Advocacy and social marketing are part of the solution equation. For example, practitioners could advocate for timely replacement of furnace filters through promoting the benefits of filters using social marketing techniques. Complementing enforcement with dialogue can help to meet the goal and sustain the outcomes. The importance of dealing with public health concerns proactively is recognized in the “promotion and protection” clause of the (Alberta) Regional Health Authorities Act. Section 5(a) (i) of the Regional Health Authorities Act (Chapter R-9.07, 1994) states:

“... a regional health authority

(a) shall

i. Promote and protect the health of the population in the health region and work towards the prevention of disease and injury...”

I.C.3 The “precautionary principle”

“Health risk assessment” as a tool for public health protection has limitations. The ability of the risk assessment paradigm to protect public health is limited by current scientific knowledge and understanding. Information and understanding can be lacking in various disciplines—toxicology, epidemiology, dose–response relationships including synergisms, low dose exposure effects and identification of the sensitive populations that affect the reliability of the risk assessment process:

The “precautionary principle” has been proposed as a new standard in environmental decision-making (Kriebel et al, 2001). The principle has four components:

1. Taking preventive action in the face of uncertainty
2. Shifting the burden of proof to the proponents of an activity
3. Exploring a wide range of alternatives to possibly harmful actions
4. Increasing public participation in decision-making

The “precautionary principle” integrates smoothly with the proactive health promotion approach. In a *Lancet* editorial, Horton (1998) described the relationship between precaution and public health as the following:

We (public health officials) must act on facts, and on the most accurate interpretation of them, using the best scientific information. That does not mean that we must sit back until we have 100 per cent evidence about everything. Where the state of the health of the people is at stake, the risks can be so high and the costs of corrective action so great, that prevention is better than cure. We must analyze the possible benefits and costs of action and inaction. Where there are significant risks of damage to the public health, we should be prepared to take action to diminish those risks, even when the scientific knowledge is not conclusive, if the balance of likely costs and benefits justifies it.

—Horton 1998

Public health professionals must understand and judiciously apply the precautionary approach for public health protection. When risk assessment inputs are relatively well understood for example, when established causal relationships and the risk characterization phase has determined that public health is endangered, the public health professional clearly has a mandate to protect public health under the prevention model. In the prevention model, causal associations and other modeling parameters are well established and are the basis for issuing advisories or taking regulatory action (Lambert et al. 2003).

In the scenario where the risk outcome does not reveal a substantive risk, the professional may still recommend preventive actions, recognizing that uncertainties still exist in a risk assessment outcome. For instance, synergistic interactions may be uncertain and dose–response relationships and toxicological understandings are subject to change. The observation in *Appendix B3 Particulates: Lead* that the acceptable level of lead in blood has been dropping over the years attests to the changing nature of our understanding of fact. In this contingency, actions and measures are recommended and implemented to minimize public exposures to potentially harmful substances.

I.D. Summary

Indoor air quality can affect human health. Although the IAQ principles are applicable to all building structures, the indoor air quality problems and solutions can vary depending on building use, construction and the characteristics of the occupants. For example, users of school buildings are children and young adults. These age groups are in particular vulnerable to environmental contaminants because of their developmental stages. Activities inside a building can generate specific IAQ problems. For example, skating rink re-surfacing machines using fossil fuels can produce combustion pollutants, such as carbon dioxide and nitrogen oxides. Attention to ventilation and equipment maintenance is of particular important.

This manual provides a general framework and a menu of tools for Environmental Public Health professionals (EHPs) in Alberta to support their investigations and management activities of indoor air quality concerns. Environmental Public Health professionals are mandated to protect public health. To protect public health and prevent disease and injury, inspector staff must be empowered. Therefore, this manual aims to provide useful information and resources for indoor air quality investigation and management.

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Chapter II

Toxicology, risk assessment and indoor air quality

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II. Toxicology, risk assessment and indoor air quality

II.A Health determinants

Living and working conditions are critical to the health of the population (PHAC 2003). In 1974, Marc Lalonde, the then Canadian Minister of National Health and Welfare, identified lifestyle, environment, human biology and health services as the key determinants of health (Lalonde 1974).

Since then, further evidence has indicated that medicine and health care contribute little to population health; rather, population health is determined by: income and social status; social support networks; education; employment and working conditions; social environments; physical environments; personal health practices and coping skills; healthy child development; biological and genetic endowment; health services; gender; and culture (PHAC 2003). These health determinants are grouped and discussed under the following four broad categories as presented in a health report prepared by the former David Thompson Health Region of Alberta (DTHR 1999):

- Human biology
 - Physical environment
 - Socio-economic environment
 - Political environment
- **Human biology**

“Human biology” is one of the fundamental determinants of health (Lalonde 1974). The growth, development and maturity of individuals depend on their nutritional and immunological status, and lifestyle factors. “Human biology” is the organic make-up of the body, the functioning of various body systems, the processes of development and aging, and the adaptive-response capability of an individual to the environment. “Human biology” is the underlying factor of a person’s robustness, health, and susceptibility to illness and disease.

“Human biology” is influenced by the environment and the individual’s genetics. The interaction between genetics and environment is complex. Early environmental influences that interface with genetics and physiology can have effects later in life. The surrounding environment, for example, indoor and outdoor, affects the growth, development and health status of individuals and populations.

Environmental influences can modify human biology by reducing the adaptive-response capability or by introducing disease that further compromises an individual’s health. Besides environmental factors, the genetic make-up of an individual or a population strongly influences human biology which then determines the individual’s and population’s response to the external environment including indoor and outdoor air.

- **Physical environment**

Air, water, soil, food and the built environment can affect the health status of individuals and populations (DTHR 1999). Water quality and food safety are important “health determinants” for individuals and populations. Chemically and microbiologically contaminated foods and drinking water are important contributors to pathology and illnesses.

Soil quality can significantly affect the health of individuals and populations. Deteriorated soil quality because of poor agricultural practices and farm-related activities, over-grazing, clear-cutting and extensive cultivation can increase erosion and decrease the soil’s organic content, resulting in low crop production and water pollution. Industrial activities and the overuse of pesticides and fertilizers can contaminate soil, groundwater and drinking water.

Natural phenomena such as temperature inversion, dust storms and forest fires can affect the quality of outdoor air and the indoor air. Industrial processes can be harmful to individuals and populations (DTHR 1999). Many Albertans view outdoor air pollution as a public health concern because of the oil and gas industrial activities.

Symptoms and health effects may include coughing, sneezing, wheezing, increased asthmatic attacks and permanent lung damage. Contaminants include heavy metals, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), nitrogen oxides, sulphur oxides and ozone.

The built environment including offices, industrial plants and residential housings both in urban and rural areas can directly or indirectly affect indoor and outdoor air quality. Choice of building materials and HVAC (heating, ventilation and air conditioning) design and maintenance can influence indoor air quality.

- **Socio-economic environment**

The “socio-economic environment” can significantly affect on the health status of individuals and populations. For example, education can affect income and lifestyles which in turn influence health, because frequency of smoking and alcohol consumption in the general population is directly related to education (DTHR 1999). The economic imbalance between the rich, the middle class and the poor can also directly and indirectly affect the overall health status of individuals and populations. Several studies have suggested that race, age and the economic status of individuals

influence one's residence location and hence the proximity to industrial sources and emissions (Perlin et al. 2001). A close residential proximity to air-polluting sources undoubtedly can affect health negatively.

- **Political environment**

Political decisions, policies and interventions affect the health status of individuals and populations. "Public policies" broadly include actions of a government or other public authorities used to address an identified problem or a set of problems. Through various bylaws, acts, regulations, guidelines and standards, the government influences public health; for example, workplace safety guidelines, building codes, drinking water guidelines, ambient air quality criteria, and Canada Wide Standards.

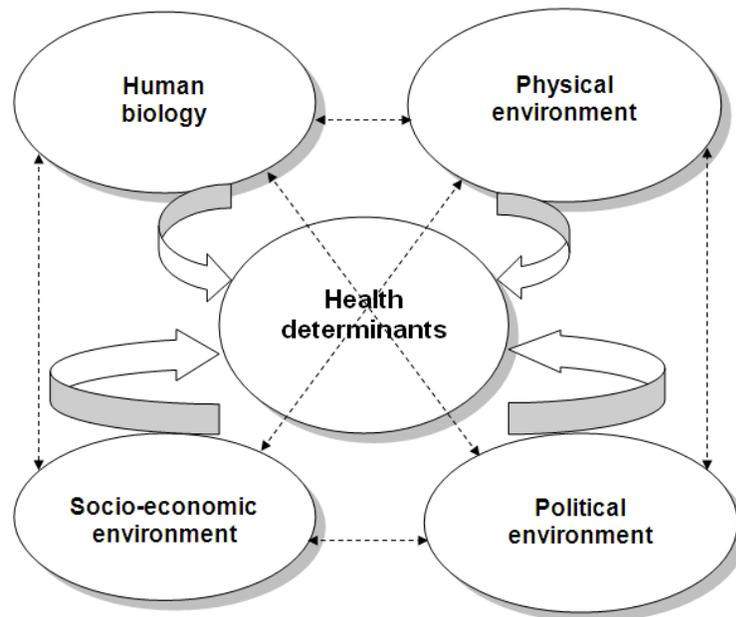
Government policies also determine the accessibility to the acute health-care system and the level of care accessible and affordable to the public. A fine balance between policies and the local economic development is critical. While public policies are designed to protect the health of individuals and populations (DTHR 1999), balancing industrial growth, economic development, environmental conservation and public health is often challenging.

II.A.1 Interaction among health determinants

"Health determinants" do not work in isolation; they interact with each other in a complex manner. Human biology, growth and development, and the physiological status of individuals and populations are affected by changes in the total environment. The socio-economic and political environments determine people's social landscapes and personal lifestyle choices which, in turn, affect their biological and health status. These complex interactions then determine individual and population health status.

From an IAQ perspective, considering all "health determinants" is important because they directly or indirectly affect our environment and health. Figure II.A-1 illustrates the complex interaction between the "health determinants" in an indoor environment.

Figure II.A-1 Interaction of health determinants in an indoor environment



II.A.1 Susceptible individuals

Scholars disagree on the reach of “Public Health”. Although most definitions share the premise that “public health” is about the health of the general public, some people believe that public health should protect everyone on an individual level including the hypersusceptible individuals (Lambert et al. 1998). While the debate continues, most individuals who are sensitive or susceptible to adverse effects of most environmental risks are already protected.

The consideration of vulnerable or sensitive populations in human health risk assessment is not new. Conservative inputs in risk assessments are standard practice to ensure protection for the most sensitive population groups.

—Lewis et al., 2011

Indoor air quality guidelines and standards have been recognizing sensitive individuals as the target populations for protection (Zummo and Karol 1996).

The *EPA National Ambient Air Quality Standards* (NAAQS), which also apply to indoor air contaminant levels, are intentionally set conservatively, aiming at protecting the most sensitive individuals, such as children, the elderly and those with asthma (Charles 2005). Likewise, the Canadian *Guidelines for Residential Indoor Air Quality* also takes “... the sensitivity of groups at special risk and the sources and mechanisms of action of contaminants” into consideration (Health Canada 1995).

The current environmental public-health approach is capable of protecting the majority of sensitive individuals by incorporating a 10-fold uncertainty factor into the dose-and-exposure calculation to account for the intraspecies variation within the human population (USEPA 2002). Based on an evaluation of the variability in pharmacokinetics and pharmacodynamics within a population, Burin & Saunders (1999) have concluded

this 10-fold safety factor protects more than 99 per cent of the human population. This finding is consistent with the findings of another study Dourson et al. (2002) also concluded that existing environmental public health methodologies protective almost 100 per cent of the general population. Guidelines and standards may not eliminate all occupant dissatisfaction, discomfort, unacceptable odours and sensory irritation; however, it is uncertain if lowering the current limits will guarantee the removal of all adverse effects for all occupants (Charles 2005).

The susceptible group is small in number in a population. In Figure II.A-2 and Figure II.A-3, the y-axes present the fractions of the population killed from the exposure to a toxic agent, and they are equivalent to the probabilities of lethality for individuals of the population. The L_{50} is the toxic load which causes 50 per cent mortality in the population. The L_{10} and L_{90} toxic loads represent 10 per cent and 90 per cent mortality, respectively (Figure II.A-2). Sensitive and resistant population groups are also presented in Figure II.A-3). In this figure, a hypothetical L_{10} (10 per cent of the population) is presented as the susceptible group. The percentage of the population that are hyper-susceptible or resistant depends on various factors, such as physiological and genetic factors, health status and type of contaminants.

Figure II.A-2 Public health population response curves (L_{10} , L_{50} , and L_{90})

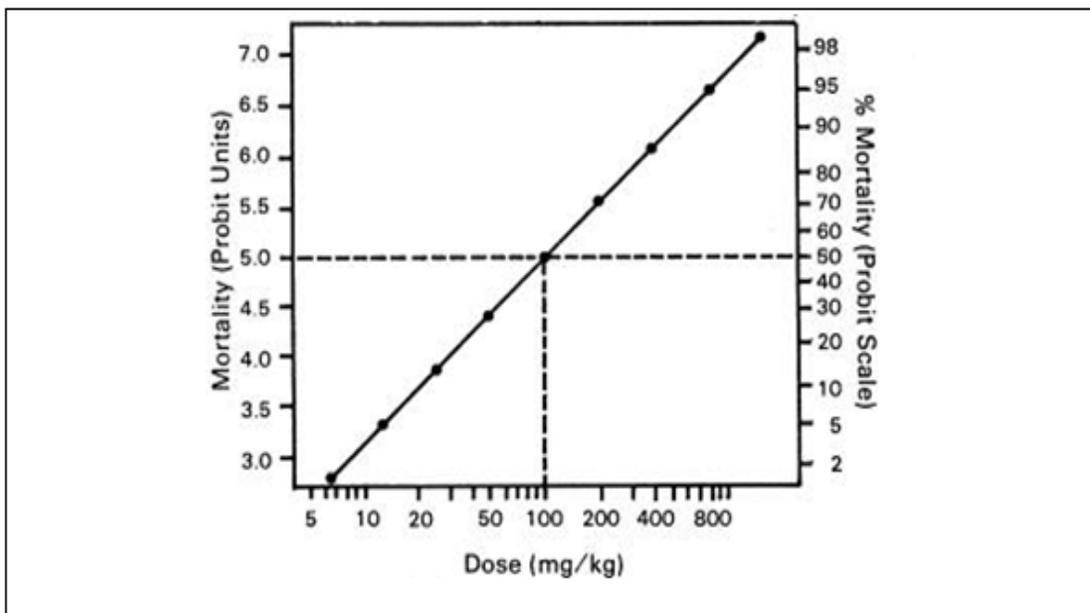
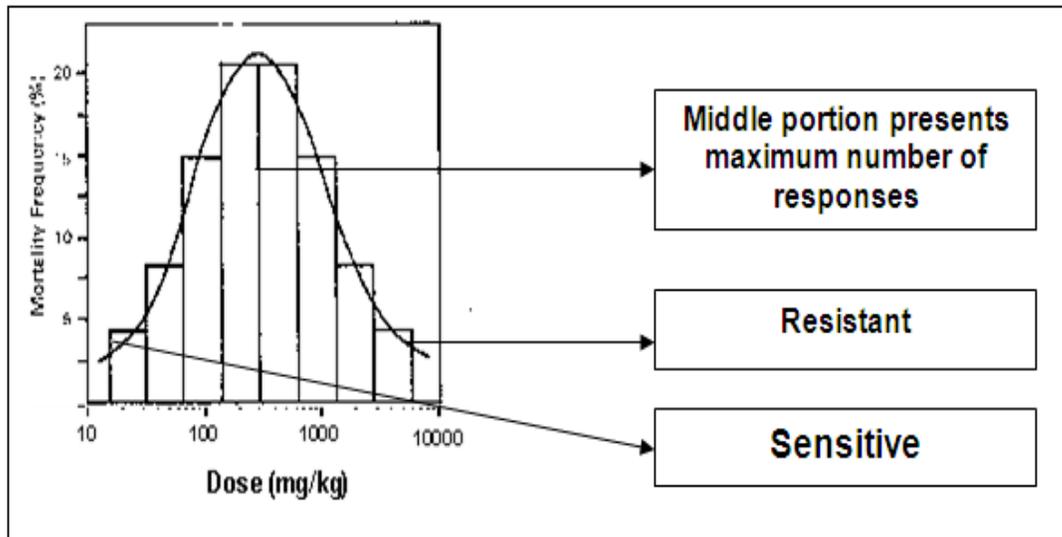


Figure II.A.3 Public health population response curves (resistant and sensitive groups)



The adverse response to a contaminant depends on the degree of exposure and individual characteristics that determine susceptibility (Lambert et al. 1998). Table II.A-1 on the following page identifies a number of susceptible subpopulation groups that are potentially at greater health risk from exposure to environmental toxicants.

Table II.A-1 Examples of subpopulations potentially at greater health risk

Sub-population groups	Health risk
Asthmatics (11% prevalence in Canadian children and 7.2% in Canadian adults) ^a	Increased airway responsiveness to allergens, respiratory irritants, and infectious agents (increased risk of hospitalization and mortality)
Fetuses	Increased sensitivity of developing organs and tissues. Retarded growth and development, increased risk of disease and permanent damage.
Infants and young children	Increased sensitivity of maturing organs and tissues. Retarded growth and development, increased risk of disease and permanent damage.
Elderly	Diminished detoxification and elimination mechanisms in kidney and liver. Reduced immune system function
Socio-economic groups	Underlying nutritional and lifestyles choices influenced by education and income
A1-Antitrypsin-deficient persons	Inherited enzyme deficiency protective against chemical damage
Glutathione-S-transferase deficient	Diminished detoxification of some carcinogens and medicines

^a *Respiratory Diseases in Canada*, Health Canada 2001

Source: Chapter 4, Volume 2, *Risk Management Final Report, 1997, Commission on Risk Assessment and Management, USEPA, 1997.*

II.A.2 Children as susceptible individuals

The following box describes specific susceptibility characteristics of children to chemicals and bioaerosol exposures.

Reasons for children's higher susceptibility to bioaerosols and chemical exposures

Children are generally considered to be more susceptible to bioaerosols and chemical exposures because:

- Brains and nervous system are still developing
- Immature immune systems until age 10 to 12. In addition, their immune systems may already be compromised because of poor nutrition and other activities of the mother during pregnancy, such as smoking or drinking.
- Immature and deficient immune systems are associated with psychological disorders, learning disabilities, attention deficit hyperactivity disorder (ADHD), depression, anxiety, phobias, psychoses, insomnia, confused states, mood swings, and criminal and delinquent behaviour (Miller 1995)
- Higher respiratory, pulse, and metabolic rates than adults
- Smaller bodies and relatively greater lung capacity per unit body weight compared to adults; so toxic effects are greater in children than in adults
- Increased breathing through their mouths (loss of nose filtration).

II.A.3 Other susceptible populations

Table II.A-2 presents data on U.S. and estimated Canadian subpopulations with increased responsiveness to indoor air contaminants.

Table II.A-2 USA and Canadian subpopulations with potentially increased responsiveness to indoor air pollutants

Subpopulation	Subpopulation size (USA)	Estimated subpopulation size (Canada) ^a	Percent of US Population
Newborns	3,731,000	450,000	1.5
Young children	18,128,000	2,300,000 ^b	7.5
Elderly	29,172,000	1,463,000 ^c	12.1
Heart patients	18,458,000	2,310,000	7.7
Asthma sufferers	9,690,000	2,474,000 ^d	4.0 (US) 8.4 (Canada)
Hay fever sufferers	21,702,000	2,700,000	9.0
Bronchitis sufferers	11,379,000	498,000 ^e	4.7 (US) 3.4 (Canada)
Emphysema sufferers	1,998,000		0.8
Smokers	69,852,000 (29%)	4,900,000 ^f	29.9 (US) 20 (Canada)

a. Estimated by using percent USA population and a total Canadian population of 30 million; b. & c., Thomas and Hrudey (1997), *In Risk of Death In Canada*, University of Alberta Press; d. Canadian asthmatics data - 1998/1999 - *Respiratory diseases in Canada*, Health Canada, 2001; e. Canadian Emphysema and Bronchitis (combined) data, 1998/99 - *Respiratory Diseases in Canada*, Health Canada, 2001; f. Smokers data - 2000 - *Respiratory Diseases in Canada*, Health Canada 2001

Source: US Statistics from 1986, except US smokers 1983, *In Risk Assessment and Indoor Air Quality*, 1998 page 111.

II.B Toxicology principles

The science of toxicology studies the quantitative effects of chemicals on living tissues and organisms. Toxicology overlaps with and incorporates aspects of other sciences including chemistry, biochemistry, physiology, microbiology, statistics, public health and pharmacology (Anonymous 1997).

“Toxicology” informs health risk assessment (SOT 2012). Under the broad discipline of toxicology, the nature and effect of toxicological agents are investigated at the organ, cellular, biochemical and molecular levels. One step in health risk assessment is “dose response”. From a toxicology perspective, “dose” is defined as the amount of a contaminant absorbed or deposited in the body for an increment of time; “dose” is the amount or concentration of contaminant to which a living organism is exposed in a medium, such as air, water, soil or other mediums. Therefore, “dose,” “exposure,” and “time” are related to each other.

$$\text{Dose} = \text{Exposure concentration} \times \text{time}$$

Chemicals are classified based on various perspectives. Depending on their potential to cause or not to cause cancer, chemical contaminants are classified either as carcinogens or non-carcinogens.

II.B.1 Carcinogens (non-threshold toxicants)

“Carcinogens” are “chemicals or physical agents that cause cancer or tumour development, typically after repeated or chronic exposure. Their effects may only become evident after a long latency period and may cause no immediate harmful effects” (Stanford University 2007). The EPA weight-of-evidence classification system for carcinogens and non-carcinogens is provided in Figure II.B-1. Also, a comparison is made with the classification system from International Agency for Research on Cancer (IARC). Detailed examples of carcinogenic chemicals are provided in *Chapter III Investigation of indoor air quality* of this manual.

“Carcinogenesis,” the process of initiating and promoting cancer, involves three sequential and successive steps (Potter 1981). According to this three-stage model, chemical carcinogens are further classified as (Pitot et al. 1991):

- Initiators
- Promoters
- Progressors
- **Initiators**

Initiators or initiating agents are incomplete carcinogens. They are responsible for initial changes or alterations in individual cells that create a potential for cancer expression (Pitot and Dragan 2001). Examples of initiating agents are polycyclic hydrocarbons.

- **Promoters**

Promoters are capable of causing the expression of initiated cells to produce a cancerous growth. Although a cancer can be initiated early in life, without exposure to the promoter the cancer will not be expressed. The lag between cellular initiation and promotion events can be considerable. For instance, the expression of a cancer can be delayed for years after initiation until the cell is exposed to a promoter. 2, 3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and nicotine are examples of tumour promoters.

- **Progressors**

Progressors are chemicals that are capable of converting cancerous cells to malignant cells. Examples of progressors are benzene, benzoyl peroxide, and tetrachlorobiphenyls (a PCB derivative).

Some carcinogens are complete carcinogens, being both a tumour initiator and promoter. Benzo(a)pyrene is a complete carcinogen (IARC 1973, USEPA 1991).

For non-threshold carcinogenic substances, some probability of harm to human health at any level of exposure is assumed (CCME 1999). Therefore, there is no threshold dose for these carcinogens. Figure II.B-1 shows a dose-response curve for non-threshold carcinogens.

Figure II.B-1 Hypothetical non-threshold (carcinogen) curve

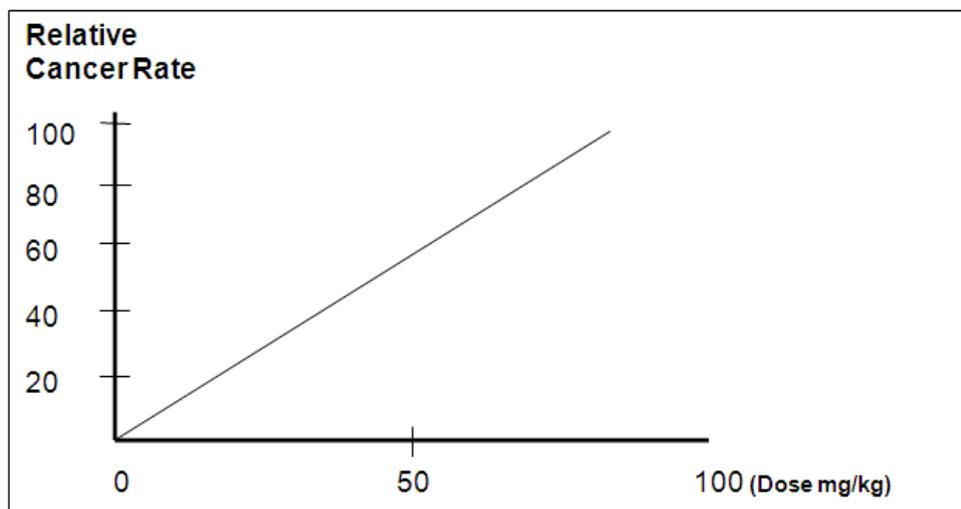


Table II.B-1 Carcinogenicity classification from USEPA and IARC

Classification number	Classification	Explanation	Comments
Group A / group 1	Proven carcinogenic to humans	This category is for chemicals where sufficient epidemiological evidence of a causal relationship between human exposure and cancer exists	Group A –USEPA ^a Group 1 - IARC ^b
Group B / group 2	Probably carcinogenic to humans	This category is divided into two subgroups because of variations in the level of evidence of carcinogenicity in humans	Group B – USEPA Group 2 – IARC
Group B1/group 2A	Probably carcinogenic to humans	Sufficient evidence of carcinogenicity in animals and limited epidemiological evidence of carcinogenicity in humans	Group B1 USEPA Group 2A –IARC
Group B2/group 2B	Probably carcinogenic to humans	humans Sufficient evidence of carcinogenicity in animals and inadequate or no epidemiological evidence of carcinogenicity in humans	Group B2-USEPA Group 2B –IARC
Group C	Possibly carcinogenic to humans	Limited evidence of carcinogenicity in animals and Inadequate or no epidemiological evidence of carcinogenicity in humans	Group C – USEPA
Group D	Not classifiable as to the v carcinogenicity	Inadequate evidence of carcinogenicity in animals, and inadequate or no evidence of carcinogenicity in humans	Group D – USEPA
Group 3	Unclassified Chemicals	Chemicals that can not be classified as to their carcinogenic effect on humans	Group 3 – IARC
Group E	Evidence of non-carcinogenicity in v	No evidence of carcinogenicity in at least two satisfactory animal tests in different species, or in satisfactory animal and epidemiological studies	Group E – USEPA

a. Source: National Environmental Health Association, Introduction to Indoor Air Quality: A Reference Manual, USEPA, US Public Health Service, National Environmental Health Association, Denver, Colorado, July 1991.

b. Source: World Health Organization, Air Quality Guidelines for Europe, WHO, European Series No. 23, Copenhagen 1987.

II.B.2 Non-carcinogens (threshold toxicants)

Unlike carcinogens, non-carcinogens or threshold toxicants have a threshold: below that dose, no toxic effects are manifested (see Figure II.B-2). The threshold dose is the chemical dose at which a specified measurable toxic effect is observed and below which such effect is not observed (Casarett and Doull's Toxicology 2001).

***“All substances are poisons; there is none which is not a poison.
 The right dose differentiates a poison from a remedy.”***

—Paracelsus (1493-1541)

Paracelsus promoted the focus on “toxicon”, the primary toxic agent, as a chemical entity as opposed to the Grecian concept of the mixture or blend.

He suggested that experimentation is essential in the examination of response to chemicals.

He made a distinction between the therapeutic and toxic properties of chemicals: **Dose** makes the difference between a therapeutic and toxic agent.

Table II.B-2 shows selected examples of the Health Canada’s non-carcinogenic toxicological reference values (TDI and TC) (Health Canada 2004).

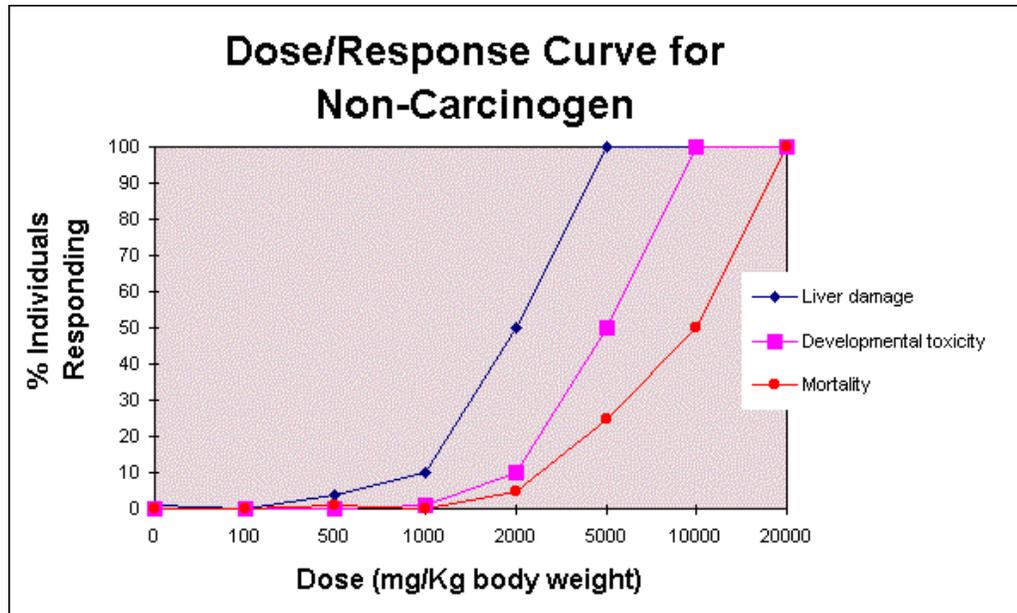
Table II.B-2: Selected health Canada non-carcinogenic toxicological reference values

Name	Non-carcinogenic toxicological reference values	
	TDI (mg/kg-d)	TC (mg/m3)
Aldicarb	0.001	
Bis(2-ethyl-hexyl)phthalate	0.044	
Chlorobenzene	0.43	0.01
Dichlorobenzene, 1,4-	0.11	0.095
DDT	0.01	
Phenol	0.06	

Source: Federal Contaminated Site Risk Assessment in Canada. Part II: Health Canada Toxicological Reference Values (TRVs)

Figure II.B-2 illustrates the dose–response curve for a threshold (non-carcinogen) toxicant.

Figure II.B-2 Hypothetical dose/response curve for a threshold toxicant (non-carcinogen)



Source: Extension Toxicology Network, Dose Response Assessment, <http://ace.orst.edu/info/extoxnet/faqs/risk/dose.htm>, Webpage accessed: February 08, 2002

Three major routes and sites of exposure to toxic agents are:

1. Gastrointestinal (GI) tract via ingestion pathways
2. Lungs via inhalation pathways
3. Skin via topical, percutaneous and dermal exposure pathways

In an indoor environment, exposure to toxic agents or chemical contaminants occurs from the inhaling contaminated air, direct or indirect contact of the skin and through ingestion.

Based on the duration and frequency of exposure, toxic exposure can be divided into four sub-categories (Eaton and Classen 2001):

- Acute (24 hours or less)
- Sub-acute (a month or less)
- Sub-chronic (one to three months),
- Chronic (more than three months)

Based on the duration of toxic response to a toxic agent, toxicity can be described under two general categories: acute (short-term) and chronic (long-term). Sometimes, chronic exposure to the low concentrations or acute exposure to high concentration of contaminants can have either acute or chronic health effects. Toxic effects can be reversible or irreversible, mild or severe.

It is important to have an understanding of the different sub-disciplines of toxicology from a risk assessment perspective. These sub-disciplines are:

1. Mechanistic toxicology

This sub-discipline deals with the mechanisms of action of toxicological agents at the cellular, biochemical, and molecular level.

2. Descriptive toxicology

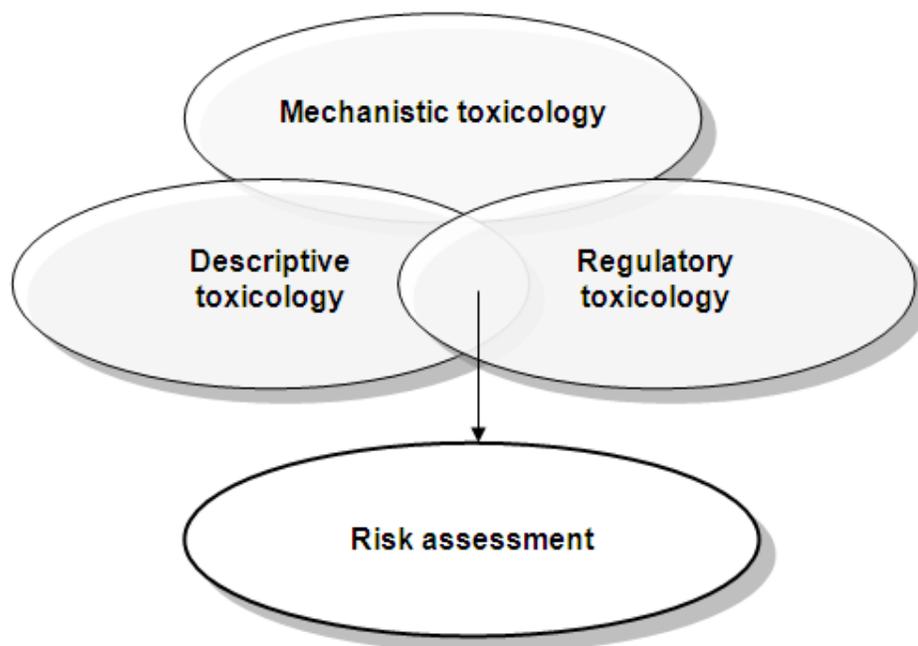
Descriptive toxicology directly deals with the testing and evaluation of a toxicant using animal tests, human chamber studies and epidemiology. Descriptive toxicology is very important in setting regulatory limits for human exposure to toxic agents.

3. Regulatory toxicology

Regulatory toxicology deals with the regulatory aspect of the toxicology. It uses the findings of mechanistic and descriptive toxicology, along with other inputs, to arrive at a regulatory decision.

From a risk assessment perspective, risk assessors must have information from the three sub-disciplines of toxicology to effectively assess and evaluate the health risks posed by a particular contaminant. Figure II.B-3 presents the interaction and relationships between mechanistic, descriptive, and regulatory toxicology and risk assessment.

Figure II.B-3 Interaction between three toxicology sub-disciplines and risk assessment



Source: Casarett and Doull's Toxicology, The basic science of poisons, 6th ed. 2001

Toxic agents can be variously classified according to several of their characteristics:

- Chemical and physical properties, such as pesticide, solvent, VOC, SVOC or particulate
- Target organ, such as liver, kidney and heart
- Use, such as industrial, cleaning, consumer product and automotive
- Biological or toxic effect, and exposure pathways

The mechanism of toxicity or injury for any chemical is a dynamic process. The degree of injury to a target tissue or the effect of a toxic agent is dependent upon the net effect of toxicodynamic and toxicokinetic processes including systemic absorption, tissue deposition, and metabolism, interaction with cellular components, elimination, and tissue repair (Bruckner and Warren 2001).

Figure II.B-4 and Figure II.B-5 illustrate the generalized toxic response mechanism and the physiologically based toxicokinetic model, respectively.

Figure II.B-4 General mechanism of toxicity in different organs

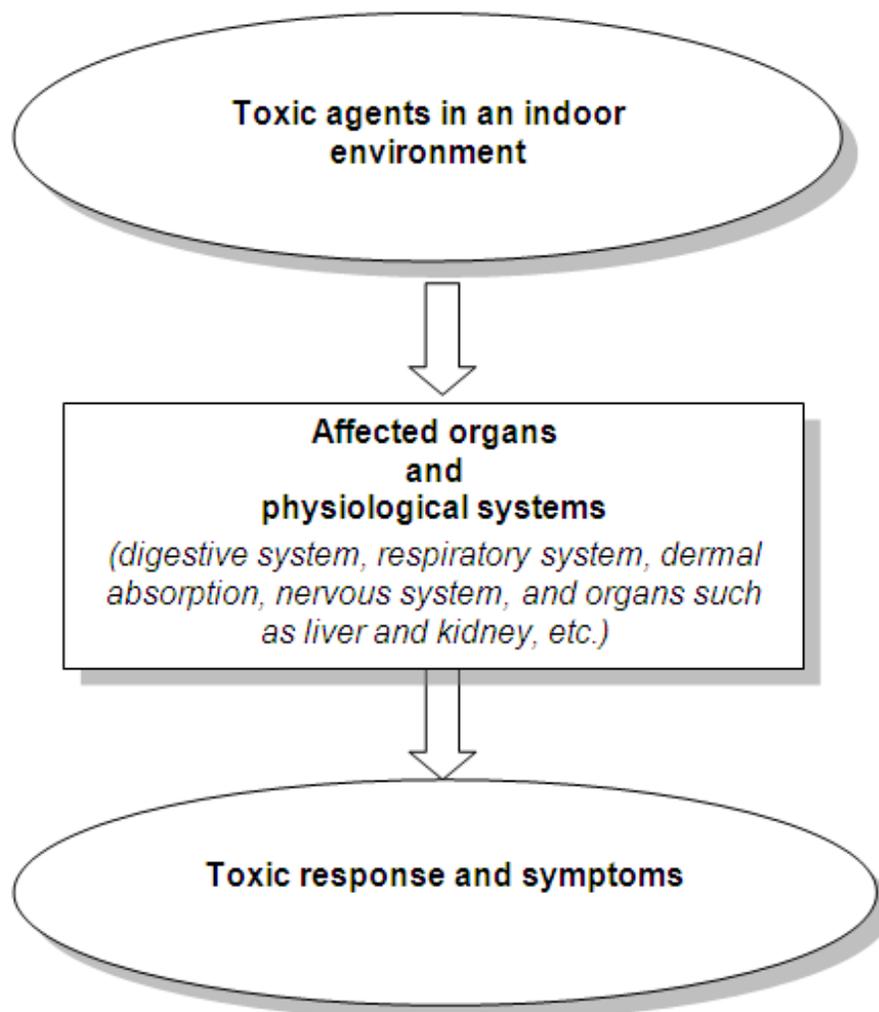
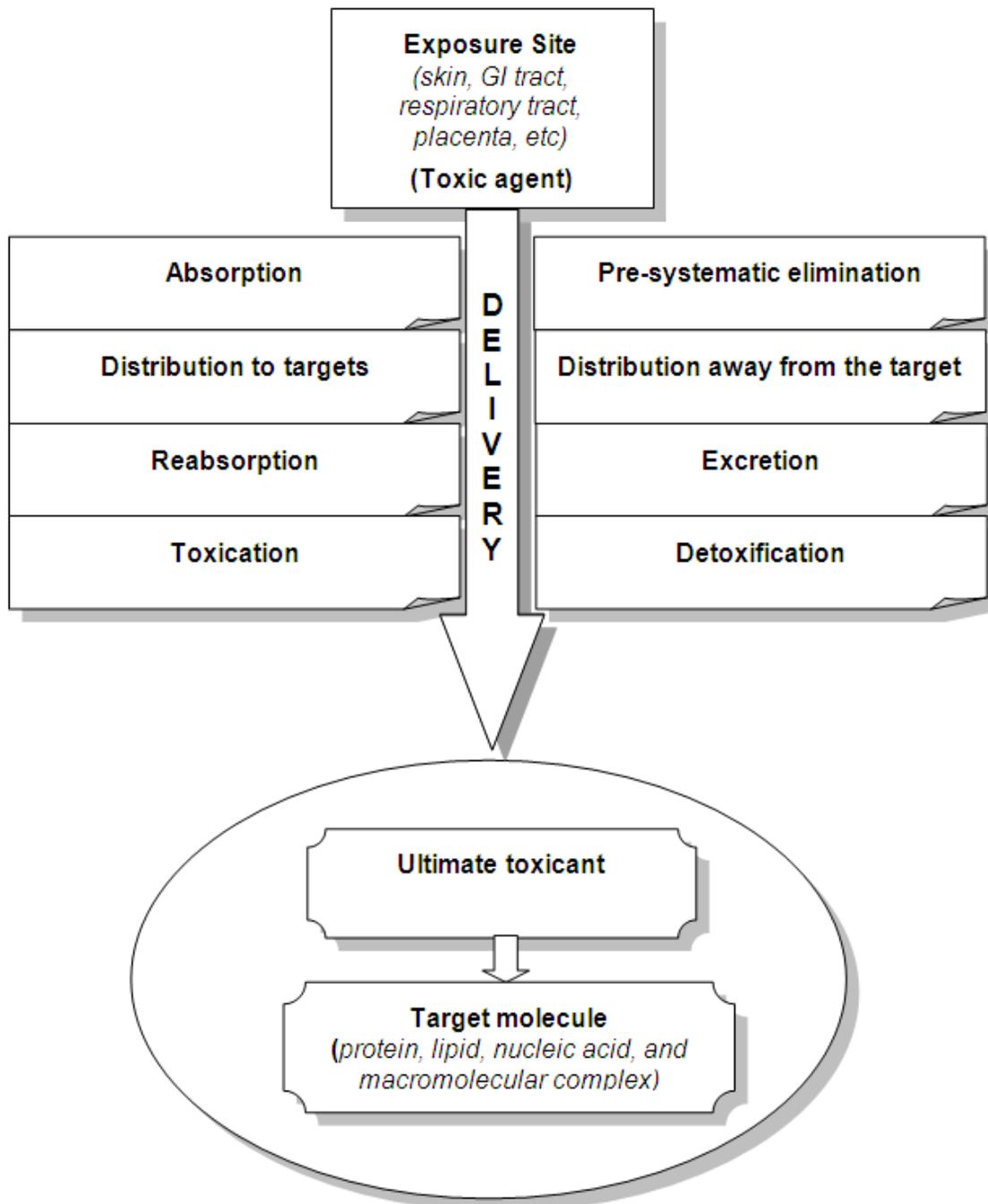


Figure II.B-5 General process of toxic agent delivery in the physiological system of animals and humans

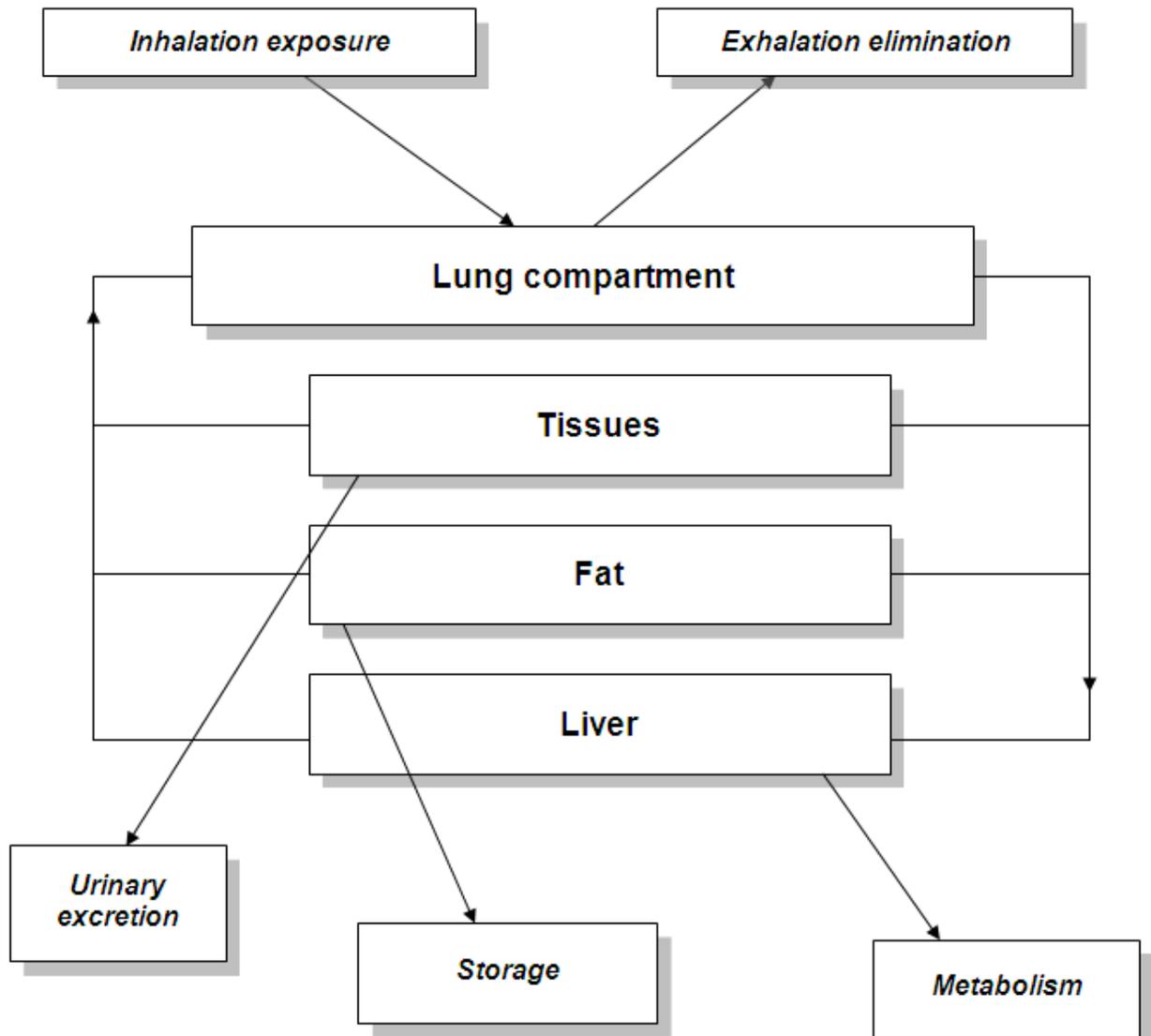


Source modified from the Casarett and Doull's Toxicology, The Basic Science of Poisons, 6th ed. 2001, Page 38

A conceptual physiologically based toxicokinetic model can be used as an investigative tool in indoor air quality research (see Figure II.B-6). In an indoor environment, exposure via inhalation can be a significant pathway when compared to other exposure routes, such as ingestion and dermal contact. Inhalation is associated with unique characteristics that present a challenge in determining the uptake and distribution of toxic agents in different compartments of the respiratory system and human body.

Differences in air flow in the various compartments of the lung that also vary with age, sex and health status, can affect the distribution of contaminants in these compartments.

Figure II.B-6 General physiologically-based toxicokinetic (PBTK) model



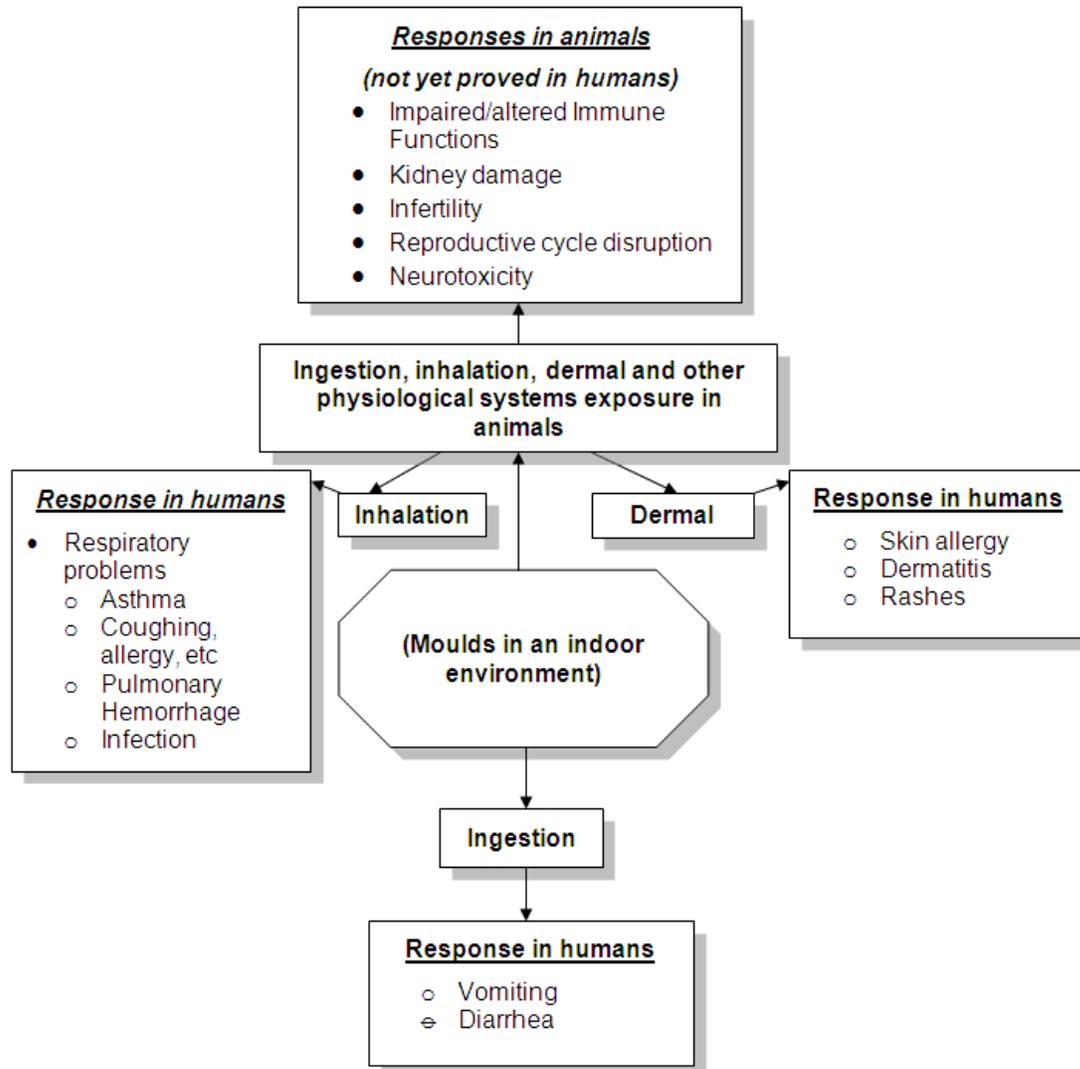
Source: adopted and modified from "The Human Health Risk Assessment Process, SACHE Project # 72, Product # 97-13, 1997.

The following example of toxic moulds illustrates the preceding concepts. Toxic mould in a poorly ventilated indoor setting can pose significant health risks to building occupants (Godish 2000). A detailed description of toxic moulds is presented in the *Appendix E Biological factors* of this manual. In this section, a general description of the toxicological and physiological effects and mechanism of toxicity of toxic moulds is discussed.

II.B.2.1 Toxic moulds

Moulds are capable of producing illness in exposed individuals and populations via ingestion, inhalation and dermal pathways (Davis 2001). For instance, airborne moulds can elicit a variety of allergic responses in individuals who are immunologically sensitized. Moulds can produce mycotoxins that can result in human and animal toxic responses (McNeel and Kruetzer 1996). Figure II.B-7-summarizes the possible effects of moulds on human and animal physiological systems.

Figure II.B-7 Effects of moulds on animal and human physiological systems



II.C Health risk assessment principles

Chemicals in the air can result in risks affecting human health. The U.S. Environmental Protection (USEPA 1997) defines risk as the probability that a substance or situation will produce harm under specified conditions and time frame; Faustmann and Omen (2000) similarly define risk as the probability of an adverse outcome. The severity of potential effects depends on the quantity, movement and transformation, exposure time and inherent toxicity (USEPA 2004). Theoretically, a health risk assessment can systematically provide the needed information to assess the health risk associated with the situation and to determine the appropriate management strategy.

Risk assessment involves determining the following:

- Hazard potential
- Dose–response relationship
- Exposure potential of chemicals in the environment
- Quantitative or qualitative characterization of risk (HC 2003)

In the past, many risk assessors have relied primarily on mathematical or quantitative estimates to communicate risk assessment findings. However, a strict mathematical definition of risk has limitations and does not capture the manifold nature of risk. Therefore, the National Research Council has stated that quantitative information must never exist in isolation in risk assessment (NRC 1994).

The U.S. Presidential Commission on Risk Assessment and Risk Management (CRARM) voiced similar concern that risk characterization based primarily on mathematical estimates could impede effective risk communication; a health risk assessment should include qualitative information about

... who is at risk, how they might be affected, what the severity and reversibility of adverse effects might be, how confident the risk assessors are in their predictions and other qualitative information that is critical to decision-making.”

—CRARM 1997a, CRARM 1997b.

The qualitative process will be discussed in more detail in “Risk characterization.”

Table II.C-1 on the following page demonstrates the quantitative approach of risk. The table quantifies causes of death from accidents, diseases, and other causes in Canadian populations in 1997 (Statistics Canada 2002).

Table II.C-1 Causes of death among Canadian population in 1997^a

Causes of death	Number of total individuals (males and females) in Canada
Infectious and parasitic disease	2, 482
Malignant neoplasms (cancer)	58, 703
Diabetes mellitus	5, 699
Diseases of the Nervous system and sense organs	6, 557
Diseases of the circulatory system	79, 457
Respiratory diseases	20, 036
Chronic liver disease and cirrhosis	2, 030
Congenital anomalies	955
Certain perinatal causes (excluding stillbirths)	896
Accidents and adverse effects	13, 049
All other causes	25, 805
Total of all causes	215, 669

^a Total Canadian population in 1997 was 30,003,955 (Statistics Canada)

Source: Mortality, summary list of causes – Shelf tables, Statistics Canada, 2002 (webpage accessed, February 2002) (<http://www.statcan.ca/english/IPS/Data/84F0209XPB.htm>)

A risk can be represented in various ways. Table II.C-2A and Table II.C-2B present two perspectives on the deaths and risks associated with automobile accidents in Canada and USA. These two tables demonstrate how risk numbers differ, based on varying perspectives.

Table II.C-2A Different perspectives on automobile accident related risks and deaths

Risks of death	Explanation	Reference
3, 055 (1 in 10,000 risk)	Number of individuals died in Canada in 1997 from a total population of 30,003,955 ^a	Statistics Canada, 2001
210.0 (2 in 10,000 risk)	Number of deaths/year per million persons in the United States	Wilson, R. and Crouch, E, Risk/Benefit Analysis, Cambridge: Baltimore, 1982
Travelling 300 miles by car (1 in 1 million)	Accidental Death, Estimated risks increase the probability of death in any year by one chance in a million	Adapted from Wilson, R., “Analyzing the Daily Risks of Life. “Technology Review. 81, 1979, pp40-46

Table II.C-2B Different perspectives on automobile and accident-related risks and deaths

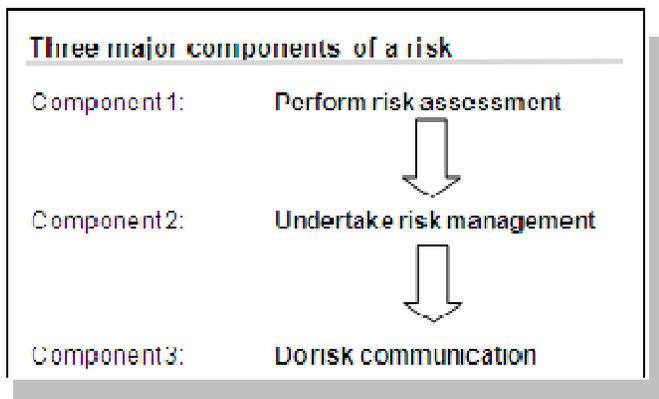
Risks of death	Explanation	Reference
3, 055 (1 in 10,000 risk)	Number of individuals died in Canada in 1997 from a total population of 30,003,955 ^a	Statistics Canada, 2001
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Travelling 300 miles by car (1 in 1 million)	Accidental Death, Estimated risks increase the probability of death in any year by one chance in a million	Adapted from Wilson, R., “Analyzing the Daily Risks of Life. “Technology Review. 81, 1979, pp40-46

II.C.1 Components of a risk

A “risk” has three major components. These components are:

1. Risk assessment
2. Risk management
3. Risk communication

These three components of risk are illustrated in the following box.



- **Risk assessment**

“Risk assessment” is the systematic scientific characterization of potential adverse health effects resulting from human exposures to hazardous agents or situations (NRC 1983, NRC 1994, Omenn and Faustman 2000). The objective of risk assessment is to provide a scientific understanding of the nature of a problem. Risk assessment consists of hazard identification, dose–response assessment, exposure assessment, and risk characterization (USEPA 1997). Risk assessment utilizes qualitative information regarding the strength of evidence and nature of the outcomes as well as quantitative information on exposure assessment, individual or population susceptibility factors, and risk characterization.

- **Risk management**

“Risk management is a decision-making process by which policy or mitigative actions to deal with hazards identified in the risk assessment process are chosen. Effective remedial measures and risk management decisions are taken based on risk assessment findings and recommendations. In this process, scientific evidence, risk estimates, along with statutory, engineering, economic, social, and political factors are considered in evaluating alternative regulatory options (NRC 1983).

- **Risk communication**

“Risk communication” is the process of making risk assessment and risk management information comprehensible to the general public, lawyers, regulatory agencies, politicians, judges, business owners, environmentalists and community groups (Faustman and Omenn 2000, in Chapter 4, Casarett and Doull’s Toxicology 2001).

II.C.2 Risk assessment practices in indoor air quality investigations

In this manual, the risk assessment process will be discussed from an indoor air quality point-of-view. Generally, the inhalation pathways play a significant role in health risks studies of indoor air contaminants. However, ingestion and dermal contact can also be significant exposure routes. For example, dermal contact with airborne moulds can produce rashes.

Application of risk assessment principles in indoor air quality investigation is challenging because of the following complex interacting factors:

- Significant variability in occupant exposure scenarios and individual response to different contaminants
- Limitations in the toxicological and exposure database of contaminants
- Multiple contaminant and exposure scenarios in indoor environments
- Inherent difficulty in effectively correlating health related symptoms to a specific causative agent

The indoor air quality risk assessment process is described in following pages. As in any scientific studies and investigations, “planning and scoping” is the first step in risk assessment (USEPA 2004).

The planning and scoping process includes (USEPA 2004):

- Assessment of problems
- Identification of stakeholders
- Description of bounds and scopes
- Development of cause and effects relationship
- Design of the overall assessment plan

Planning and scoping closely resembles the preparatory activities prior to a complaint investigation. The process includes, in layman’s terms, preliminary information collection, reviewing of file and historical information, understanding the complainant’s perspective, development of a hypothesis, identifying expertise within the organization, confirmation and identification of parties involved, confirmation of relevant statute, authority and regulatory requirements, devising investigation procedures, sampling regime and acquiring sampling equipment.

After the preliminary preparation, it is the carrying out of the actual health risk assessment process. There are four classical steps in the risk assessment process (Health Canada 2006):

1. Hazard identification
2. Dose response
3. Exposure assessment
4. Risk characterization

II.C.2.2 Hazard identification

Hazard identification describes the contaminant sources and chemicals involved, possible exposure scenarios and types of biological effects that can occur. Experimental and epidemiological evidence is taken into consideration in the data review process to glean insight into the problem. Then risk assessor reviews the information about the site of exposure, and develops a list of “study chemicals” or “chemicals of concern” that might pose health risks to the building occupants in an office, a day care centre, a paint shop or other building.

II.C.2.2.1 Identification of chemicals of concern (CoCs)

Identification and sources of indoor air contaminants can be described under several broad categories. In a report to Congress on Indoor Air Quality, USEPA (1989a) grouped indoor air contaminants under several broad source categories (Table II.C-3).

Table II.C-3 Sources of indoor air contamination

Contaminants	Characteristics
Environmental tobacco smoke	Smokers in the indoor areas and nearby outdoors; Types of contaminants include VOCs, Formaldehyde, Particulate Matter, Polycyclic Aromatic Hydrocarbons
Radon and derivatives	Colourless and odourless radioactive gases, decay products from rocks, primary sources are soil, well water, and building materials
Biological contaminants	Moulds, pollens, bacteria, viruses, insects, animal and human dander, can originate from indoor and outdoor sources such as HVAC systems, carpets, outdoor air, etc
Volatile organic Compounds	Organic compounds with limited number of carbon atoms; sources include paints, stains, adhesives, dyes, solvents, caulks, cleaners, pesticides, building materials, office equipment, and petroleum products
Formaldehyde	Although it is a VOC, it can be treated separately. Important sources: ETS, foam insulation, particle board, plywood, furnishings, and upholstery
Polycyclic aromatic hydrocarbons	They are defined as organic compounds with more than one benzene ring and have a boiling point equal to or greater than 100°C.
Pesticides	Exposure to pesticides can occur during and after application through inhalation or dermal contact. Ingestion of contaminated foods.
Asbestos	Old buildings and building materials
Combustion products	Primary products of combustion are: carbon monoxide, carbon dioxide, nitrogen oxides, and sulphur dioxide. Also, VOCs, formaldehyde, PAH, trace metals, and other residual chemicals.
Particulate matter	Several sources, PM is classified based on size, as a determinant of human health impact: PM ₁₀ , PM _{2.5} , PM ₁ , and PM _{0.1}

Limitations associated with the hazard identification step are presented in Table II.C-4. The specific hazards and health risks associated with specific indoor air contaminants are presented in Appendices of the manual.

Table II.C-4 Limitations of hazard identification in the IAQ risk assessment process

Limitations of hazard identification process	Issues associated with the limitations
1. Identification of chemicals of concern	<ul style="list-style-type: none"> • Multiple sources and multiple chemicals. • Single chemical or multiple chemicals
2. Site specific conditions	<ul style="list-style-type: none"> • Variability of indoor environmental factors such as emission level (constant or variable), temperature, humidity, wind speed, geographic/building topography/layout), HVAC system, etc.
3. Specificity of IAQ symptoms	<ul style="list-style-type: none"> • Similarity IAQ related symptoms to common illnesses such as influenza, food poisoning, GI disorders, Alzheimer’s disease, angina, and neurological disorders • Underestimation or overestimation of symptoms and illnesses

Source: Modified from Indoor Air Quality and Risk Assessment, 1999, Ed. E. Anderson and R.E. Albert, Centre for Indoor Air Research, Lewis publishers, 1999

II.C.2.3 Dose–response (toxicological) assessment

In this step, the mathematical relationship between the exposure and the incidence of adverse effects is characterized. Information on acute, subchronic and chronic toxicity of the contaminants of concern is compiled. A distinction is made between carcinogens, which may promote or initiate cancer; and non-carcinogens, which may have threshold toxic effects at the cellular, tissue, organ system level. A variety of toxic endpoints, such as neurotoxic, mutagenic and teratogenic are identified and evaluated in this step. From an indoor air quality perspective, consideration of factors such as body weight, breathing rate, health status, diet and personal habits as well as contaminant intake and dose are important (Anderson and Albert 1999).

Identifying and determining a contaminant dose that is unlikely to cause any potential adverse effect in an indoor environment is a challenging task. This task is complex because of the limitations and variation in responses among humans and experimental animals (Anderson and Albert 1999). In an indoor environment, the dose–response assessment process can involve a single as well as multiple contaminants. Although multiple chemical interactions are a growing subject of investigation in the scientific literature, this subject is beyond the scope of this manual.

II.C.2.3.1 Non-carcinogens

Toxicologists have attempted to develop a procedure to calculate a safe dose; that is, a “Reference Dose” (RfD), or a “Reference Concentration” (RfC). An RfD or an RfC is the lifetime dose or concentration of a contaminant that is unlikely to cause any adverse effects. Usually, an RfD is calculated for non-carcinogenic chemicals while an RfC is calculated for ingestion and inhalation exposure pathways. The following box presents the general steps in the derivation of an RfD or an RfC.

Steps in the determination of RfD or a RfC

An important note before reviewing the following steps: Determining a RfD or RfC for a contaminant using this method is associated with various uncertainties and limitations. One must understand these uncertainties and limitations.

Step 1

Review of experimental and epidemiological studies to find out the lowest dose where adverse effects occur. This dose is defined as "Lowest observed adverse effect level" (LOAEL). Then, find the next lower dose where no adverse effects occur. This dose is defined as "No observed adverse effect level" (NOAEL).

Step 2

Based on the availability of toxicological data, uncertainty factors are applied to convert the LOAEL to a NOAEL. The NOAEL is then converted to a RfD or RfC using adjustment factors that can consider the steepness of the dose-response curve and the variability of response in the human population (targeting hypersusceptibles). In the absence of human data, a LOAEL or NOAEL derived from animal studies is divided by a factor of 10 to extrapolate from animals to humans. The result can be again divided by a factor of 1 to 10 if the experimental exposure duration is less than the total life span of the animal. This step is used for both ingested and inhaled doses of chemicals.

Step 3

The last step in this process is to qualitatively describe the scientific confidence in the derivation of RfD or RfC. An adjustment factor between 1 and 10 is applied depending on the outcome of this assessment.

Source: Indoor Air Quality and Risk Assessment, 1999, Ed. E. Anderson and R.E. Albert, Centre for Indoor Air Research, Lewis publishers, 1999

Experimental animal toxicological, human chamber study data and epidemiological human health data studies provide valuable information to an IAQ risk assessment study. Animal toxicological studies are used to extrapolate and predict effects in humans. Animal studies are conducted to derive information on various toxic endpoints, such as carcinogenicity, developmental toxicity, reproductive toxicity, neurotoxicity, and genotoxicity.

In order to reduce the uncertainties and limitations associated with the animal experimental data, epidemiological studies provide valuable information on illness and disease of exposed populations (Anderson and Albert 1999). Epidemiology is limited by statistical sensitivity and confounders. Human chamber studies provide some insight into human response but are limited to relatively healthy volunteers and mild toxic endpoints, such as bronchial reactivity. Table II.C-5 describes target organs or effects associated with various the general hazards and effects associated with different indoor air contaminants.

Table II.C-5 Target organs or effects of IAQ contaminants and health effects of indoor air pollutants

Target organs or effects	Health effects (response)
Respiratory and sensory irritative toxicity	Irritation, inflammation, wheezing, cough, chest tightness, dyspnea, respiratory infections, lung function decrement, respiratory hypersensitivity, acute respiratory illness, and chronic respiratory diseases (Samet and Speizer 1993, Becher et al. 1996)
Neurotoxicity	Fatigue, headaches, dizziness, nausea, lethargy, and CNS depression
Carcinogenicity	Cancers of the lung, liver, kidney, breast, prostate, etc. (malignant and benign tumours)
Immunological toxicity	Respiratory hypersensitivity, immunological changes, asthma, perennial rhinitis and atopic dermatitis (Chapman et al. 1995)
Developmental and reproductive effects	Low birth weight, congenital malformations, premature births and miscarriages (Sram and Benes 1996).

Epidemiological studies are used to derive conclusions on probable associations between a chemical dose and a health effect or response. Epidemiological studies usually take into consideration the sensitive population groups based on susceptibility differences in age, sex, genetic endowment, nutritional status, health status, and life style.

Epidemiology relies on statistical interpretation and as a result requires careful consideration of biases that may influence conclusions. Therefore, epidemiological data should be considered carefully along with other data in establishing a cause and effect relationship. Ideally, causality is often established following Hill’s criteria. Table II.C-6 describes Hill’s criteria for judging if an association is causal (Hill 1965).

Table II.C-6 Hill’s criteria for evaluating evidence of causation

Factors	Explanation
Strength of association	A very large increase in the adverse outcome in association with a risk factor
Consistency	A finding that arises over and over again in different studies involving different places, circumstances or times
Specificity	A finding that is limited to very specific groups and to particular sites or types of disease
Temporality	Exposure must precede the disease
Biological gradient	Existence of a dose–response relationship
Plausibility	Helpful if the suspected causation makes sense in light of available
Coherence	The cause-effect hypothesis should not conflict with well founded knowledge or principles
Experiment	If controlled experiments can be done these can lend support to causation
Analogy	Having learned by experience how some agents cause disease we should be open to similar modes of action by other agents

II.C.2.3.2 Carcinogens

Cancer is considered a dose-related stochastic process. There is always a chance to acquire cancer from exposure to a carcinogen, no matter how small the dose is. However, the smaller the dose, the smaller the chance of getting cancer will be (Burmester and Wilson 1996). USEPA has assumed that there is no safe dose for a carcinogen and that cancer can result from a single DNA mutation caused by a single carcinogenic molecule (Amdur et al. 1991). The cancer slope factor (CSF) is used to estimate the cancer risk for an exposed population. CSF assumes a linear relationship between the carcinogen dose and carcinogenic response (see the following box.).

Hypothetical example of application of CSF

A person is exposed to 0.05 mg of benzene per kilogram of body weight per day for lifetime. The CSF is 0.08 (kg.d)/mg. Therefore, the incremental cancer risk estimate is $0.05 * 0.08 = 0.004$ or 4 additional cancers per 1000 individuals.

II.C.2.3.3 Types of doses

There are three dose metrics commonly used in exposure and dose assessment (Burmester and Wilson 1996).

- **Exposure dose**

The mass of chemical contaminant enters a human body via ingestion, inhalation or dermal contact. No distinction is made for excretion or exhalation or for absorption and metabolism. Usually, it is measured in milligrams of chemical per kilogram body weight per day (mg/kg/day). It is important to use body weight to make a distinction between exposures among different age groups (Burmester and Wilson 1996).

For example, the exposure dose for an adult exposed to PERC (Perchloroethylene) at an airborne concentration of $70 \mu\text{g}/\text{m}^3$ for one day is highlighted in the following box.

$$70 \mu\text{g}/\text{m}^3 * \text{inhalation rate (20 m}^3 / \text{day)} / \text{body weight of an adult (70 kg)} \\ = 20 \mu\text{g}/\text{kg}/\text{day}$$

In its simplest form, exposure dose is often expressed as the amount of contaminant in the air breathed in or water ingested. The exposure dose can be expressed, for example, as 40 ppm, 1-hour average carbon monoxide concentration. This format, airborne concentration and a specified averaging time, is commonly specified in air quality criteria for both ambient and indoor air; it satisfies the concentration and time requirements of a dose measurement.

- **Absorbed dose**

An absorbed dose is the mass of chemical absorbed by the receptor's body. It is measured in the same unit as the exposure dose. However, absorbed dose is always less than the exposure dose. The ability of a chemical to pass from the lungs or alveoli into the blood stream depends on the solubility of the chemical and ability to pass into the bloodstream. Additionally, some of the chemical is exhaled or excreted from the body before absorption by the lungs or GI tract. There are different ways to measure the absorbed dose, such as directly in the blood or by measuring the ratio of inhaled and exhaled concentrations (Burmester and Wilson 1996).

The absorbed dose is always preferred than the exposure dose. Absorbed dose depends on so many other factors such as health status, age and physiological status of the exposed individual. Absorbed dose is also used in the extrapolation of one exposure pathway to another (Burmester and Wilson 1996).

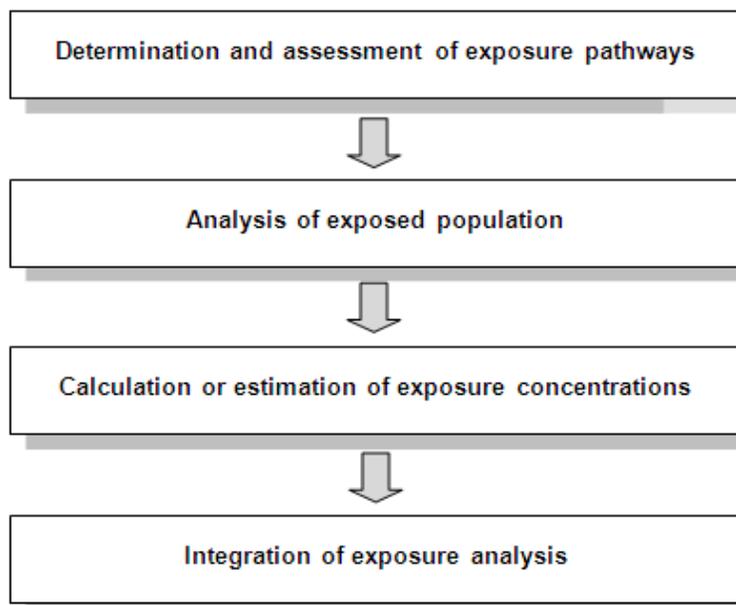
- **Biologically effective dose**

The "Biologically effective dose" is the concentration of a chemical contaminant that reaches the target organ or tissue and causes damage. It is rarely used in the risk assessment process because it is a very difficult parameter to measure and determine (Burmester and Wilson 1996).

II.C.2.4 Exposure assessment

Exposure assessment evaluates receptor exposure pathways and exposure concentrations for the chemicals of concern identified in the hazard identification step. It is an important step in the risk assessment process. In the simplest terms, exposure is the integration of exposure concentration and exposure duration. Figure II.C-1 presents a flow chart of indoor air quality exposure assessment process.

Figure II.C-1 Components of an indoor air quality exposure assessment process



Source: Modified from Indoor Air Quality and Risk Assessment, 1999, Ed. E. Anderson and R.E. Albert, Centre for Indoor Air Research, Lewis publishers, 1999

II.C.2.4.1 Determination and assessment of exposure pathways

An important step in the exposure assessment process is to determine the exposure pathway or pathways that are relevant by asking: for instance, is exposure occurring by the general ventilation system or by infiltration mechanisms? Estimates of exposure concentration can be derived by quantitative air quality measurement assessment of the emission source correlated to qualitative receptor symptoms. The U.S. Environmental Protection Agency (USEPA 1989a, 1989b and 1992) has published exposure assessment guidelines and an exposure assessment handbook for estimating exposures under different exposure pathways, such as inhalation, ingestion or dermal. It is recommended that those guidelines be followed to facilitate the exposure assessment process.

Contaminants enter into the body in a step-by-step manner (USEPA 1992):

- The individual is exposed to contaminants in the air, water, food and soil.
- The contaminant enters into the body through inhalation, ingestion or dermal pathways. Afterwards the chemical is absorbed into and variously distributed in the human body.
- The contaminant reaches a target organ or tissue and exerts an adverse effect.

Indoor air exposure pathways are complex. Indoor human populations can be exposed through the infiltration of contaminants from the outdoor air, tracked in contaminated soil, and aerosolized or volatilized contaminated water. Exposure through volatilization of chemicals from indoor surfaces and materials and emissions from indoor equipment and activities are also considered significant. An understanding of the physical and chemical properties of different indoor contaminants and their sources are required to facilitate the investigation and assessment process.

II.C.2.4.1 Analysis of exposed populations

Human population characteristics vary according to age, sex, genetic disposition, nutritional status and life style. Therefore, in the exposure assessment process of indoor air quality investigations, it is important to identify sensitive individuals and populations. Refer to the “Susceptible Populations” section for more information.

II.C.2.4.2 Calculation or estimation of exposure concentrations

Concentrations of indoor air contaminants are either estimated or measured. There are different methodologies and equipment available for measuring contaminant concentrations in indoor air. The choice of measurement tool depends on the time, cost and type of indoor air contaminants. This issue is discussed in more detail in *Chapter III Investigation of indoor air quality*.

Exposure calculations can be as simple as noting the averaging time over which a sample was collected and the measured concentration. For instance, 20 ppm CO measured with a real-time analyzer may have an averaging time of seconds, minutes, hours or days. The end result is a measure of exposure concentration (concentration and time).

More complex exposure calculations can be calculated by using protocols and procedures from various regulatory agencies such as Health Canada and USEPA. The following box presents a modified equation for general exposure.

Modified equation for general exposure

$$I = \frac{C \times CR \times EF \times ED}{BW \times AT}$$

Intake: the amount of chemical at the exchange boundary (mg/kg/day); for evaluating exposure to noncarcinogenic chemicals of potential concern (COPC), the intake is referred to as average daily dose (*ADD*); for evaluating exposure to carcinogenic compounds, the intake is referred to as lifetime average daily dose (*LADD*)

C = Chemical concentration in media of concern (e.g., mg/kg for soil, mg/m³ in air or mg/L in water)

CR = Consumption rate: the amount of contaminated medium consumed per unit of time or event (e.g., kg/day for soil, L/day for water m³/day air)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Average body weight of the receptor over the exposure period (kg)

AT = Averaging time: the period over which exposure is averaged (days); for Carcinogens, the averaging time is 25,550 days, based on a lifetime exposure of 70 years; for non-carcinogens, averaging time equals *ED* (years) multiplied by 365 days per year.

“Biological markers” can be used to determine exposure (NRC 1991) levels or doses. Examples of biological markers are:

- Urinary cotinine metabolized from nicotine in inhaled tobacco smoke
- Carboxyhemoglobin formed in the blood from the inhalation of carbon monoxide
- Accumulation of lead in blood, teeth, and hair from inhalation of airborne lead and ingestion of lead contaminated food

II.C.2.4.3 Integration of exposure analysis

Information is compiled in the integration phase to more broadly understand the nature of the indoor air quality problem. This compilation includes information on:

- Sources of the indoor air contaminants
- Their fate and transport
- Duration and frequency of occupant complaints and symptoms
- Characterization of the exposed population
- Characterization of estimated or measured concentration
- Characterization of relevant confounding factors, such as outdoor factors, other possible sources of exposure or illness (personal or external), social and psychological factors

The following box describes the limitations and uncertainties associated with the indoor air quality exposure-assessment process.

Causes to limitations and uncertainties in the indoor air quality exposure assessment process

(Patrick 1992):

- Different sources of exposure to indoor air contamination
- Temporal and spatial variation of a typical air contaminant
- Dispersal (three-dimensional distribution) of indoor air contaminants
- Distribution of contaminants among different exposed individuals
- Location of exposed individuals or population, either close to or away from the exposure source (a particular room, or a particular hallway)
- Lack of knowledge of population exposure scenarios which is linked to population lifestyles and activity patterns
- Variations in the human intake of contaminants (e.g., single contaminant versus multiple contaminant exposures)
- Variation and differences in the emission characteristics of contaminants at different time intervals
- Differences in the duration and frequency of exposures to contaminants
- Lack of knowledge in the fate and transport process of indoor air contaminants
- Limitations in the calculation of concentrations of indoor air contaminants. There are errors associated with the fluctuating concentrations of contaminants. These fluctuating concentrations and errors are because of delay, negligence, change in the life cycle processes of biological agents, and failure to identify the source of hazard in the indoor environment.

II.C.2.5 Risk characterization

“Risk characterization” is the actual process of determining a “risk”. The risk compilation process is “to describe a potentially hazardous situation in as accurate, thorough and decision-relevant manner as possible, addressing significant concerns of the interested and affected parties, and to make this information understandable and accessible to public officials and to the parties” (NRC 1996). Information from the previous three steps—hazard identification, dose response, and exposure assessment—is analyzed in the risk characterization step.

The deterministic risk assessment approach is commonly used in regulatory applications for its simplicity. Risk, as we recall, is the probability of injury, damage, or loss. A common practice of the deterministic risk assessment approach is to derive point estimates of risk using conservative inputs. (James et al. 2000). Risk characterization based on a point estimate does not indicate the uncertainty of the estimate or range of exposure, for example, the high end of the range of risk as well as the central tendency (Poulter 1999). For screening level purposes such a conservative approach may be warranted; however, the practice of applying conservative inputs can produce an unrealistic overestimate of risk (Burmester and Wilson 1996).

Human health risk assessment to chemical exposure is shifting to the probabilistic paradigm (Burmester and Wilson 1996). Instead of using point values for inputs as in the deterministic approach, the probabilistic approach considers variability, uncertainty,

and the probability distributions to denote the range of exposure and toxicity so as to more accurately capture the distribution of risk attributable to a specific scenario. This approach involves extensive work. Two factors determine if a probabilistic assessment is needed for more detailed analysis and to better inform decision-making (USEPA 2004):

- Magnitude of the estimates of risk; that is, the value of hazard indices [HIs] or cancer risks for COPCs
- Level of confidence in these estimates

A detailed discussion of the probabilistic risk assessment process is beyond the scope of this manual. The reader is encouraged to refer to other relevant publications for additional information.

From a public health perspective, information on the exposure concentration and duration may not be needed to determine if a “nuisance” exists. The identification of “chemicals of concern” (COCs) in an indoor environment, coupled with symptoms in affected populations that are biologically plausible and that correlate to the COCs, is often enough to satisfy the public health definition of nuisance (Refer to *Chapter I Introduction to indoor air quality* for the definition of nuisance.)

The following two examples further exemplify the definition of nuisance and provide an introduction to the “qualitative approach”.

- Examples:
 - Tenants complain of vehicle-exhaust smells in their apartment complex suites. On investigation, symptoms of headache and nausea appear to be associated with the presence of an underground parkade immediately below the suite and the observation of unsealed sewer and water pipe penetrations through the kitchen and bath floor slab into the parkade. The unsealed pipe penetrations provide a direct pathway for vehicle exhaust to easily and directly migrate into the apartment even when parkade exhaust systems are functioning as required. Therefore, in this case air monitoring may not be required. The mere existence of a direct pathway is sufficient to enough to associate health complaints with likely exposure to vehicle exhaust and to require mitigation.
 - Employees at a warehousing business in a strip mall complain of paint smells, headache and nausea. Inspection reveals the presence of an adjacent business where spray-painting activities occur that are not in accordance with industry codes of practice, the building code or occupational guidelines. In this example, there is no paint spray booth. In this case, the presence of paint smells and correlating health effects in the adjoining business are sufficient to require the installation of a paint spray booth.

The National Research Centre (NRC 1994) has suggested that descriptive information is essential and must always be an integral part of the risk assessment. Words are useful in elucidating differences in assumptions and uncertainties, and non-scientific considerations in environmental statutes that can result in different management decisions. The risk characterization step can use either the qualitative or the quantitative approach depending upon the requirements and availability of data for a particular situation. However, when the risk characterization process uses the combined approach, readers can benefit from both the “words’ and “numbers”.

II.C.2.5.1 Qualitative approach

In the qualitative approach, as demonstrated in the two examples above, all the acquired information is integrated and discussed qualitatively without the extensive involvement of number crunching! Many qualitative social and perception factors can influence risk acceptability. For example, is the risk known or unknown, catastrophic or not, voluntary or involuntary, man-made or natural, immediately manifested or delayed, what are benefits versus the harms? While it is acceptable to use the qualitative approach alone, the investigator must be aware of limitations and uncertainties associated with the qualitative approach.

II.C.2.5.2 Quantitative approach

In the quantitative approach, numerical estimates are presented for each category of chemicals. For non-carcinogenic chemicals exposure, the acceptability of measured airborne concentrations can be determined by calculating the “total hazard quotient” (hazard index) or by comparing with a numeric standard or criterion. For carcinogenic chemicals, exposure or measured concentrations can be used to calculate “total incremental lifetime cancer risk” or a direct comparison can be made to a risk-based standard or criterion.

The “hazard quotient” (HQ) is used for non-carcinogenic chemicals. It is defined as the average daily dose of exposure divided by the reference dose or reference concentration for that chemical via the same exposure pathway (see the following box) (Burmester and Wilson 1996).

$$\text{HQ} = \frac{\text{(average daily dose) year}}{\text{RfC}}$$

HQ = Hazard quotient, unitless

(Average daily dose) year = Average daily dose averaged over one year, expressed in mg of chemical per kilogram body weight per day

RfC = Reference Concentration (usually used for inhalation exposures) for the chemical and route of exposure (e.g., inhalation), expressed in mg of chemical per kilogram of body weight per day

Based on the exposure route, units of exposure will change

By summing up all hazard quotients (HQ) for chemicals for all exposure pathways, the Hazard Index (HI) can be determined. The hazard index is a unitless number (a ratio of positive numbers).

Values of the HQ may range from less than 0.1 to infinity, with values less than 1.0 considered being acceptable risk. For example, an HQ of 1000 may present a very high risk and unacceptable scenario whereas, HQ <0.1 may immediately support a “no further action” management decision. A value of 0.1 for a chemical is considered acceptable where no other exposures from other sources or pathways are possible.

Usually, an HQ > 1 suggests possible adverse health effects from exposure to a chemical agent, whereas, an HQ < 1 implies no significant risk.

The incremental lifetime cancer risk for carcinogenic chemicals is defined as the average daily dose averaged over a lifetime multiplied by the cancer slope factor (Burmester and Wilson 1996) (see the following box.).

Incremental lifetime cancer risk = (average daily dose) life * CSF

ILCR = The incremental lifetime cancer risk for chemicals and exposures. It is unitless.

(Average daily dose) life is the average daily dose averaged over a lifetime, generally taken as 70 years. It is expressed in mg /kg/body weight per day.

CSF = Cancer slope factor for the chemical and route of exposure, expressed in the inverse of (mg of chemical per kg of body weight per day).

Based on the exposure route, units of exposure will change.

The total incremental lifetime cancer risk is determined by adding up ILCR of all the chemicals and exposure pathways. In order to see which exposure pathways contribute significantly in a particular exposure scenario, it is recommended that a sub total of incremental lifetime cancer risk be calculated from each individual exposure route (inhalation, dermal, or ingestion).

The carcinogenic risk is interpreted as a probability of developing cancer sometime during a lifetime; the value may range from 0 to 1. There are different regulatory standards on how to interpret the carcinogenic risks.

1 in 1000000 ($1 * 10^{-6}$)

1 in 100000 ($1 * 10^{-5}$)

The above two standards are acceptable among regulatory agencies. It is considered acceptable risk if, either 1 in 1 million or 1 in one hundred thousand human population is having risk of getting cancer. In Alberta, AEW (and AHW) set acceptable cancer risk levels at 10^{-5} .

II.D Summary

Chapter II Toxicology, risk assessment and indoor air quality began with a revisit to the 1974 *Lalonde Report*. It was recognized that health determinants are more than health care and medicine; the physical and socio-economical environments also played an important role in determining people's health status. The definition of "public health" was also revisited. While public health concerns itself with the health of the community, current air-quality standards are conservative, protecting almost 100 per cent of susceptible groups in the community.

This chapter brought forth some toxicological principles and the "health risk assessment" processes to the attention of the readers. Traditionally, health risk assessors have relied on mathematical models; however, "words" and "numbers" could complement each other and together provide a better description of the risk, uncertainty and limitations. Although the probabilistic approach is becoming popular, the deterministic approach based on a point estimate remains the choice for regulatory purpose because of its simplicity.

This chapter presented some numbers and values useful for risk calculations, for example, "toxicological reference values." As science and knowledge continually advances, reviews and changes in these numbers and values are anticipated. For that reason, PHIs and EPHOs are reminded to continually update their resources.

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Chapter III

Investigation of indoor air quality

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III. Investigation of indoor air quality

III.A Introduction

Public health agencies are increasingly being asked to resolve complaints related to IAQ concerns in different types of residential (single-family dwellings, condos and apartment complexes) and non-residential buildings (offices, commercial buildings, strip malls and institutions) (Calgary Health Region, 1993). Some IAQ complaints originate from specialized facilities, such as schools, swimming pools, ice arenas, nursing homes, hospitals and day-care facilities.

Because of the complex nature of indoor air concerns, it is often difficult to correlate adverse physiological effects to a specific contaminant. The question of perceived or real health effects requires careful assessment. Even though indoor air quality complaints may at times be based more on a psychological perception than a biological or physical reality, the investigator should not dismiss such perceived complaints without a thorough assessment (Calgary Health Region, 1993).

The principal assumption in this chapter is that all IAQ complaints will be investigated to some degree. Therefore, whether it is a residential, non-residential building or a specialized indoor facility, complaints from occupants and users of these buildings should be dealt with seriously.

Many people entering the Environmental Public Health (EPH) field with previous experience in the field of engineering-related discipline will have an advantage understanding general or dilution ventilation system design. However, the majority of Environmental Health officers (EHOs) or Public Health inspectors (PHIs) lacking a strong engineering background, often become frustrated, even intimidated when asked to comment or to render decisions on general ventilation systems. Therefore, this chapter is primarily written for EHOs and PHIs without engineering-related experience.

First, Environmental Public Health practitioners (EPHPs) need to acquire a basic knowledge of the fundamentals of ventilation systems. While EPHPs will not be

involved in the design of a ventilation system, they may find it necessary to do the following:

1. Recommend the installation of a local exhaust ventilation (LEV) system as an exposure control measure. A nail salon using acrylic-based applicators or industrial shops in junior and high schools are two examples of places that may require a LEV system.
2. Periodically test, troubleshoot and evaluate the performance of
 - General ventilation systems for elevated carbon monoxide levels in a residential home or follow up on a Legionellosis outbreak at an hotel
 - LEV systems as exposure-control measures in commercial or institutional facilities

It should be acknowledged that it is virtually impossible to thoroughly present the many intricacies of general ventilation and LEV design and their relationship to the IAQ concerns in a short chapter. Fortunately, there are many books dedicated to each one of those subject areas. An e-library of materials is also available as part of this document and a hard copy library is available through the Alberta Health Services, Environmental Public Health - Scientific Advisory Team. Hopefully, this chapter will serve as a starting point for those who are not familiar with the fundamental concepts of LEV or general ventilation systems.

III.B General investigation process

The purpose of the IAQ investigation is to gather information about a complainant's concern and information relating to the potential cause of those concerns. Information can be gained in various ways:

- Interview the complainant and other occupants, the building manager or maintenance providers, if applicable
- Onsite observation and inspection
- Environmental sampling and monitoring

In order for the investigation to be effective in evaluating IAQ problems or concerns, the Public Health Inspector (PHI) or Environmental Health Officer (EHO) will need sufficient background knowledge in several areas:

- General IAQ principles
- Interviewing techniques
- Building design and construction
- Heating, cooling and ventilation systems
- IAQ evaluation equipment and environmental sampling procedures
- Data interpretation

There are two basic types of IAQ complaints and problems: (a) those involving health complaints or symptoms, which may already or should involve a physician, and (b) those complaints involving thermal and comfort discomfort. The complaint or problem can arise from exposure to indoor pollutants or unacceptable conditions resulting from:

- Elements of the building, such as layout, construction materials, uses and activities
- Interaction between the conditioned and ventilated space, and occupants
- Equipment in the building
- Building envelope
- Outdoor conditions or sources
- Flaws in the building design, construction, operations, or maintenance
- Changes in building usage or modification from the original design

Regardless of the origin of the complaint or problem, it will eventually fall into one of three categories: biological, chemical, or physical. These categories are discussed further in the appendices.

Successfully analyzing and resolving an IAQ problem will depend on the nature and complexity of a particular complaint as weak as the skills, experience and judgment of the investigator. Because of the complex nature of indoor air concerns, it is often difficult to correlate adverse physiological effects to a specific contaminant.

The principal assumption in this chapter is that all IAQ complaints will be investigated to some degree. Therefore, whether it is a residential building, non-residential building or a specialized indoor facility, complaints from occupants and users of these buildings should be dealt with seriously.

This section will discuss the IAQ investigation process and also provide guidance on how to characterize receptors, buildings and environments.

III.B.1 Phase I – Initial screening

The first phase of the investigation process is the initial screening of the complaint. Many complaints are received by the local Alberta Health, Environmental Public Health offices; however, not all complaints are within the jurisdiction of public health legislation. As such, the complaint must be screened to determine if the complaint falls within the public health mandate.

The step-by-step process, illustrated in Figure III.B-1, should be followed when screening incoming complaints received over the telephone.

Step one: In the initial screening step, determine whether the complaint falls under the public health mandate.

This process may be completed by the administrative staff at the local Zone EPH office. The PHI/EHO or administrative staff will determine whether the complaint is within the jurisdiction of the public health mandate. The following box lists some sample complaints.

Nature of the complaint	Within the public health mandate	Outside the public health mandate
If the complaint involves a rental living unit	<input checked="" type="checkbox"/>	
If the facility involved is a public facility	<input checked="" type="checkbox"/>	
If the complaint comes from a non-residential facility; if the source of the problem is not controlled by the employer	<input checked="" type="checkbox"/>	
If the complaint is covered by public health legislation	<input checked="" type="checkbox"/>	
If the complaint is from a privately-owned and occupied dwelling		<input checked="" type="checkbox"/>
If the complaint is from a workplace where the employer has control over the source of the problem, or problem is an occupational health and safety concern		<input checked="" type="checkbox"/>
If the subject of the complaint is controlled by a local by-law or associated with fire protection and prevention		<input checked="" type="checkbox"/>

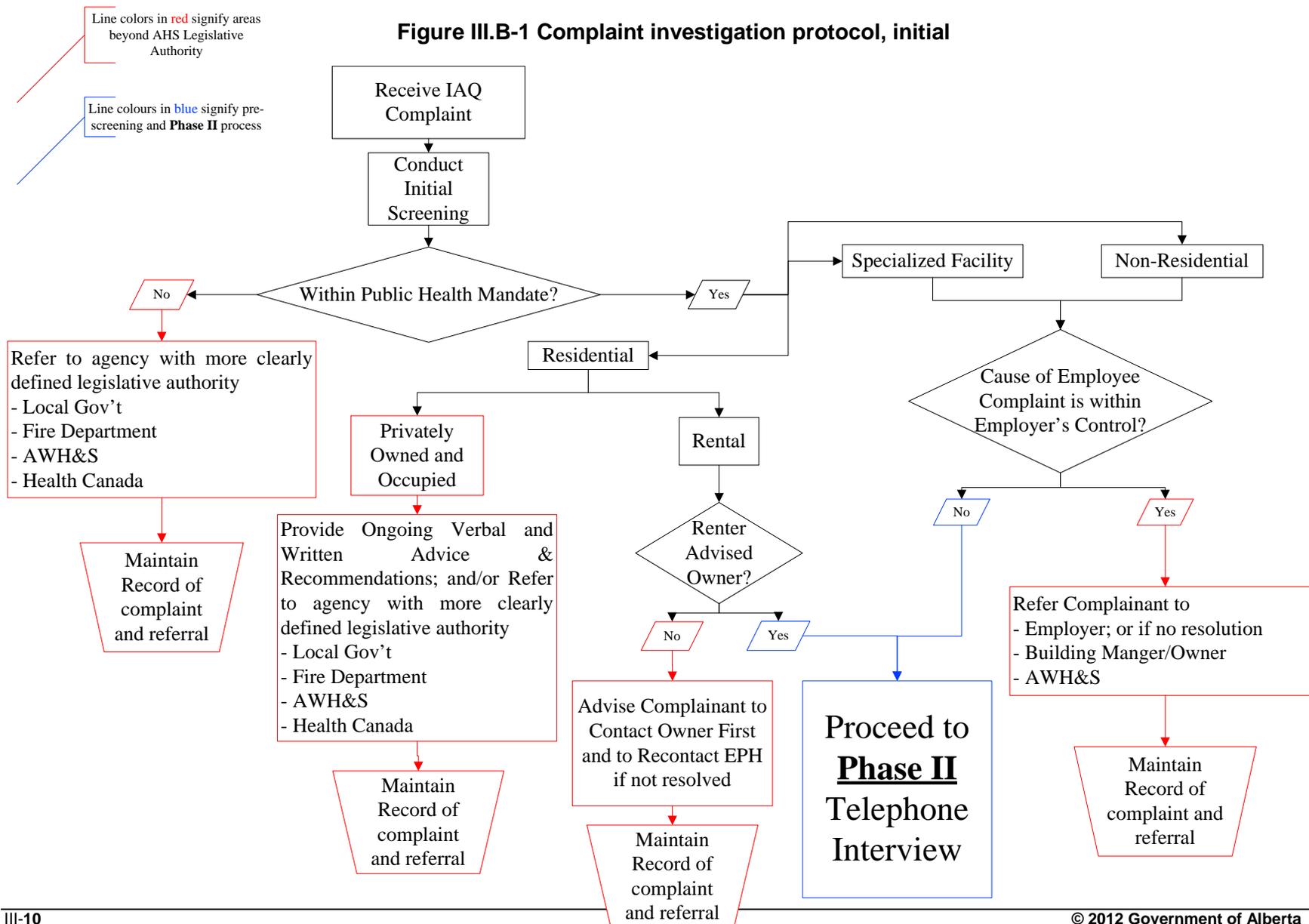
Step two: If the initial screening process places the complaint within the public health mandate, proceed to Alternative one; if the complaint is not within the public health mandate, proceed to Alternative two.

- ▶ **Alternative one:** If the complaint falls under the public health mandate, then proceed to collect information from the complainant and proceed to Phase II – the Telephone interview.
- ▶ **Alternative two:** If the complaint does not fall under the public health mandate, then refer the complainant to other agencies that have a more clearly defined legislative authority or may be willing to help the complainant. Some examples of agencies to consider for the referral.
- ▶ Alberta Workplace Health and Safety: if the complaint is from a workplace and is between an employer and employee.
- ▶ Local Government: if a building code issue is involved, refer the complainant to a municipal building inspector, safety codes officer or bylaw officer.
- ▶ Alberta Environment and Sustainable Resource Development (SESRD): if the complaint is within the regulatory environmental mandate of AEW.

NOTE: If the complaint does not fall within the public health mandate, making a referral completes EPH involvement and the file can be concluded.

Following the Phase I initial screening, the PHI or EHO will proceed to Phase II to conduct a telephone interview with the complainant.

Figure III.B-1 Complaint investigation protocol, initial



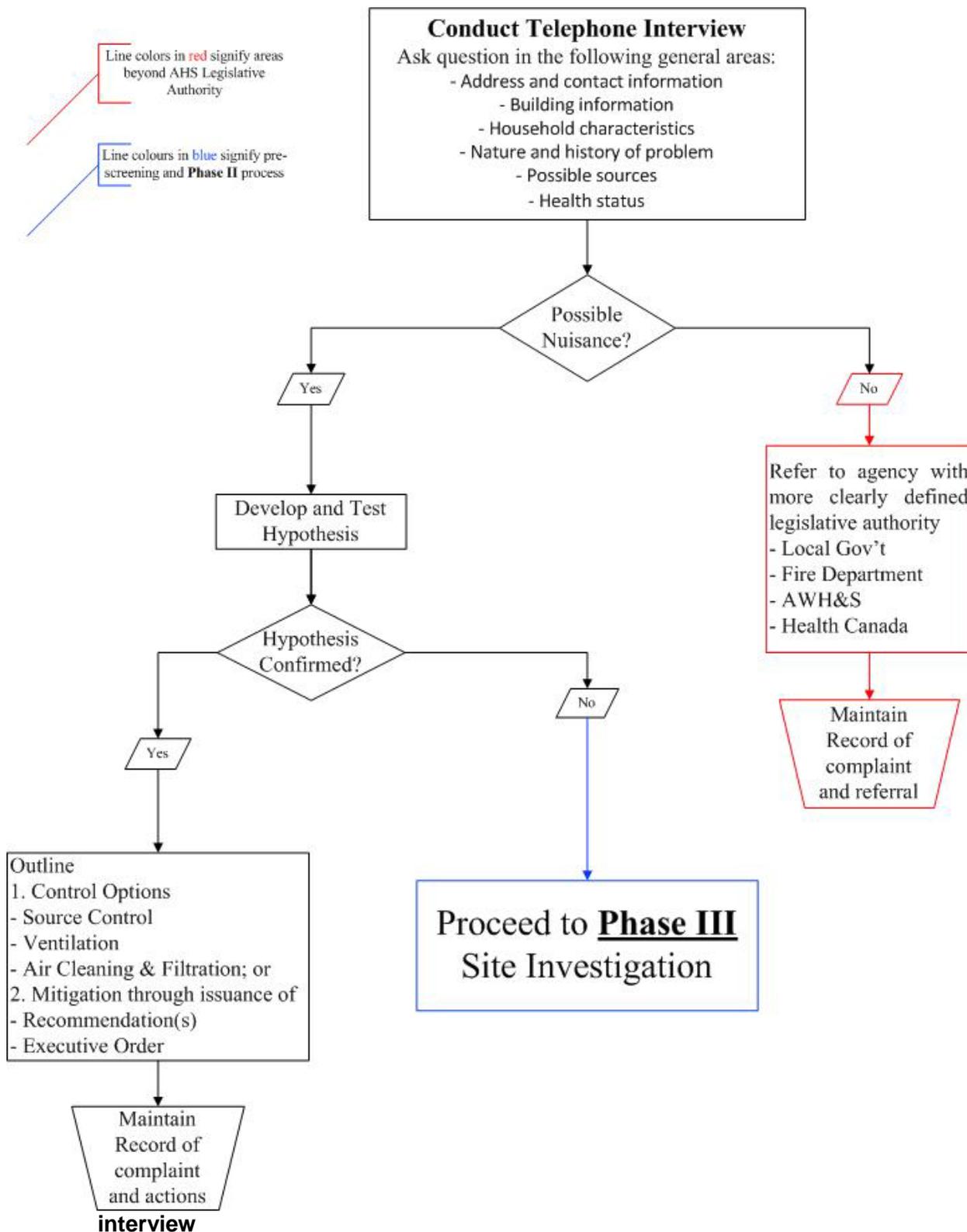
III.B.2 Phase II – Telephone interview

Once the initial screening is completed and it is determined that the complaint falls within the public health mandate, the Zone PHI or EHO can proceed with Phase II of the investigation – the Telephone Interview (see Figure III.B-2 interview flowchart.)

The purpose of the telephone interview is to characterize receptors, the building and the environment that is the subject of the complaint. In the telephone interview, the PHI or EHO gathers information to help form a hypothesis of potential sources or causes. Although the focus is on complainant and building characterization, it is important to consider interviewing all key stakeholders. For instance, if investigating a complaint from a renter or commercial space leaseholder, it is important to interview the building owner or manager. The investigator will use scientific and professional judgment while collecting information on the following (ASTM, 2006):

- Complainant’s address and contact information in order to allow for an appropriate follow-up.
- Complainant’s complaint characterization
 - Nature of the complaint and history of problem
 - Health symptoms or discomfort experienced by the complainant
 - Symptom-related information, such as onset, when symptoms are worst and when they are better, where symptoms are most often experienced and where they are not experienced, how often, how long
 - Activities or environmental changes that may coincide with IAQ concerns or health symptoms or discomfort
 - The nature, frequency and duration of any odours and if they coincide with symptoms
- Complainant characterization and health status
 - Background health problems
 - Unaffected individuals
 - Any medical evaluations; if a physician has been engaged, the doctor’s contact information should be acquired
 - Indoor activities and uses
- Building information
 - Building type
 - Building age or year of construction
 - Remodeling and renovation history of building including what renovations were done and when
 - Other building uses
 - New furnishings, equipment or activities
 - Number of bedrooms or other occupancies if commercial

Figure III.B-2 Phase II – IAQ Complaint investigation protocol, telephone



- Types of major appliances, other occupant uses and activities
- Type of ventilation system
- Physical or thermal comfort factors, such as relative humidity and temperature
- Outdoor influences, usually nearby
- Other occupant characteristics
 - Number of occupants and other complainants
 - Ages of occupants
 - Other indoor activities or uses
 - Health symptoms of other building occupants
 - Sensitive or vulnerable individuals

The interview will aid in identifying possible sources or causes of the complaint. However, the identification is reached following the review of information gathered throughout this step and subsequent steps.

A sample questionnaire that can be used for the telephone interview is available in *Appendix I IAQ investigation questionnaires*. The questionnaire should be reviewed and modified by the PHI or EHO before initiating the telephone interview to ensure its relevance to the specific situation under consideration.

It should be noted that information-gathering over the telephone is very qualitative in nature. The symptoms experienced by an occupant, coupled with a preliminary building assessment and the interview of other key stakeholders can help the inspector narrow down the long list of potential indoor air contaminants and sources to just a few, or even one. Health inspectors should cautiously correlate specific contaminants to health symptoms. Before making an association, PHIs should consider different factors, such as the sensitivity or health status of the occupant, and the characteristics and history of a building.

At this point, the PHI or EHO should evaluate the gathered information to develop an initial hypothesis or hypotheses and to identify areas to focus on during the subsequent investigation. Also determine if there is sufficient information to confirm the hypothesis. Relying exclusively on the health symptoms to identify a possible contaminant of concern without considering building related factors is not justifiable.

If the information gathered during the telephone interview is insufficient to confirm the hypothesis, the PHI or EHO will proceed to Phase III-Site Investigation (see Figure III.B-3)

However, if there is sufficient information at the completion of the telephone interview and the hypothesis is confirmed, the PHI or EHO will outline recommended control options and then proceed to mitigate the complaint or issue an executive order if deemed necessary.

III.B.3 Phase III – Site investigation

Because of the complex interaction of different physical, chemical and biological factors in indoor air, it is possible that results from a telephone interview may not be sufficient to confirm the hypothesis or verify the association between the reported symptoms and a causal factor. In these cases, the PHI or EHO will proceed to Phase III and complete an onsite investigation. A Phase III - Site Investigation process is required under any of the following conditions:

- The hypothesis made during the phase II telephone interview cannot be confirmed
- The hypothesis made during the phase II telephone interview is inconclusive because of various limitations
- A site investigation is required under the Public Health Act, Nuisance and General Sanitation Regulation or a Department Standard Operation Procedure (DSOP).

The purpose of the onsite investigation is to gather further information through interactions with building occupants and users, and to conduct a detailed assessment of the building and environment. Figure III.B-3 is a diagrammatic reiteration of the steps involved in phase III site investigation process.

The site investigation process is divided into of three distinct areas for information gathering:

- **Interaction with occupants**

Interaction with occupants is an important part of the site investigation process. Information from the occupants helps the investigator to further develop the hypotheses. The EHO should talk to different occupants, the building manager or owner to gather as much information as possible. Interviewing identified sensitive or vulnerable individuals among the building occupants or users is also important. When talking to different occupants, differentiate them according to their age, sex and health status. These interactions will identify particular areas of concern that need to be emphasized during the building assessment. Use of the IAQ Investigation Questionnaire that is provided in *Appendix I IAQ investigation questionnaires* to facilitate this dialogue.

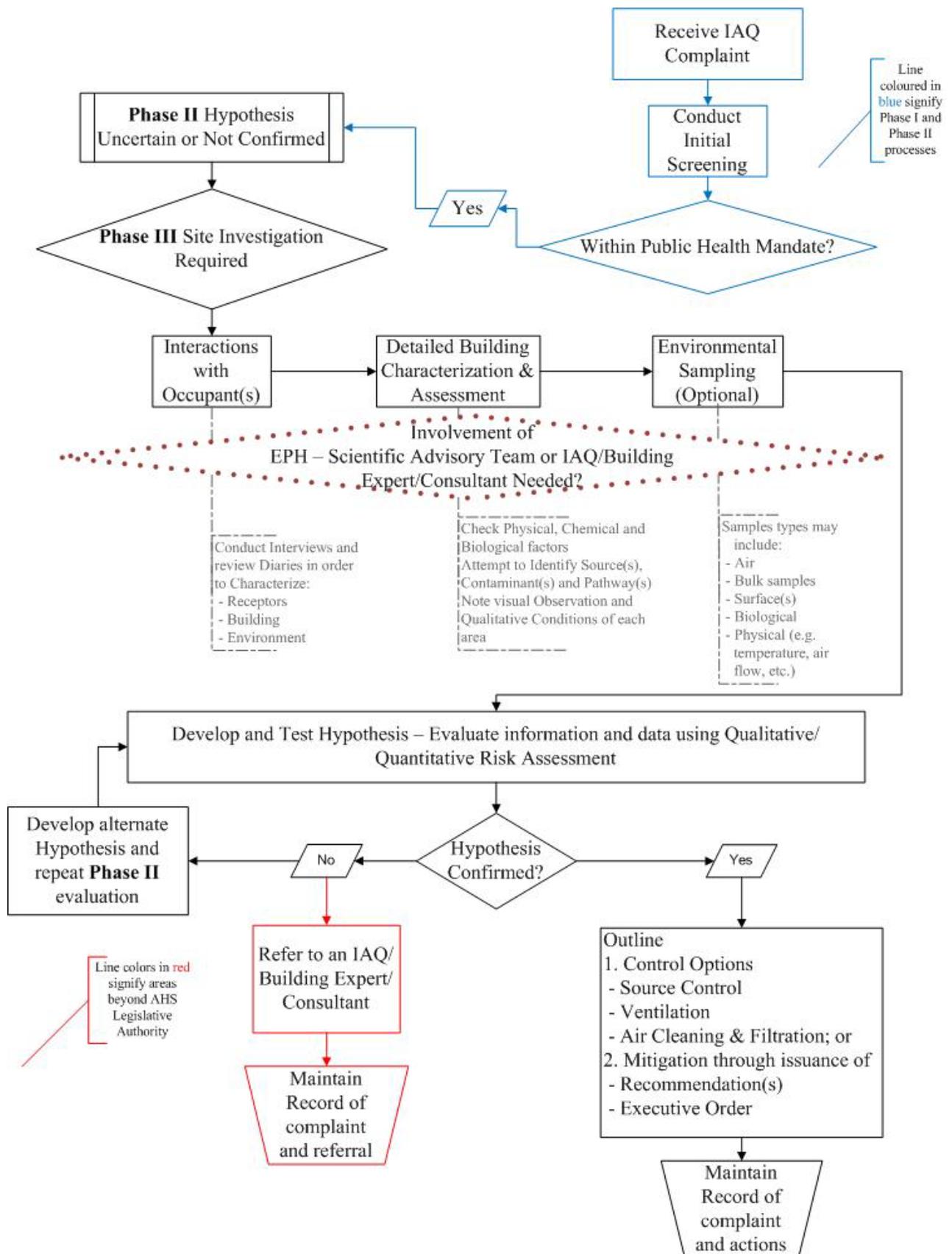
- **Detailed building characterization and assessment**

Complete a detailed building characterization and assessment. Identify and assess different sources of contaminants and their pathways. Identify different factors (including physical, chemical and biological) that may be responsible for the health symptoms reported by different occupants. Perform a thorough walk-through survey of the building, including HVAC, if necessary. Use questions provided in the *Appendix I IAQ investigation questionnaires* as needed.

- **Environmental sampling**

Based on the information gathered from the above two steps, determine if a sampling program is necessary to further investigate the extent of indoor contamination. A sampling program is not always necessary or required. If sampling is required, then follow the procedures in Section IIIC-2.

Figure III-B-3: Phase III: IAQ complaint investigation protocol site



Investigations

After the completion of each of the above areas, the PHI or EHO should briefly analyze the information collected and re-evaluate the hypothesis, based on the qualitative and quantitative risk-assessment framework. The qualitative risk assessment incorporates all information collected from the various sources. The quantitative risk-assessment analysis would incorporate the results of any environmental sampling. Quantitative risk assessment involves calculation of doses, exposure concentrations and quantitative risk characterization. Refer to *Chapter II Toxicology, risk assessment and indoor air quality* for additional information.

If information gathered during the site investigation is insufficient to confirm the hypothesis, then the PHI or EHO will need to re-define the hypothesis and re-analyze the information and data. If required the PHI or EHO may involve the EPH Scientific Advisory Team located in Edmonton or Calgary, or an IAQ consultant or expert.

If there is sufficient information at the completion of the site investigation and the hypothesis is confirmed, then the PHI or EHO will make recommendation to outline control options and proceed to mitigation or issue an executive order as deemed necessary.

If, at any point, the PHI or EHO feels that the nature of the complaint is beyond their experience and knowledge, the inspector may contact the EPH – Scientific Advisory Team located in Edmonton or Calgary) or recommend the involving of an IAQ consultant.

III.B.3.1 Receptors' Characterization

A receptor is a biological organism that may be affected by exposure to a hazard under consideration. For example, people are often subdivided on the basis of age group (Health Canada 2004). Typical age groups are:

- Infants (0 to six months)
- Toddlers (seven months to four years)
- Children (five years to 11 years)
- Teens (12 – 19 years)
- Adults (20+ years and older)

Age groups are assessed separately because many of the factors determining the degree of exposure are different. In addition, certain age groups are more susceptible to chemically mediated effects, such as infants, toddlers and pregnant women (Health Canada, 2004).

The receptor (human individuals or population) exposures can be identified and characterized by following criteria:

- **Location**

The location (distance and direction) relative to a contaminant source determines the potential for exposure. Individuals that are the closest or most often occupy the area of concern will more likely come into contact with hazardous compounds.

- **Activities and activity patterns**

Activities and activity patterns in a building and adjacent outdoor sources, may influence indoor exposure. The following land use classifications include activities that may provide unique exposure conditions:

- Residential
- Commercial and industrial
- Recreational
- Agricultural

Each use is associated with specific human activities and activity patterns:

- Residence time on the site
- Activities on the site
- Location of activities, either indoors or outdoors
- Seasonal changes of activities

- **Sensitive subpopulations**

In specific subpopulations, exposure to hazardous substances may lead to an increased risk. Subpopulations of potential concern are:

- Infants and children, pregnant and nursing women, elderly people
- People with chronic diseases or genetic predispositions
- The infirm or sick
- People with behaviour patterns that may cause high exposure, such as athletes, construction workers and children
- People exposed to hazardous substances from other sources or through occupational activities

III.B.3.2 Environment characterization

“Environmental characterization” is the prediction or measurement of the spatial and temporal distribution of a stressor and its co-occurrence or contact with the ecological components of concern. A brief but complete description of the environment around the building of concern should be provided, including all characteristics pertinent to understanding potential indoor exposures and risks. Subsections may include:

- Site location
- Current and adjacent land use
- Summary of adjacent sources and activities that are potentially capable of affecting IAQ in the building of concern
- Local or regional background concentrations of contaminants, as available and appropriate

In the context of IAQ, environmental characterization also includes built environment factors such as temperature, lighting, dust and relative humidity.

III.B.3.3 Building characterization

“Building characterization” is the process of gathering information on building and ventilation parameters needed to incorporate into the IAQ assessment. The information is important to determine the operating set points and schedules consistent with acceptable IAQ (Abdul-Wahab, 2011).

Building parameters to consider include (Abdul-Wahab, 2011):

- Building type
- Building size
- Age of structure
- Location
- Building fabric or envelope construction
- Furnishings and equipment
- Building occupants
- Occupant activities

Ventilation parameters from both natural and mechanical systems should be considered and include (Abdul-Wahab, 2011):

- Air-flow rate
- Air volume
- Air velocity

III.C Investigation tools

There are several tools available to the PHI or EHO when investigating IAQ complaints. This section will discuss the physical tools that the PHI or EHO should carry in their inspection kit, the various considerations around environmental sampling, and using air movement and odour threshold as diagnostic tools for IAQ problems.

III.C.1 Tools

The tool kit of a PHI or EHO performing IAQ investigation should contain a number of tools to aid in identifying the potential source of the IAQ problem. Below is a list of the common tools and a brief description of the tool's use:

- Mirror to look into small and difficult places
- Flashlight to look into dark areas
- Thermometer to determine temperatures
- Humidity sensor or meter to determine relative humidity
- Manometer to establish pressure differentials
- Smoke pencil or bottle to determine air-movement patterns and directions

There are additional tools that may be of value when conducting IAQ investigations:

- Air velometer to determine air velocity in ducts or passageways.
- UV flashlight to see staining
- Moisture meter to determine moisture content of materials
- Combustible gas meter to determine concentration of combustible gases
- CO meter to determine CO concentration
- CO₂ meter to determine CO₂ concentration
- Multi-gas meter to determine concentration of specific gas concentrations (dependent on sensors present in meter)
- Pitot-tube devices to determine the velocity pressure inside a duct for calculating air changes per hour (ACH)
- Manometer to measuring pressures and determine pressure differentials
- Clear tape and slides or surface sampling kit to sample materials settled onto a surface
- Sample bags to hold physical samples
- Air sampling equipment to sample for various parameters of concern (see Table III.C-1 for details)

III.C.2 Sampling, process and analysis

Indoor air quality contaminant measurements are conducted for hypothesis-testing purposes; that is, to determine the contaminant's source and then to evaluate or document potential cause-and-effect relationships between suspected contaminants and various illnesses and symptoms. The various techniques available for contaminant measurements are briefly described in this section. Contaminant measurements can include testing for gas, vapour or particulate phase substances (Godish, 2000) and, can include biological materials, such as pollens, moulds and fungi. Based on the goal of the sampling and analysis program, various sampling protocols or techniques can be followed to collect samples that are subsequently sent to a laboratory for analysis.

III.C.2.1 Indoor air sampling plan

When designing a sampling plan, the following points should be considered (ACGIH, 1999):

- The nature and expected concentrations of materials and substances
- The relevance of average or worst case concentration measurements
- The cost, accessibility and availability of various types of sample analyzes, devices, techniques and methods
- Limitations of analytical methods that may affect sample collection
- Technical expertise of field and laboratory personnel
- Time constraints of sample transport and analyzes

Usually, the hypothesis under consideration guides the development of a sampling program. A hypothesis is usually developed based on information gathered from the complainant during the early interview process (Phase I - Telephone Interview) and face to face interviews and detailed investigations as part of Phase II. The purpose of the hypothesis is to either confirm or disprove the suspected association between the presence of contaminants (if any) and the health symptoms reported by the building occupants (University of California, 1999).

The hypothesis should test the relationship between the contaminant source and health effects or symptoms. To test the hypothesis, the following fundamental steps should be considered (ACGIH, 1999):

- State the aim of the study and outline the goals and expectations of the sampling program.
- State the explicit hypothesis question or statement to be addressed and the information required for answering them.

Example: A complaint is received from a tenant of paint smell from a nearby auto-body paint shop close to the residential building. Then the hypothesis is that the VOC emission from the auto-body paint shop is causing all the paint-smell complaints and the tenant's symptoms. As mentioned earlier, a hypothesis can be presented in the form of a question or a statement. An example of the hypothesis as a question: "Is the VOC emission from the auto-body paint shop causing the paint-

smell complaints for the tenant?” Based on this hypothesis, the PHO can plan to investigate the auto-body paint shop including reviewing business licenses and the paint-booth exhaust and filtration system, and collecting and analyzing air to either confirm or disprove that the auto paint shop is the source of the tenant’s complaint. Note: common paint-booth filtration systems are designed to capture paint aerosols with 100 per cent of VOCs being exhausted into the ambient or outside air.

- Design a sample collection plan to obtain the required information.
- Collect and analyze samples.
- Compile and summarize data.
- Perform statistical analysis of the data, if required.
- Determine if the goals of the sampling program have been met and if the hypothesis posed at the outset of the investigation can be confirmed.

The reader can appreciate the similarity of the sample planning process with the plan-do-check-act model. An integrated management approach can be applied to a sampling program as well.

III.C.2.2 Indoor air sampling processes

Based on the requirement of the sampling program, a PHI or EHO can make a decision as to what type of sampling process or a combination of samples should be conducted. The type of sampling process to be used during the investigation of an IAQ complaint will vary, depending on the following factors:

- Suspected indoor air contaminant
- Accuracy requirements
- Sampling time necessary to correspond with recommended indoor air quality guidelines
- Most importantly, the availability of suitable testing equipment or the services of an accredited analytical laboratory

For instance, instantaneous sampling would be useful in situations where general pollutant identification is sufficient. For instance, if a furnace was suspected of malfunctioning and releasing combustion gases indoors, an instantaneous sample for CO could provide the PHI or EHO with immediate knowledge about the extent of the problem. The use of detection tubes in this situation would be a simple and inexpensive method for determining the presence of CO (Calgary Health Region, 1993).

Before initiating air sampling or testing, a written protocol should be established to standardize the method in which the air sampling is to be performed. A written protocol should document, but is not limited to, information regarding:

- When, where and how to sample including quality control or quality assurance samples, a control sample or field blank is often essential; duplicate samples may also be considered
- A description of the environment being sampled
- The number of samples required and sampling time of each sample
- Calibration of equipment to ensure quality and accuracy of measurements
- Access to laboratory facilities, if required, and a storage and shipping protocol
- How the data is collected during the sampling process will be correlated to existing indoor air quality guidelines or toxicological information
- Characterization of relevant indoor and outdoor variables and parameters, if required.
Examples: source characterization, air exchange, ventilation system (on or off), windows and doors (open or closed), outside versus inside temperature, relative humidity, wind speeds and direction
- Necessary assumptions
- Possible interferences

In general, indoor air measurements can be categorized as either area measurements or personal measurements. Personal measurements are collected by attaching a sampling device, such as a portable personal pump or passive sorbent badge, to a person near the breathing zone. Area samples are collected at a fixed sampling location in a room at a height approximate to the breathing zone and in areas of the building where the occupants tend to spend the majority of their time and most often experience symptoms.

III.C.2.3 Types of sampling measurements

IAQ contaminants are typically found at concentrations much lower than normally sampled for in industrial hygiene investigations. In most IAQ investigations, air monitoring will not be necessary; instead simple screening methods are sufficient. Types of air sampling for chemical contaminants include (Burton, 1995):

- **Spot sampling detector**
Spot sampling detector (colorimetric/indicator) tubes are an easy-to-use pre-screening tool, to perform real-time spot checks¹ to determine whether a particular chemical compound, such as CO₂, is present at a given location.
- **Personal monitoring**
This sampling device, such as a passive dosimeter or diffusive sampling badge is worn or placed² near the breathing zone of the person being sampled. Personal monitoring is often used when there is a question about personal health effects.

¹ Results are usually not accurate (i.e. $\pm 25\%$ error).

² Samplers are worn on the lapel or collar on the person. Samplers may also be held in place by a stand.

- **Area sampling**

Area monitoring including fixed sampling, environmental monitoring, station sampling involves the use of a sampling device that is either placed in a fixed location, or moved about in the space being tested. The results show the ambient background concentrations of the chemical contaminant at the sampling location, and may not represent the actual exposures of the breathing zone of people.

- **System sampling**

Air samples may be obtained from the ductwork itself as in stack sampling at the air supply and return registers, or at the air intakes. This type of sampling is used to:

- Complement investigations in identifying pathways of chemical contamination
- Ascertain whether or not the HVAC system is contributing to the problem

- **Time-average measurements**

This process averages the concentration of a contaminant over a specified time period, ranging from several hours to several days. However, no indication of the peak concentration of the contaminant is provided.

- **Continuous measurements**

This measurement process records a series of spot measurements (grab samples) or short time-averaged measurements for a specified time period from hours to days. The advantage of this measurement process is that both the peak and time averaged concentration for a specific contaminant can be recorded.

III.C.2.4 Contaminant measurement techniques

The remainder of this section lists various common contaminants (see Table III.C-1) and outlines some examples of routine air sampling equipment. In addition, some basic background information on the measurement techniques for each contaminant is also provided. This material is not presented in detail, but is merely provided as a guide for indoor air sampling. For more detail regarding sampling equipment, or specific measurement techniques, please consult with the EPH – Scientific Advisory Team, a local laboratory, regulatory agencies such as Health Canada, OSHA, NIOSH, ASTM, ACGIH, or any other organization or source you feel may be of assistance.

There are various types of air monitoring equipment that are available for use. Make sure that you can proficiently use the equipment and interpret the results before taking it on an inspection. Air monitoring devices include the following:

- **Combustible gas analyzers**

These devices are useful for detecting hydrocarbons and combustible products in the air that may be caused by:

- Cracks in a heat exchanger
- Raw gas leaks because of poor connections or mechanical damage
- Spillage or back-drafting through the draft hood
- Gas or vapour intrusion into the premise

- Sometimes it is difficult to know what is activating the detector device (CDA, 2005a).

- **Carbon monoxide sensors**

Carbon monoxide detectors are used to identify carbon monoxide (CO(g)) in the air. Remember CO(g) is a product of the incomplete combustion that may be result from:

- Malfunctioning heating equipment, such as a gas or oil furnace, and vents
- Exhaust products entering the house; for example, from a cracked heat exchanger or spillage through the exhaust system
- Incomplete combustion of natural gas or oil
- Tobacco smoke
- Motor vehicle exhaust or forklift exhaust
- Internal combustion engines
- Steel-production facilities (Burton, 1995; CDA, 2005a)

- **Carbon dioxide detector**

Carbon dioxide (CO₂) can essentially be viewed as an occupant-based measurement³. It can act as an excellent surrogate for indicating elevated concentrations of contaminants that are more difficult to measure. Experience has shown that occupants are likely to experience signs and symptoms such as stiffness, headaches, fatigue, eye and respiratory tract irritation if the indoor CO₂ level exceeds the outdoor level by two or three times.

Although this elevated CO₂ level is not responsible for the complaints, it suggests that other contaminants in the building may have increased to undesirable levels (Burroughs and Hansen, 2004). The takeaway lesson is that CO₂ measurements may be used as a pre-screening tool to assess the amount of ventilation air being introduced to the indoor environment.

³ Keep in mind that some IAQ complaints are occupant-related.

Table III.C-1 Air sampling equipment measurement techniques for common contaminants

Contaminant	Air sampling equipment	Measurement techniques
Radon	o Activated charcoal detectors	The charcoal detectors are to be placed in a cool, dry, occupied room in the lowest place in the house, usually the basement, for one week or less. The canisters are then to be sealed and sent to the laboratory for analysis. To get an accurate reading, it is preferable to use two canisters.
	o Alpha-track devices	Alpha-Track devices should be placed in an occupied room located at the lowest level of the home for at least four weeks, but preferably several months. The devices are then sent to a laboratory for the particle tracks on the Alpha-Track film to be counted. To obtain accurate results during the sampling process, keep the doors and windows closed as much as possible. In addition, try to avoid sampling during periods of high wind or humidity as these conditions may affect the test results. As these devices sample over a longer period of time than the charcoal canisters, they are generally considered more accurate and are often used to verify measurements obtained previously with activated charcoal detectors.
	o Electret ion detectors	Electret ion detectors should be placed in an occupied room located at the lowest level of the home for at least four weeks, but preferably several months. The device consists of a Teflon disc, which is statically charged. When an ion generated from radon decay strikes the Teflon disc, the electrical charge is reduced. In the laboratory, the charge reduction is measured and the radon level is calculated.
	o Scintillation counter	The radioactive decay products of radon are electrically charged and, as a result, can adhere to particulates. Consequently, radon can be measured by collecting a particulate sample by using a pump and filter and then determining the radioactivity with a scintillation counter. This measurement process requires approximately one hour to complete. Unfortunately, because of the quickness of the test, the effect that changing environmental parameters, such as increases or decreases in wind velocity and relative humidity, can have on indoor radon levels and primarily because of the capricious nature of radioactive emissions, this process may have a large degree of error (i.e., up to ± 20%).
Carbon dioxide (CO ₂)	o Direct reading monitor (Electrical Conductivity) o Sorbent sample tubes o Short-term or long-term colour detection tubes	Carbon dioxide measurements should be taken during building occupancy and in areas of the building where the occupants tend to spend the majority of their time. It is preferable to obtain CO ₂ data over a long-term period (e.g., 24 hours to several days) to assess the effect that increases or decreases in building occupancy or ventilation rates may have on indoor CO ₂ levels. If long-term monitoring equipment is not available, then a set number of grab samples over a specified time period (e.g., one sample per hour for eight hours) with short-term colour detection tubes may suffice.
Combustion products (CO, NO ₂ and SO ₂)	o Direct reading monitor (Electrical Conductivity) o Sorbent sample tubes o Short-term or long-term colour detection tubes o Impingers	Measurements for combustion products should occur in areas where the combustion sources are located and in areas of the building where the occupants tend to spend the majority of their time. The PHI or EHO will have to make a decision concerning what type of sampling process will be most suitable.
Formaldehyde (HCHO)	o Impingers o Sorbent sample tubes o Short-term or detection tubes o Passive colour badge	There are many different methods for measuring formaldehyde, and consequently the PHI or EHO must choose the sampling equipment best suited for his specific needs. As formaldehyde levels vary diurnally, measurements should occur during the time of the day and in an area of the home where the symptoms appear to be the worst.
Ozone (O ₃)	o Impingers o Short-term or long-term colour detection tubes o Direct reading monitor	Measurements should occur close to potential sources of ozone and in areas where the occupants tend to spend the majority of their time.

Contaminant	Air sampling equipment	Measurement techniques
	(Electrical Conductivity)	
Volatile organic compounds (VOCs)	Direct reading monitors (portable gas Chromatograph/Mass Spectrometry) <ul style="list-style-type: none"> ○ Sorbent sample tubes ○ Short-term or long-term ○ Detection tubes ○ Collection using stainless steel canisters 	<p>Since VOCs are a category rather than just a single indoor air contaminant, extensive sampling and analysis may be required, depending on the sampling equipment chosen. For instance, indoor air investigators may know exactly what VOC they are looking for (e.g., xylene) and in such a situation a low cost method of sampling may be explored (e.g., colour detection tubes). Colour detection tubes, however, may not be sufficiently sensitive to detect VOCs at very low concentration. Therefore, if possible, PHI or EHO should use sampling equipment that can detect VOCs in the part per billion (ppb) to part per trillion (ppt) range. If a PHI or EHO is not sure which specific VOC is causing the symptoms of building occupants, then more elaborate testing procedures will have to be carried out (e.g., sorbent tubes, portable GC/MS analysis, stainless steel canisters).</p> <p>Sorbent tubes are probably the most economical method of sampling, as the purchase of a portable GC/MS is cost prohibitive.</p> <p>Stainless steel canisters have a chemically treated inner surface, containing an inert chrome-nickel oxide (Godish, 1989) which collects VOCs passively or through pressurized sampling, depending on the atmospheric pressure (NEHA, 1991). After sampling is complete, the canisters are sent to a laboratory for analysis. The stainless steel canister method can identify VOCs in the ppb to ppt range. However, the laboratory costs required for analysis may limit the use of this sampling method.</p> <p>Measurement for VOCs should occur in areas of the building where possible sources exist and where the occupants tend to spend the majority of their time.</p>
Particulates	<ul style="list-style-type: none"> ○ Direct reading monitor (light scattering automatic particle counter) ○ Impingers ○ Filters ○ Packaging of material samples for identification 	<p>The main reason for sampling particulates is to obtain sufficient data to make estimates regarding the concentration of particulates in the air. By obtaining information as to the concentration and size of particulates in the air, the PHI or EHO can determine the amount of particulates that will be inhaled by building occupants. The volume of air to be obtained during sampling varies. However, the primary goal is to obtain a representative sample of indoor air that is of sufficient volume to allow particles to be accurately weighed, counted or chemically analyzed. Air samples should be obtained as near as possible to the height of the occupant's breath zone. After sampling, the particulate sample is sent to a laboratory for analysis.</p>
Asbestos	<ul style="list-style-type: none"> ○ Filters ○ Packaging of material samples for identification 	<p>To determine if asbestos is the contaminant of concern in a specific situation, a sample of the material should be packaged and sent to a laboratory for identification. When air sampling in buildings, where asbestos exists or is being handled, stationary samples should be collected approximately five feet off the ground for a period of six to eight hours. The air sampling duration may change depending on the volume of air sampled, the pump flow rate, and the minimum detectable concentration (fibres/cubic centimetre [fibres/cc]) of asbestos required for laboratory analysis. The pump flow rate determines how quickly the desired air sampling volume is collected and, therefore, the sampling pump must be calibrated to the prescribed sampling period.</p>
Lead (Pb)	<ul style="list-style-type: none"> ○ Packaging of material samples for identification 	<p>A sample of the suspected lead sources (e.g., paint chips) can be collected and sent to a laboratory for analysis. To facilitate correct testing, at least 0.5 grams of paint chips should be collected. If a lead removal program is to be carried outside, surface samples should be collected before and after the lead abatement process with surface wipes (commercial wipes or recommended filter paper). The surface samples are then sent to a laboratory for analysis.</p>
	<ul style="list-style-type: none"> ○ Lead check swabs 	<p>Instant lead testing can be done with "lead check swabs", which will detect the presence of lead (minimum detection level is 2 µg of lead) through a colour change. Instantaneous lead test kits are of dubious value to the significant number of false positive and negatives results produced and because a colour change does not allow for comparison to any numeric guidelines.</p>
	<ul style="list-style-type: none"> ○ Filters (mixed-cellulose ester) 	<p>Filters can be used for monitoring airborne lead levels during abatement processes.</p>

Contaminant	Air sampling equipment	Measurement techniques
Hydrogen sulphide (H ₂ S)	<ul style="list-style-type: none"> ○ Sorbent sample tubes ○ Impingers ○ Short-term or long-term Detection tubes 	Exterior readings should also be obtained for reference purposes, as H ₂ S is primarily an outdoor pollutant.
Pesticides	<ul style="list-style-type: none"> ○ Sorbent sample tubes: ○ Low volume polyurethane foam (PUF) with analysis by gas chromatography/ ○ Electron capture detection (GC/ECD) 	<p>Air samples: A large number of pesticides can be sampled by using a sampling pump which draws air through a borosilicate glass tube that contains polyurethane foam (PUF). Low flow rates (approximately one to five litres per minute) are then used to collect the sample during a 4 to 24-hour sampling duration. After sampling, the borosilicate glass tube is sent to a laboratory and the pesticide is extracted from the PUF, concentrated, and then analyzed using GC/ECD.</p> <p>Measurements of pesticides should be taken in each living area of a home.</p>
	<ul style="list-style-type: none"> ○ Surface wipes 	<p>Surface samples: Surface samples, also referred to as wipe or smear samples, are useful for obtaining information as to the extent of the pesticide contamination. Samples can be collected from walls, floors, furniture and other areas within the building (except carpets or furnace filters). If it is necessary to obtain a pesticide sample from carpet or a furnace filter, a section of the material should be removed and sent to a laboratory for analysis. Measurements of pesticides should be taken in each living area of a home.</p>
Polycyclic aromatic hydrocarbons (PAHs)	<ul style="list-style-type: none"> ○ Sorbent sample tubes and filter 	The indoor air sampling procedure for PAHs usually involves the use of solid sorbent tubes to trap PAH vapours along with a membrane filter to trap particulate matter, therefore ensuring total collection (Health Canada, 1986). After the sampling is complete, the tubes and filters are sent to a laboratory for analysis. Air sampling for PAHs should occur in areas of the building where suspected contaminant generators exist, such as combustion related processes which may produce benzo(a)pyrene.

NOTE: See Appendix x for additional information

- **Chemical factors**

This section provides some basic information regarding the various technical options available for IAQ investigations. Each IAQ measurement technique provides the PHI or EHO with an overview of the various measurement alternatives and their operating principles.

Specific air sampling, storage and shipping protocols are detailed in various sampling protocols such as the *NIOSH Manual of Analytical Methods*. The reader should seek similar information from other agencies including USEPA, Health Canada, Alberta Environment, OSHA, ACGIH and scientific publications.

- **Summa canisters**

Summa canisters can be used to collect gaseous and volatile airborne pollutants. Air samples can be collected at a specific site and taken to a laboratory for analysis. Summa canisters are typically pre-voided creating a vacuum into which the air being sampled is drawn at a predetermined sampling rate and a corresponding averaging time, such as one, eight, and 24 hours.

Note: additional equipment often used with summa canisters:

- ▶ Pressure gauge
- ▶ Various canister accessories

- **Sorbent sample tubes**

A large number of gases and vapours can be sampled by the use of sorbent tubes. Air is pulled through the tube by means of a pump, trapping airborne chemicals in the absorbent layer of the tube. After sampling, the tubes are sealed with push-on caps and sent to a laboratory for analysis. Absorbed pollutants can be solvent or thermally extracted from the tube and analyzed by various techniques, such as gas chromatography. A number of different sorbent tubes are available including charcoal, tenax and alumina, depending upon the airborne chemical family being tested. Passive sorbent badges are also available. When using sorbent tubes for IAQ investigations, the following equipment is required in addition to the test tubes:

- ▶ Sample pump
- ▶ Pump flow meter for sample pump calibration:
 - ◇ Electronic calibrators with computer interface
 - ◇ Film calibrators with a digital stopwatch

- **Colour detection tubes and badges**

With colour detector tubes, a known volume of air is drawn through a tube by a pump. The reagent in the tube changes colour in response to the air contaminant being tested. The length of the stain is proportional to the concentration of the contaminant. The results from indicator tubes and badges are subject to large errors (± 25 per cent) and, therefore, are not very accurate. Their accuracy is affected by humidity, temperature and other compounds which may interfere with the colour change. However, some passive detection devices work by

diffusion, such as passive colour badges. Three colour detection methods are stated below:

- ▶ Passive colour badges

The air contaminant enters the badge by diffusion and can react with various types of collection media, such as liquid medium and solid absorbents. The extent of the colour change or length of stain is proportional to the sampling time and concentration of the air contaminant. Depending on the badge type and the suspected air contaminant, gas chromatography instead of the usual colour change will be necessary to provide an indication of the concentration of the airborne contaminant.

- ▶ Long-term tubes

As this method implies, detector tubes are used with constant or low flow pumps to obtain an airborne sample over a long-term. Some long-term tubes are passive and do not require pumps.

- ▶ Short-term tubes

These detector tubes are used with small hand-held pumps (GASTEC or DRAGER pumps) to obtain instantaneous or grab samples.

- **Impingers**

Impingers are glass bubble tubes which contain a liquid medium that reacts with the air contaminant of interest when a known volume of gas is bubbled through it. This reaction allows the liquid to be analyzed so as to determine the concentration of the airborne contaminant. As impingers collect contaminants in a liquid medium, they are designed to collect particulates and specific chemicals, such as acids and anhydrides. There are various types of impingers that are available for use.

Note: additional equipment used with impingers:

- ▶ Air sampling pump
- ▶ Pump-flow meter (for sample pump calibration)
- ▶ Various impinger sampling accessories

- **Sample bags**

Sample bags can be used to collect airborne pollutants. Air samples can be collected at a specific site and taken to a laboratory for analysis. Different types of sample bags are available in the market place and their specific use is dependent on the contaminant being sampled for. Sample bags are typically filled using a vacuum sampling apparatus.

Note: additional equipment used with sample bags:

- ▶ Sample pump and flow meter
- ▶ Various sample bag accessories
- ▶ Vacuum sampling apparatus

- Filters
 - Filters are used to collect indoor air contaminants, such as particulates, dust, fumes and mists, in aerosol form by pulling air through a filter of specific type and pore size using a sample pump. After the contaminant is collected, the sample is sent to a laboratory for analysis. The type of filter used during the sampling process will vary depending on the contaminant of interest.

Note: Additional equipment for use with filters:

- ▶ Air sampling pump
 - ▶ Pump flow meters for sample pump calibration
 - ▶ Various filter sampling accessories, such as cassette blanks, holders and tubing
- Direct reading monitors

Various sampling instruments exist for the measurement of indoor air contaminants. These instruments can operate based on numerous measuring principles.

As numerous monitoring instruments exist, a PHI or EHO must make a decision as to which monitoring device to purchase, rent or use. Such a decision should be based on the following parameters.

- Accuracy of the instrument
- Portability
- Sampling range
- Minimum detection limit
- Ease of use (including calibration)
- Contaminants of concern
- Cost
- Availability

However, it is recommended that the monitoring equipment used be flexible enough to provide both instantaneous readings and data storage capabilities for the measurement of indoor air contaminants for at least 24 hours and preferably for longer periods.

III.C.2.5 Physical factors

This section lists physical comfort parameters (Table III.C-2) and outlines some examples of routine air sampling equipment that may be used. In addition, some basic background information on the measurement techniques for these parameters is also provided. This material is not presented in detail, but is merely provided as a guide for indoor air sampling. For more detail regarding sampling equipment, or specific measurement techniques, consult with the EPH – Scientific Advisory Team.

Table III.C-2 Air sampling equipment and measurement techniques for thermal comfort parameters

Thermal Parameter	Air sampling equipment	Measurement techniques
Relative humidity (% R.H.)	Wet and Dry Bulb Thermometers (used in conjunction with a psychometric chart) Short-term or long-term colour detection tubes (used in conjunction with a psychometric chart)	Relative humidity measurements should take place in locations where the occupants spend a large proportion of their time (e.g., living room, bedroom,). When collecting data indoors, outdoor sampling should also be performed, and qualitative information concerning wind velocity and cloud cover should be recorded.
Heat stress (°C)	Direct reading monitors(The Wet-Bulb Globe Temperature [WBGT])	The WBGT can be used for calculating "heat stress", as it incorporates data from the wet-bulb temperature (twb), the globe temperature (tg), and the dry-bulb air temperature (ta). The measurement of parameters necessary to calculate the WBGT Index should be obtained from an area of the building that is representative of the environmental conditions to which the occupants are exposed.
Ventilation	Velometers	Velometers are used to give readings of air velocity in feet per minute (FPM) or meters per second (m/s). A velometer is a swinging vane type anemometer which is used to calculate the volume flow rate by multiplying the average velocity in an opening by the area of the opening. However, for small openings, a velometer is not considered suitable and smaller probes such as a hot wire thermometer, heated thermocouple, or thermistor should be used.
	Pilot-static tube	This type of air measuring equipment is used to measure the air velocity and pressure in the ductwork of a ventilation system.
	Balometer	Balometers measure air flow accurately and directly as they are placed over the top of grilles and diffusers. This one step measuring process eliminates the need to take multiple readings to obtain an average air flow. Supply or exhaust readings can be made in cubic feet per minute (CFM), cubic meters per hour (m3/hr.) or litres per second (l/s).
	Smoke tubes	Smoke tubes contain chemicals that produce fumes (e.g., titanium tetrachloride) when air is passed through the tube by a rubber squeeze ball. Smoke tubes are an effective way to monitor the direction of air flows, identify dead air spaces, identify the movements of contaminants from a source, and to test fume hoods (e.g., determining the approximate capture distance for hoods).

- **Biological factors**

The discussion provided below focuses primarily on sampling and analysis of mould and related fungi. A brief discussion on the requirements of a sampling plan has already been presented in this chapter. For more information, consult publications by Health Canada, ACGIH and various researchers for a detailed discussion on different organisms, their sampling and analysis.

Bioaerosols include particles originating from living organisms and can vary in their composition based on various sources and from one indoor environment to another. They include viable (alive), non-viable (dead) microorganisms, pollens, spores, skin cells, insect parts, fragments of fungal reproductive propagules and vegetative hyphae, toxins and waste products (ACGIH, 1999; Godish, 2000).

There are two primary bioaerosol sampling methodologies used for air sampling.

- Culturable and viable sampling
- Total spore and particle sampling (including both viable and non-viable organisms)

1. Culturable and viable sampling

This method is used to measure airborne concentrations of viable mould and bacteria including actinomycetes. For example, samples can be collected by a “Biotest” RCS sampler. After collection of samples, organisms in the nutrient media are allowed to grow at selected temperatures. Different media are available for selective sampling. After maturing of colonies, they can be identified up to their genus and species level. Concentrations are usually expressed as colony forming units per cubic meter (CFU/m³).

Refer to Table III.C-3 for a summary of information on sampling methodologies and devices used for viable (alive or culturable) bioaerosol sampling. Different sampling devices differ in collection efficiency, principle of collection, sampling rate and collection time. All the sampling devices employ a solid culture medium to grow out viable/culturable organisms (Godish, 2000).

Viable or culturable microorganism samplers have limitations; only viable organisms can grow on the nutrient media. Biological aerosols of health concern include both viable and non-viable organisms. In case of moulds, the total spore counts are usually more than 10 times the viable/culturable concentration (Godish, 2000). The ability of different organisms to grow and be detected varies from one medium to another. Fungi can be classified as hydrophilic including *Fusarium* and *Stachybotrys*, or mesophilic including *Alternaria*, *Cladosporium*, *Ulocladium* and *Aspergillus versicolour*. Hydrophilic and Mesophilic fungi require wet and dry materials to grow, respectively. Xerotolerant fungi can also grow under these conditions and some others (some *Penicillium spp.*, *Aspergillus glaucus* group) can also colonize relatively dry materials.

Table III.C-3 Devices and techniques used for viable and culturable bioaerosol sampling

Sampler	Operating principle	Sampling rate (ft ³ /sec)	Recommended sampling time (min)
Slit to slit agar impactor	Impaction onto solid culture medium on rotating surface	30-700	1-60 (depends on models and sampling circumstances)
Single stage, portable impactor	Impaction onto solid culture medium in a "rodac plate"	90-180	0.5 ⁵
Single stage (N-6) impactor	Impaction onto solid culture medium in a 10 cm plate	28.3	1-30
Two-stage impactor	Impaction onto solid culture medium in a 10 cm plate	28.3	1-30
Multistage impactor	Impaction onto solid culture medium in a 10 cm plate	28.3	1-30
Centrifugal impactor	Impaction onto solid culture medium in plastic strips	40±	0.5
All glass/AGI-30 impingers	Impingement into liquid; jet 30 mm above impaction surface	12.5	1-30
All glass /AGI-4	Impingement into liquid; jet 4 mm above impaction surface	12.5	1-30
Cassette filters	Filtration	1-2	5-60

Usually, sampling time varies from 1 to 5 minutes

Source: adapted from Godish, T (2000), in *Indoor Environmental Quality*, Lewis publishers, 2001.

2. Total spore and particle sampling

In a typical total spore and particle sampling device air is drawn into the device via a tapered slit at relatively high velocities. Total spore and particle sampling includes both viable and non-viable organisms. The particles are then collected on a silicon-grease or adhesive covered microscope slide. After staining and slide preparation, mould spores and hyphal fragments are identified and enumerated at higher magnification, for example, 1000X oil immersion magnification (Godish, 2000). Usually, in this technique, moulds are identified up to genus level (unlike in the viable sampling, where both genus and species can be identified).

There are three impaction type techniques for total mould spore and particle sampling. Two of them are sampling instruments with integrated pumps. The other one is a sampling cassette⁴ that relies on gravitational settling. Total mould spore and particle samplers give better estimates than viable or culturable micro-organism samplers because allergenicity or toxicity is not depended on viability (Godish, 2000).

▶ Cellophane tape sampling

Another technique, which is commonly used for collecting mould spores, is by utilizing thin cellophane tapes. The sticky surface of the tape is pressed against the mould-contaminated surface to collect mould samples. Then the

⁴ In the case of a sampling cassette, particles are impacted on a greased cover slip and then mounted on a slide and counted at 400 to 600 times magnification.

tape is placed on a slide. The spores are observed under a microscope after a staining procedure, such as lactophenol cotton blue, and counted per square centimetre area. Although, it is an easier method of collecting samples, care should be taken in terms of data interpretation and analysis (ACGIH, 1999).

► Measurement techniques for house dust mites and Legionella bacteria

Table III.C-4 and Table III.C-5 presents a brief summary of measurement techniques for house dust mites and Legionella bacteria are provided. For additional information, see *Appendix F Biological factors or Bioaerosols: Assessment and Control*, edited by Janet Macher and published by ACGIH (1999) and other publications.

Table III.C-4 Measurement techniques for house dust mites

Contaminant	Air sampling equipment	Measurement techniques
Dust mite faecal pellets	Semi-quantitative analysis of guanine levels in house dust	House dust mites: testing for dust mite allergen levels through guanine analysis (guanine is found in the excreta of dust mites) is a relatively simple procedure. The guanine is dissolved out of the dust sample and the solution is then tested with an azo reagent contained within a testing strip (NEHA 1991). A positive test is shown by a colour change, which varies in intensity depending on the concentration of guanine present in the dust sample (NEHA 1991).
	RAST (Radio-immunoassay) method	Another method for quantifying dust with allergenic content is to collect dust from a vacuum cleaner and have it analyzed by radioimmunoassay or by monoclonal antibodies (Godish 1989). The measurement of dust mite allergenic material would be useful to doctors investigating a connection between environmental factors, allergies and asthma.

For details regarding the sampling and analysis of bacteria and viruses, the PHI or EHO should consult the ACGIH guidelines for infectious disease causing organisms.

Table III.C-5 Measurement techniques for Legionella

Contaminant	Air sampling equipment	Measurement techniques
Legionella pneumophila	None (use water sample bottles)	Legionella pneumophila: Air testing for Legionella is not practical. However, if Legionella pneumophila is present in water sources at sufficient concentration to cause disease, water samples may be collected for analysis.

III.C.3 Air movement

Movement of air can affect building occupants by affecting IAQ, energy use and thermal comfort. Air flow is responsible for the spread of mould spores and other chemical, biological, or radiological pollutants. Because air currents can rapidly transport these agents throughout a building, understanding air flow patterns and air movement within the building or occupied space is essential to understanding the dispersion of such pollutants and is a useful tool for diagnosing the source of the IAQ problem/complaint.

Chemical smoke tubes can be used to determine air flow directions and connections between the complaint area and surrounding spaces (including the outdoors), and to reveal air circulation patterns within the complaint area or the area suspected to be the source of the IAQ problem (USEPA, 1991). Air movement will create pressure

differentials between connected spaces with the space where air is leaving having a “low” pressure and the space air is moving to having a “high” pressure. As such, manometers may also be used to help determine air flow and movement patterns.

When using smoke tubes, the evaluation of air flow and air movement patterns is completed (USEPA, 2008):

- Near supply air outlets - the dispersal pattern provides information about the velocity and direction of the supply air
- Near exhaust vents to make sure the exhaust is drawing air out of the room
- Near combustion chamber of combustion appliances to insure that there is no backdraft of flue gases
 - Turn the appliance on.
 - Close all doors or other openings that might possibly be closed in normal operating conditions and turn on all exhaust fans or other equipment, such as clothes dryer, that may exhaust air from the room.
 - Release puffs of smoke next to the combustion chamber and around the flue fittings where flue gases might leak into the room to detect any air movement from the flue or combustion chamber into the room.
 - If any flue gas leakage is occurring, turn off the appliance, open windows and doors, and exit the room. This is a potentially life threatening hazard.
- At drain trap openings, make sure no air is flowing up from the trap.
- At seams in the ducts, to check for air leaks.
- At the entrance to an exhausted room to ensure the room is under negative pressure relative to the occupied spaces.
- Ensure the room is under positive pressure.

More generally, identify spaces that are positive or negative relative to other spaces to determine if this may be causing pollutants or moisture to travel in undesirable paths (USEPA, 2008).

Air flow and air movement patterns can change depending upon weather conditions, windspeed and direction, equipment operation within the building, traffic through doors and other factors, such as systems throttling back or coming up to speed. Therefore, it may be necessary to make observations under such different conditions. There are a number of operating conditions that also affect air flow and air movement patterns; switching air handlers or exhaust fans on and off, opening and closing doors, and simulating the range of operating conditions in other ways can help to show the different ways that airborne contaminants move within the building (USEPA, 1991). Observing patterns in the dust around door frames can also reveal the dominant direction of air and pollutant movement (USEPA, 1991).

Another tool available for determining air flow and air movement patterns are tracer gases, such as sulfur hexafluoride (SF₆). Such gases can provide qualitative and quantitative information on pollutant pathways and ventilation rates; however, the use of

tracer gases to obtain quantitative results requires considerable technical expertise (USEPA, 1991).

If the IAQ problem requires a sophisticated study of pathways or ventilation rates, tracer gases may need to be used as well as an IAQ consultant or expert with experience in the use of tracer gases and quantitative analysis.

Air flow and air movement patterns are complex and vary considerably; therefore, the PHI or EHO cannot be expected to understand how air moves within the building under all potential operating conditions. However, data on pathways and driving forces can be obtained from architectural and mechanical drawings, if available and can help to locate potential pollutant sources and to understand how contaminants are transported to building occupants based on the design of the building (USEPA, 1991).

III.C.3.1 Determining air flow & amount of make-up air

When HVACs are operated in an unbalanced state, the system can become the source of indoor IAQ complaints. According to Burroughs and Hansen (2004, pp.80-81), there are a number of items that can create inadequate ventilation within the building:

- Not enough fresh outdoor air is supplied to the office space
- Poor air distribution and mixing which causes stratification, draftiness and pressure difference between rooms or offices
- Malfunctioning of the system because of blocked or restricted make-up air louvres
- Temperature and humidity extremes or fluctuations, which are sometimes caused by poor air distribution or faulty thermostats. Barriers to air flow and circulation from divider walls and working station partitions
- Improper or inadequate maintenance with respect to the building ventilation system
- Inappropriate energy conservation measures:
 - Lowering thermostats or economizer cycles in winter
 - Reducing infiltration and exfiltration
 - Eliminating humidification or dehumidification
 - Early afternoon shut-down and delayed morning start-up of the ventilation system

For the occupant, it really doesn't matter how much air is entering the building if it is not reaching them. Testing ventilation rates in a variety of locations where the people are finds the origin of complaints (Burrows and Hansen, 2004, p.92). Therefore, air flow measurements are conducted to verify that the vents are functioning properly and the air flow is suitably directed to the occupant in that area:

1. Use smoke tubes to check the movement of air through vents.

Smoke tubes contain chemicals that produce fumes when air is blown through the tube. To use, break off the tube tips, using an appropriate glass cutter, and then insert a rubber squeeze bulb. The air is blown through the tube by squeezing the bulb. The smoke follows the air current that is flowing into the hood or diffuser, or

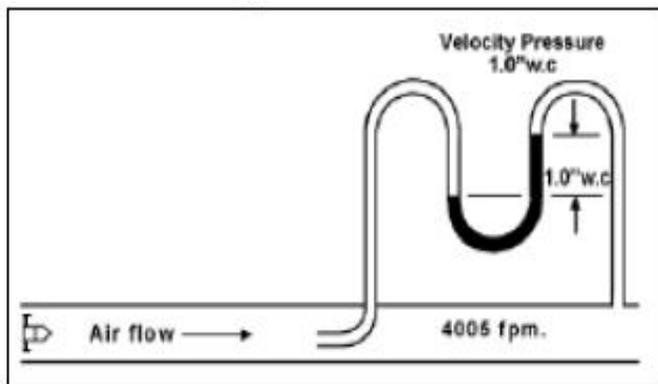
into the room. Caution: care should be taken with smoke tubes, especially in health-care facilities, because the fumes are pungent and irritating if directly inhaled. As an alternative, in this type of facility, it may be preferable to use dry ice. The fumes from dry ice in warm water will provide a benign but visible substitute for the more offensive smoke pencil. But if dry ice is used instead of the smoke test, be aware of the fact that the fumes will affect CO₂ monitoring or readings (Burroughs and Hansen, 2004).

2. Measuring the amount of air movement through a duct is fairly straightforward.

In the following example, a Pitot tube (Figure III.C-1) and manometer are used for the measurement and calculation of air flow in a round duct is illustrated below (NMA, 2008).

- Insert the Pitot tube into a small hole in the side of the duct.
- Make sure that the open of the Pitot tube is facing into air flow. The manometer should be connected to the Pitot tube.
- Record the reading manometer reading.

Figure III.C-1 Using a Pitot tube & manometer to take ventilation measurements



Source: NMA, 2008, p. 60.

The manometer reading represents the difference between the static pressure and total pressure. That difference, called the “velocity pressure” (VP) is the air stream in the duct. The following box shows a sample manometer reading.

Example of a manometer reading

Manometer reading = 1 inch on the water column; thus, vapour pressure (VP) is equal to ‘1’.
 Diameter of the round duct = 12 in. (1 ft.)

Calculate: Air flow Rate (Q) in ‘cfm’ and ‘m/s’

$$V = (4005)(VP)^{0.5} = (4005)(1)^{0.5} = 4005$$

$$\text{Area of duct opening} = \pi r^2 = \pi(0.5)^2 = 0.785 \text{ ft}^2$$

$$Q = AV = (0.785)(4005) = 3145 \text{ cfm} = 5343 \text{ m}^3/\text{s}$$

Note: For air flow unit conversions, go to http://www.comairrotron.com/air_flow_calc.shtml.

The total volume of air being recirculated can be used to determine whether it meets the guidelines⁵(Burroughs and Hansen, 2004):

3. Determine required outdoor air

- ▶ Count the number of occupants in the area and multiply that number by the required cfm/person⁶.
- ▶ Obtain the recorded total volume of recirculated air from the recent balancing report or by measuring with a Pitot tube and manometer.
- ▶ Calculate the percentage of outdoor air required for that area.

$$\% \text{ Outdoor Air} = [(\# \text{ of People})(X \text{ cfm/person})(100) \div [\text{total flow of system}]]$$

4. Determine delivered outdoor air

- ▶ Make sure that the outdoor intake is in minimum position.
- ▶ Measure the temperatures in:
 - ◇ Return temperature (RT) downstream from the return fan
 - ◇ Mixing temperature (MT) at several points upstream from the supply fan (take the average reading)
 - ◇ Outdoor temperature (OT) in the vicinity of the intake

Note: It is best to do this portion of the test when there is a significant temperature difference between OT and RT.

- ▶ Calculate the percentage outdoor door delivered by the system.

$$\% \text{ Outdoor Air} = [(RT - MT) \div (RT - OT)](100)$$

- ▶ Compare the required outdoor air to the delivered amount. If the values differ, adjust. Wait approximately 10 minutes and repeat the steps for deriving the percentage of outdoor air delivered by the air distribution system.

Note: the “carbon dioxide method” may be used to estimate the amount of outdoor air. CO₂ concentrations can be measured using direct reading instruments.

⁵ Refer to section H of this chapter.

⁶ Table 2 from the ANSI/ASHRAE 62.1 (Ventilation for Acceptable Indoor Air Quality) provides the recommended dfm/occupant levels for the various commercial, institutional, and industrial facilities.

Sample velocity measurement calculation

Example: Velocity measurements inside a 16" x 10" rectangular duct supplying one work area show the average velocity to be 820 ft/min. There are 12 people in the work area. CO₂ readings at the three specified locations were (McDermott, 2009):

$$\text{CO}_2 (\text{return}) = 535 \text{ ppm}$$

$$\text{CO}_2 (\text{mixed}) = 425 \text{ ppm}$$

$$\text{CO}_2 (\text{outdoor}) = 300 \text{ ppm}$$

Calculate the amount of outdoor air per person being supplied to the area.

$$\text{Formula: \% Outdoor Air} = (100\%)(\text{CO}_2 (\text{return}) - \text{CO}_2 (\text{mixed})) \div (\text{CO}_2 (\text{return}) - \text{CO}_2 (\text{outdoor}))$$

$$\text{Calculate the } Q_{\text{total}} (\text{total flowrate}) = V \times A$$

$$A = 16 \text{ in} \times 10 \text{ in} = 160 \text{ in}^2 (1 \text{ ft}^2/144\text{in}^2) = 1.11 \text{ ft}^2$$

$$Q_{\text{total}} = (820 \text{ ft/min})(1.11 \text{ ft}^2) = 910 \text{ ft}^3/\text{min}$$

$$\% \text{Outdoor Air} = (100\%)(535-425)/(535-300) = 46.8\%$$

$$Q_{\text{outdoor}} = (Q_{\text{total}})(\% \text{Outdoor Air}) = (910 \text{ ft}^3/\text{min})(0.468) = 426 \text{ ft}^3/\text{min}$$

Amount of Outdoor Air per person = $(Q_{\text{outdoor}})/(\# \text{ people in occupied area}) = (426 \text{ ft}^3/\text{min})/12 = 35.5 \text{ ft}^3/\text{min}$
 per person = $60.3 \text{ m}^3/\text{min}$ per person (note: for air flow unit conversions, go to http://www.comairrotron.com/air_flow_calc.shtml).

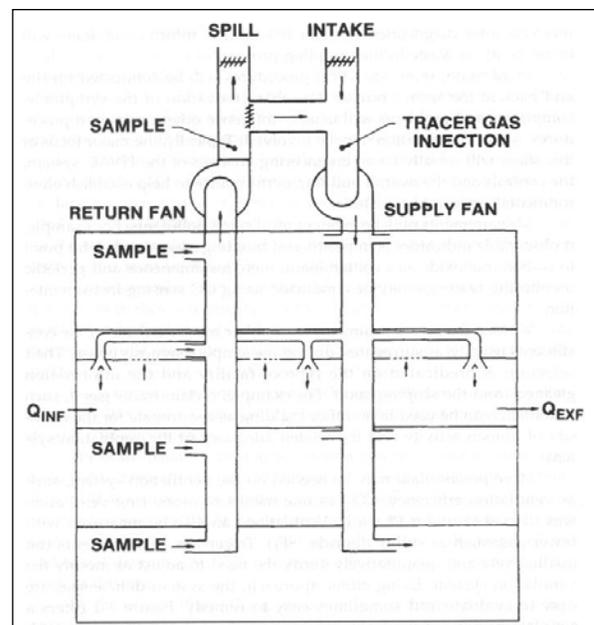
The above 'Q_{outdoor} per person' value is then compared with the latest version of ASHRAE Standard 62 for the type of occupancy (office building, school, etc).

III.C.3.2 Tracer gas study

Ventilation can also be measured with tracer gas, such as sulphur fluoride, SF₆. Tracer gas measurements can qualitatively and quantitatively verify the need to adjust or modify the ventilation system. Figure III.C-2 is a diagrammatic representation of the tracer gas technique for measuring infiltration and ventilation performance in a large building (Burroughs and Hansen, 2004).

With some HVAC systems, it is not feasible to determine the amount of outdoor air using duct or other velocity or air flow measurements in the following situations: (1) Rooms with very high ceilings where duct and outlet measurements are not feasible, (2) Buildings where a significant amount of outdoor air infiltrates through doors, windows, or other openings.

Figure III.C-2 Tracer gas technique

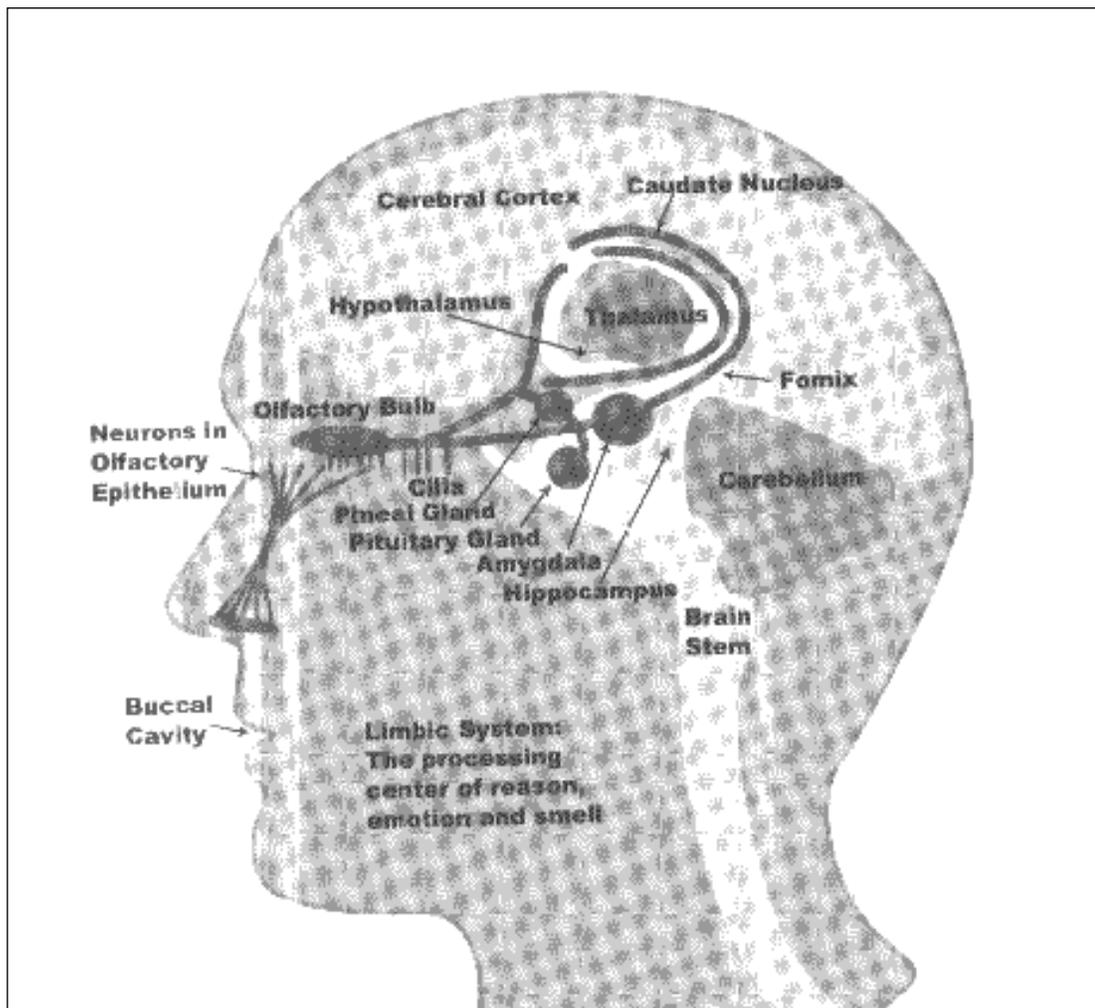


Source: Burroughs and Hansen, 20004, p.96

III.C.4 Odour threshold

Our awareness of the presence of chemical in our surrounding environment comes in part from our sensory systems, such as through olfaction and Chemesthesis). Figure III.C-3 shows the olfactory system surrounding our nasal and buccal cavity.

Figure III.C-3 Human olfactory system



Source: adapted from http://cdn.dsultra.com/images/image_redirect/shopwiki.com.gif, Website accessed: Sept 20, 2002

Our sense of smell is responsible for our capability to differentiate between various odours. Chemesthesis gives rise to the perception of pungent sensations, such as tingling, piquancy, burning, freshness, prickling, irritation and stinging sensation (Cometto-Muniz, 2001, cited in Spengler et al., 2001). Our capability to differentiate between different types of odours is mediated by the olfactory nerve, otherwise known as the cranial nerve I. Olfactory receptor cells and specialized neurons are found in the olfactory epithelium. The olfactory epithelium is a small patch of tissue located in the extreme upper back portion of the nasal cavity.

III.C.4.1 Sources of odours

There are thousands of chemical or biological agents found indoors, originating from household and office products, building materials, furnishings, carpeting, ventilation systems, cooking, cleaning and the human body that can give off odours. Table III.C-6 lists some of the important sources responsible for odours in indoor environments. For more information on indoor sources of chemicals, refer to *Appendix A.1 Chemical factors: gases* and *Appendix A.2 Chemical factors: vapours*.

Table III-C.6 Sources of different odours and their characteristics

Sources	Explanations
Furniture, plywood	Sharp irritating odour from formaldehyde
Curing of phenolic resins, wire enameling, electric motor overhauling, creosote and tar applications, smoke	Phenolic smell from phenols, cresols and xylenes
Sewer gas	Rotten egg and pungent odour from H ₂ S
Electronic devices	Ozone smell
Indoor combustion	Irritating odour from SO ₂
Air cleaning devices (ionizers and purifiers)	Ozone smell
Mould contaminated air conditioning systems	Sweet and musty odours from different vocs (mesityl oxide, benzoquinone, diacetyl alcohol and furfuryl alcohol)
Bathrooms	Faecal and rotten cabbage smell from skatole, indole and methyl mercaptan
Laundry bleach	Bleach smell from sodium hypochlorite
Cleaners	Sweet, nail polish remover smell from acetone; Pungent and irritating smell from ammonia; sweet smell from alcohol.
Carpeting	Plastic, ester, sharp, airplane glue smell from ethyl acrylate, methyl acrylate and other chemicals
Insecticides, pesticides and mothballs	Pungent smell
Paint, lacquers and varnishes	Sweet and sour smell from different paints and other products
Shoe polish, waxes	Almond, shoe polish smell from nitrobenzene

Source: Duffee and O'Brien (2001), cited in Spengler et al. (2001), *In Indoor Air Quality Handbook, Chapter 21*

III.C.4.2 Odour threshold

Odours are very subjective in nature. For example, personal care products such as scents, perfumes and cologne and room fresheners may be pleasant to some individuals yet offensive to other individuals. Measurement of odourous chemicals can be helpful in certain situations. An odour threshold parameter can give some idea about how much of a particular chemical might be present indoors.

However, the presence of an odour is not always a good indicator in determining if something is hazardous. Some of the hazardous gases (CO) are odourless (Aerias, 2001). Some carcinogenic chemicals have high odour threshold values. Some chemicals, such as hydrogen sulphide, have very low odour thresholds below which has no diverse physiological effect is not anticipated. Other chemicals, such as tetrachloroethylene or perchloroethylene (PERC) provide an interesting diagnostic tool during IAQ measurement in dry cleaning facilities. PERC has an odour threshold of 1 ppm (ATSDR, 1997) in the air and Health Canada recommends 0.05 ppm as tolerable inhalation concentration. Toluene has an odour threshold of 8 ppm in the air (ATSDR, 2000) and Health Canada recommends 1 ppm as tolerable inhalation concentration. Similarly,

ozone has an odour threshold of approximately 0.02 ppm and WHO recommends exposures below 0.05 ppm. For these chemicals, the ability to smell the chemical suggests that unacceptable exposures are occurring.

For a detailed list of chemicals and their odour threshold, refer to ATSDR's toxicological profile for chemicals at <http://www.atsdr.cdc.gov/>.

The PHI or EHO should consider the following principles when dealing with nuisance odour complaints (Duffee and O'Brien, 2001).

- Odour sensation depends on the concentration of the particular chemical or chemicals that are available to olfactory receptor of individuals. Therefore, odour perceptions vary among individuals.
- Air temperature and humidity change odour perception.
- Odour perception is a complex physiological reaction that involves the central nervous system (CNS). Odour perception can invoke various psychological and physiological responses.
- In the presence of a mixture of chemicals, identification of odours becomes difficult and complex.

III.D Specific building-related concerns and investigation specifics

This section will provide information on the following:

- Common ventilation systems found in the various types of buildings
- Common concerns associated with each building type
- Investigation specifics helpful in identifying potential causes of an IAQ concern

Building types discussed in this section include:

- Residential
- Commercial
- Specialized facilities
- Recreation facilities
- Personal and social-care facilities and institutions
- Industrial workplaces

Note that the Alberta Building Code defaults to the ASHRAE Standard 62.1, “Ventilation for Acceptable Indoor Air Quality,” as the basis for specific ventilation information.

III.D.1 Residential

The primary purpose of a residential premise is to provide shelter and lodging for people. However, there are many activities that take place in the residential building that may have an effect on indoor air quality – cooking, home office and cleaning

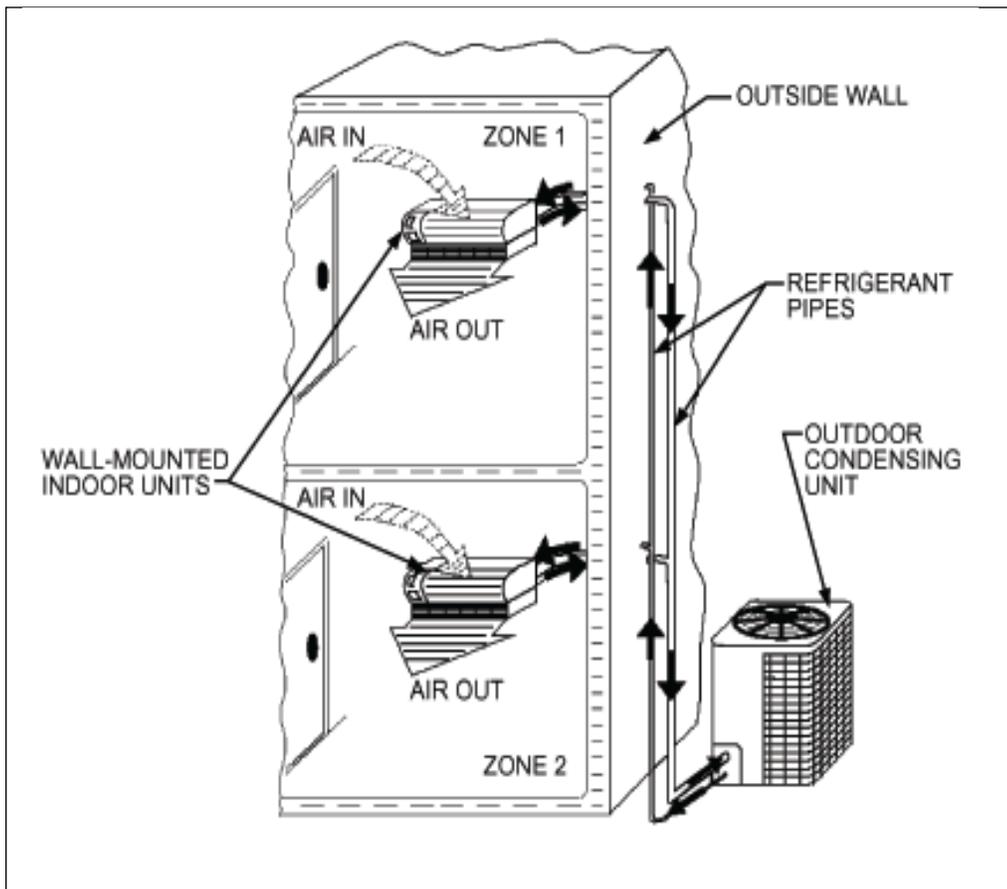
In residential premises, the most common indoor air quality problems are associated with presence of combustion products, such as CO, Nox; biological agents, such as mould, dust mites and animal dander; and consumer products (Park, 1987, cited in Calgary Health Region, 1993). IAQ complaints have become more common because of tighter building construction and the increased use of synthetic construction materials, furnishings and finishes. Other influencing factors may include the infiltration and mechanical intake of outdoor air contaminants (Health Canada, 1995).

At first glance, IAQ investigation of residences appears to be a simple undertaking because of the small size of residential structures and their simple ventilation systems, compared to large public buildings and other facilities. It is generally assumed that residential IAQ problems can be more easily defined, identified and resolved in comparison to IAQ problems in larger buildings. However, IAQ professionals and health officials in Alberta have found that even though residential premises are generally more amenable to the resolution of IAQ problems, approximately 50 per cent of residential IAQ investigations do not lead to identification of the source or contaminant and subsequent complaint resolution.

The most common systems used in residential buildings are central forced air, central hydronic and zoned systems (Figure III.D-1). The geographic climate determines the services that will be included with the system. Such services are heating, cooling, air cleaning including filtration or electrostatic systems, and humidification (see Figure III.D-2) (ASHRAE, 2011).

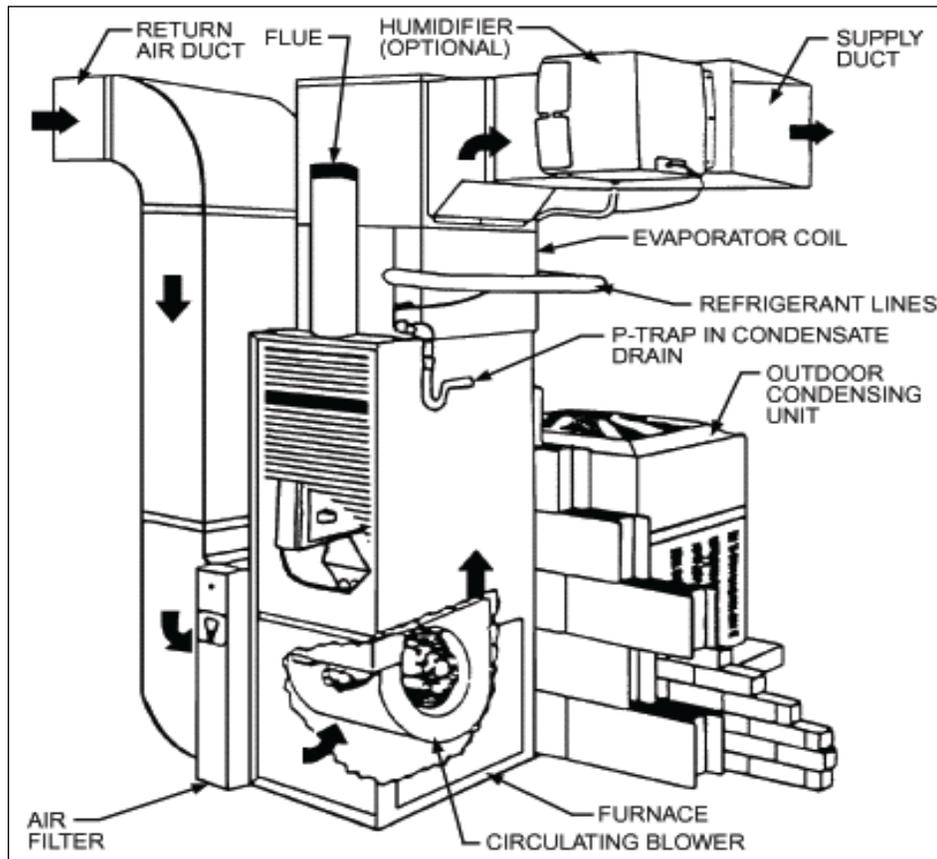
There are many variations of residential premises, including single-family, multifamily, and mobile or manufactured homes. Each of these types of residential premises will be discussed in this section in the context of their ventilation systems and configurations, common IAQ concerns, and some investigation specifics.

Figure III.D-1 Example of two-zone system in a residential installation



Source: ©ASHRAE (2011 ASHRAE HANDBOOK – HVAC Application (SI Edition)), (Chapter 1- Residences), (2011).

Figure III.D-2 Typical residential installation of heating, cooling, humidifying and air filtering system (HVAC)



Source: ©ASHRAE (2011 *ASHRAE HANDBOOK – HVAC Application (SI Edition)*), (Chapter 1- Residences), (2011).

III.D.1.1 Single-family

A single-family home is a single dwelling unit occupied by just one household or family. This type of home is easily identifiable as a free-standing residential building. They are usually constructed on a lot of land that will surround the complete structure and constitute the yard.

- **Concerns**

Here is a list of common concerns associated with single-family residences:

- Outdoor sources of poor air quality brought into the home by the ventilation system, open windows or air leaks in the building. Examples of common outdoor sources that impact indoor air quality include:
 - ▶ Vehicle emissions from traffic and of parked idling vehicles
 - ▶ Neighbouring industrial or commercial activities
 - ▶ Odours from diesel trucks entering through windows, vents or air intakes
 - ▶ Combustion byproduct intake from vehicle emissions or fires or wood burning (soot) or yard waste burning

- ▶ Civic improvements, such as road paving
- Soil emissions including radon and other soil gases
- Indoor sources of pollutants
- Occupant activities including but not limited to:
 - ▶ Smoking indoors
 - ▶ Hobbies, such as painting and model construction
 - ▶ Cooking
 - ▶ Use of wood burning or gas fireplaces
- Presence of pets
- Cleaning products
- Improper storage of chemicals, such as paints and paint thinners, WD40
- Furnishings
- Finishes
- Building materials, such as asbestos
- Ventilation system components including:
 - Humidification systems and condensation pans may provide an environment for growth of biological agents
 - Combustion air which is back-drafting into the living space or being circulated in the distribution system
- Moisture intrusion, unwanted condensation, sweaty and leaking pipes, valves, joints, gaskets or the use of humidifiers added to ventilation system or as personal units causing material damage and biological contamination
- Sewer gas infiltration because of lack of water in traps of drains for sinks and tubs, and floor drains
- Lower air exchanges in dwelling units with radiant heating either electrical or hydronic as the primary or only heating source can result in a build-up of moist air and odours from occupant respiration and activities, such as cooking, cleaning and smoking.
- Buildings employing radiant heating and having lower air exchanges rates than acceptable may be more likely to exhibit poor air quality, as shown by CO₂ monitoring and mould growth because of moisture build-up and poor air circulation (CMHC, 2008).

More information is available in the appendices on sources of poor indoor air quality.

III.D.1.2 Multifamily

Multifamily housing is a classification of housing where multiple separate housing units for residential uses are contained within one building or several buildings within one complex. Common forms include apartment buildings, condominiums, duplexes, semi-detached homes, row or townhouses.

Mixed-use buildings—buildings with space for commercial, business, office and residential uses—are also common when considering multifamily housing types. Possible arrangements include commercial or business use on the first couple floors with one or more apartments or condominiums on the upper floors. Another possibility is to have the commercial or business area in the front of the building and the residential area in the back of the building.

- **Concerns**

Multifamily housing will have many of the same IAQ concerns experienced in single-family residences (see Section A.4.1.1.1 above). Some of the specific concerns associated with multifamily housing include:

- Unconditioned or contaminated air from common areas, such as hallways, infiltrating into private living areas under doors or through improper seals.
- Lower air exchanges in dwelling units with radiant heating (electrical or hydronic). As the primary or only heating source, radiant heat can result in a build-up of moist air and odours from occupant respiration and activities, such as cooking, cleaning and smoking.

The minimum acceptable air exchange rate should not be less than 5 L/sec as per Part 9 of the 2006 Alberta Building Code (and ASHRAE 62.1). All current and recent residential construction, even those with radiant heating, must satisfy this requirement. Multi-story residential units with radiant heating as the primary heating source are designed and approved to meet the above criterion by pushing hallway air into occupied units. Hallway ventilation consists of conditioned outdoor air distributed to all the common hallways of all floors in a building through a central fan unit. These hallway ventilation systems must operate continuously. However, older residential construction may not have been designed or built to achieve the minimum. The date for this transition is unclear.

- Buildings employing radiant heating and having lower air exchanges rates than acceptable may be more likely to exhibit poor air quality, as shown by CO₂ monitoring and mould growth, resulting from moisture build-up and poor air circulation (CMHC, 2008).
- Poor air quality or air contamination from another dwelling unit being transported through common ductwork.

III.D.1.3 Mobile and manufactured homes

The homes that fall into this category are all constructed in a factory away from the location where the home will eventually be located. These types of homes are constructed on a transport frame or in the case of a mobile home on a chassis with axles and wheels. In 2001, manufactured homes accounted for 6.4 per cent all housing units and 11 per cent of all new single-family dwellings in the United States (ASHRAE, 2011).

- **Concerns**

Mobile and manufactured homes will have many of the same issues as experienced in a single-family residence (see Section A.4.1.1.1 above). Some of the specific concerns associated with mobile or manufactured homes include:

- Increased IAQ problems associated with poorly ventilated areas or stale air.

Because most mobile and manufactured homes are equipped with forced-air down flow units that do not have designated return air ducting, they are more likely to experience IAQ problems associated with poorly ventilated areas or stale air.

- Increased concentration of formaldehyde.

Because mobile homes have a high loading of pressed wood products relative to their size and air change rate, the concentrations of formaldehyde are significantly higher than in other housing.

More information on sources of poor indoor air quality is available in the Appendices Commercial

III.D.2 Commercial

A commercial building is a building that is used for commercial use. Types of commercial buildings include office buildings, warehouses, convenience stores, big-box stores, shopping malls and strip malls. In urban locations, a commercial building or complex often combines functions, such as offices on higher floors above a retail area on the first floor. These buildings have different indoor air quality system components than residential buildings. The reader should understand that ventilation systems in commercial buildings can vary based on their unique requirements, era of construction and design parameters.

There are many sources of and activities that cause IAQ problems in the various types of commercial buildings: environmental tobacco smoke; asbestos from insulating and fire-retardant building supplies; formaldehyde from pressed-wood products; other organics from building materials, carpets, and other office furnishings; cleaning materials and activities; restroom air fresheners; paints; adhesives; copying machines and photography and print shops; biological contaminants from dirty ventilation systems or water-damaged walls, ceilings and carpets; and pesticides from pest management practices (USEPA, 2010).

The ventilation system design, operation and maintenance greatly influence the effect of these sources and the overall quality of indoor air in commercial buildings (USEPA, 2010). Mechanical ventilation systems in large buildings are designed and operated to heat and cool the air, and also to draw in and circulate fresh outdoor air. However, if

they are poorly designed, operated, or maintained, the ventilation systems can contribute to indoor air problems in various ways.

In addition, buildings originally designed for one purpose may end up being converted to serve another purpose. If the building renovations, to room partitions, and the ventilation system, were not properly carried out, the reconfiguration can contribute to indoor air quality problems by restricting air re-circulation or the supply of outdoor air.

The two most common HVAC designs used in modern commercial buildings are constant volume and variable air volume systems.

- **Constant volume systems (CVS)**

These systems are designed to provide a constant air flow and to vary the air temperature to meet heating and cooling needs. The percentage of outdoor air may be held constant, but is often controlled either manually or automatically to vary with outdoor temperature and humidity. Controls may include a minimum setting that should allow the system to meet ventilation guidelines for outdoor air quantities under design conditions.

- **Variable air volume (VAV)**

(VAV) systems condition supply air to a constant temperature and ensure thermal comfort by varying the air flow to occupied spaces. Most early VAV systems did not allow control of the outdoor air quantity, so that a decreasing amount of outdoor air was provided as the flow of supply air was reduced. Some more recent designs ensure a minimum supply of outdoor air with static pressure devices in the outdoor air stream. Additional energy-conserving features such as economizer control or heat recovery are also found in some buildings.

Good quality design, installation, testing and balancing, regular inspections and maintenance are critically important to the proper operation of all types of HVAC systems and are important factors contributing to air quality.

There are many configurations for commercial premises, including multi-unit and multi-storey. Each of these types of premises configurations will be discussed in this section in the context of their ventilation systems, common IAQ concerns and some investigation specifics.

III.D.2.1 Multi-unit buildings

Regional shopping centers are considered to be a multi-unit building. The typical shopping mall incorporates enclosed, heated and air-conditioned common spaces connecting individual units and providing areas for users to come together and to travel between destination units while protected from the elements. Major department stores in shopping centers are typically considered separate buildings. Some regional shopping centers and strip malls are designed with an open pedestrian mall between rows of stores.

- **Concerns**

- Indoor air pollutants can be circulated from portions of the building used for specialized purposes, such as restaurants, print shops and dry-cleaning stores, into offices in the same building.

- Carbon monoxide and other components of automobile exhaust can be drawn from underground parking garages through stairwells and elevator shafts into office spaces.
- Older commercial construction may not have both a fresh air intake and a combustion air intake. Because of the lack of a dedicated fresh air intake and combustion air intake, they are more likely to experience IAQ problems associated combustion byproducts and poor air exchange.
- In strip malls with adjoining bays, pressure differentials caused through the use or non-use of the specific bays air handling units, may:
 - ▶ Drive contamination from the offending bay into adjoining units

-or-

- ▶ Draw air from the offending bay into the adjoining bay

The flow of air and any contamination the air carriers will move from areas of high pressure to low pressure. Adjoining bays with the HVAC systems operating in the intermittent demand heat or cooling modes will temporarily pressurize a bay when HVAC fans turn on. This pressurization will push any air contaminants into the adjoining bays where ventilation fans are not operating because HVAC systems are also operating in intermittent demand modes. Intermittent fan operation in the adjoining bays will generate low pressures, when the fans are off, that will pull contamination in from neighbouring bays whose HVAC systems are operating. That is, a bay is pressurized when fans intermittently turn on in the demand mode creating pressure-driven flow into adjoining bays of low pressure where fans in the intermittent demand mode are off. Under these situations the air will move between adjoining bays through penetrations and cracks in the adjoining walls.

Note: By ensuring all-air handling unit fans are in the continuous operation mode during business hours, according to building code requirements, pressure differentials will be reduced (and so will migration of air between bay). After hours, the HVAC systems can be switched to the demand mode to conserve energy.

When inspecting strip mall bays, the PHI or EHO should lift ceiling tiles to inspect the ceiling cavity and the demising wall between the adjoining bays for penetrations that accommodate plumbing pipes, electrical cable and conduits, and duct penetrations. As well, the PHI or EHO will need to consider activities that are conducted in adjoining bays for potential sources of contamination, such as a dry cleaner business. In two-storey strip malls, air movement and contaminant migration can also occur vertically.

The observation in the ceiling space by the inspector of a common or shared return air system between bays will negate all of the above. In the case of a common or shared return air system, the situation should be referred to the Building Code and Fire Code Inspectors for follow-up for possible code violations.

In addition, any activities in a bay that suggest a requirement for local exhaust ventilation, on examination of MSDSs, chemical or manufacturing processes, and

process equipment, should be referred to Alberta Occupational Health and Safety regarding worker exposure concerns and to a building code Inspector. The requirement to install local-exhaust ventilation by another authority will also likely address any nuisance concerns of occupants in adjoining bays.

III.D.2.2 Tall and multi-storey buildings

There is no absolute definition of what constitutes a tall building (CTBUH, 2011), but for this manual a tall building is a multi-storey building with three or more storeys. Tall buildings may have combined uses, such retail space, food services, restaurants and office space. Typically, tall and multi-storey buildings include some or all of the following areas:

- Interior or surface parking areas
- Security
- Retail outlets
- Health club or physical fitness area
- Offices
- Conference rooms
- Convenience store or vending machines
- Lobbies
- Atria or common spaces such as cafeterias, dining rooms or restaurants
- Private toilets or restrooms
- Child care centers
- Administrative support spaces
- Operation and maintenance spaces:
 - General storage
 - Food preparation area or kitchens
 - Telecommunications closets
 - Computer/information technology closets
 - Maintenance closets
 - Mechanical and electrical rooms

- **Concerns**

Here is a list of common concerns associated with tall or multi-storey buildings:

- Indoor air pollutants can be circulated from areas of the building used for specialized purposes, such as restaurants, print shops and dry-cleaning stores, into offices in the same building.
- Carbon monoxide and other components of automobile exhaust can be drawn from underground parking garages through stairwells and elevator shafts into office spaces.
- Since the surfaces of the air-distribution components in a low-temperature system are colder than in a conventional system, there is often concern about condensation.

- **Large spaces and units**

Warehouses, big-box stores and grocery stores all fall under the category of large spaces and units. These facilities are meant to provide the proper environment for the purpose of storing and displaying goods and materials, and some of the big-box stores or superstores may include a food service area, auto service area, supermarket, pharmacy, bank, garden shop and beauty parlours. Most large stores also have areas for storing equipment and material inventory. Warehouses are generally not

accessible to the public; however, some may be open to the public. Large or big box stores must be air conditioned and ventilated to provide a comfortable shopping experience as well as a tolerable working environment. The large stores also must provide acceptable storage and warehousing, (ASHRAE, 2011), associated handling equipment (forklifts), and shipping and receiving space, complete with bay areas to accommodate large trucks.

◦ **Concerns**

- ▶ Hardware, lumber and furniture are also sold in big-box facilities. A particular concern in this type of facility is ventilation for merchandise and material-handling equipment, such as forklift trucks.
- ▶ Lower air exchanges in areas with radiant heating, whether electrical or hydronic, as the primary or only heating source can result in a build-up of moist air and odours resulting from occupant respiration and activities.
- ▶ Buildings employing radiant heating and having lower air-exchanges rates than acceptable may be more likely to exhibit poor air quality as shown by CO₂ monitoring and mould-growth, resulting moisture build-up and poor air circulation (CMHC, 2008).

III.D.2.3 Specialized facilities

Specialized indoor facilities, such as swimming pools, ice arenas, schools and care facilities, have different IAQ system components because of their specific functions. Each of the categories of the specialized facilities will be discussed in this section.

• **Schools**

Kindergarten (K) to Grade 12 schools typically one- to three-story buildings that serve as elementary, middle (junior high) or high schools. Schools include classrooms, plus accessory use areas, such administration offices, a gymnasium and a library. Some also have a cafeteria. Typical areas found in K-12 schools are shown in Table III-D.1.

Table III-D.1 Typical spaces in K-12 schools

Typical area	School		
	Elementary (K-5) ^a	Middle (6-8) ^a	High (9-12) ^a
Classrooms	☒	☒	☒
• Science	☒	☒	☒
• Computer		☒	☒
Laboratories & science		☒	☒
Administrative areas	☒	☒	☒
Gymnasium	☒	☒	☒
Libraries	☒	☒	☒
Auditorium			☒
Home economics room			☒
Cafeteria	☒	☒	☒
Kitchen	☒	☒	☒
Auto repair shop ^b			☒
Industrial shop			☒
Locker rooms		☒	☒
Ice rink			☒
Natorium ^b			☒
School store ^b			☒

Notes: ^aSchool grades can vary. ^bThese zones are not typical

Source: 2011 ASHRAE HANDBOOK-HVAC Applications S addition

Elementary schools are the smallest of the school buildings, generally comprised of 10 to 15 classrooms plus accessory-use areas. Middle schools are larger than elementary schools and include computer classrooms and locker rooms. High schools, the largest type of the school, includes a cafeteria and auditorium, and may include additional spaces such as a natatorium or ice-skating rink.

IAQ concerns are important in schools because the occupants, such as children and young adults, are particularly sensitive.

◦ **Concerns**

In older school buildings constructed during 1960s and 1970s, exterior classrooms were heated and ventilated using unit ventilators, which have a significant ability to negatively affect IAQ if they are poorly maintained and operated.

Older school construction and portable school structures may not have both a fresh air intake and a combustion air intake. Because of the lack of a dedicated

fresh air intake and combustion air intake they are more likely to experience IAQ problems associated with combustion byproducts and poor ventilation.

The following publications are available for additional information on school indoor air quality concerns and investigation protocols.

1. *Indoor Air Quality - Tools for Schools Action Kit for Canadian Schools* –. Is available on the Health Canada website: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/tools_school-outils_ecoles/index-eng.php.
2. *IAQ Tools for School Kit* – This United States Environmental Protection Agency (USEPA) publication offers schools a practical plan of action to improve indoor air quality. See the USEPA website: <http://www.epa.gov/iaq/schools/actionkit.html>.

III.D.2.4 Recreation facilities

- **Ice arenas**

An ice arena is a building with a floor surface covered with a frozen body of water or hardened chemicals where people can ice skate or play winter sports, such as ice hockey. Besides skating, ice arenas may also be used, curling, basketball, boxing, track meets; exhibitions, circuses; rodeos; convocations; meetings; rock concerts; and car, cycle and truck shows when the ice is not in use.

There are two types of rinks in prevalent use today:

- Natural – freezing occurs from cold outside temperatures
- Artificial or mechanically-frozen – a coolant produces cold temperatures in the rink surface, causing the water on the rink to freeze
- **Concerns**
 - ▶ In enclosed ice arenas, a primary source of indoor air concerns is the release of combustion pollutants such as carbon monoxide (CO), nitrogen dioxide (NO₂) and particulate matter (PM), into the indoor air from the exhaust of fuel-fired ice resurfacing equipment.
 - ▶ Combustion pollutants are produced whenever any fuel, such as gasoline, propane, or diesel, is burned.
 - ▶ Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems.
 - ▶ Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the building.
 - ▶ High temperature and humidity levels can also increase concentrations of some pollutants.
 - ▶ Excess moisture in indoor air will cause corrosion of metal structures, rotting of wooden structures, fungi and mould growth, increased energy consumption and ice quality problems (USEPA, 2012).

- **Swimming pool facilities and natatoriums**

A swimming pool facility, sometimes called a natatorium, houses a pool of water intended for swimming or water-based recreation. Many other buildings, such as health clubs, fitness centers, private clubs, hotels and condominiums, also have swimming pools and hot tubs.

Natatorium requires year-round humidity control and ventilation to provide adequate indoor air quality in response to pool-water chemistry and pool-water evaporation (ASHRAE, 2011).

- **Concerns**

- ▶ Air quality problems in pools and spas are often caused by water quality problems so simply increasing ventilation rates may prove both expensive and ineffective (ASHRAE, 2011).
- ▶ Water treatment equipment, chemical storage and chemical use can affect IAQ. Equipment and chemicals should be located in a separate, dedicated, well ventilated space that is under negative pressure (ASHRAE, 2011).
- ▶ Because indoor pools usually have high ceilings, temperature stratification and stack effect can have a detrimental effect on indoor air quality (ASHRAE, 2011).
- ▶ Pool air is sometimes supplies air to showers, toilets and locker rooms. These spaces should be provided with separate ventilation and maintained at a positive pressure to prevent influence from pool water chemistry and chloramine odour migration) (ASHRAE, 2011).
- ▶ Warmer water and water with high agitation levels off gas chemicals at higher and allows body oils to become airborne; therefore, exhaust air intake should be located as close as possible to these areas). NOTE: Exhaust air intakes located directly above whirlpools produce the best air quality (ASHRAE, 2011).

III.D.2.5 Personal and social-care facilities and institutions

A personal and social-care facilities and institutions are defined as “an institutional facility: a building or part thereof used by persons who require supervisory care, medical care or medical treatment (Ontario, 1999).”

These facilities may be similar to a normal residential building or have complex designs similar to the varied types of commercial structures. In general, the buildings can be divided into many spaces for specific activities, such as critical-care spaces, operating rooms, emergency rooms, delivery rooms and a nursery, laboratories, intensive-care nursing, a kitchen, dining and food service, morgue and central housekeeping support (ASHRAE, 2011).

Personal and social-care facilities and institutions include the following (Government of Alberta, 2011; Ontario, 1999):

- Crisis nurseries
- Day care centres
- Foster homes
- Group homes for children in crisis
- Long-term institutions for children with disabilities
- Out-of-school care centres

- Homes for the aged
- Hospitals
- Nursery schools
- Nursing homes
- Youth shelters
- Women's shelters
- Safe houses for children involved in prostitution
- Secure treatment facilities for children and youth
- Treatment facilities for children involved in prostitution
- Treatment facilities for children with disabilities
- Child and youth residential treatment centres⁷

- **Concerns**

- Highly infectious agents transported within air or air-and-water mixtures, and droplets or infectious agents of 5 µm or smaller can remain airborne indefinitely. NOTE: 99.9% all bacteria present in a hospital are removed by filters with a Minimum Efficiency Reporting Value (MERV) of 14 filters. A high efficiency p99.9% of all bacteria present in a hospital are removed by high-efficiency particulate air (HEPA) filter that has been dioctyl phthalate (DOP)-tested for quality assurance will remove 99.99% of all bacteria. Because bacteria are typically larger than 1µm, HEPA and ultra low-penetration (ULPA) filters provide the greatest efficiency for both bacteria and also viruses (ASHRAE, 2011). HEPA and ULPA filter specifications require capture efficiencies of 99.97% and 99.999%, respectively for 0.3 um particles.
- Research knowledge to deactivate viruses with ultraviolet light and chemical sprays has advanced, but design guidance and operational requirements are still not fully developed, so these methods are not recommended by most codes as a primary infection control measure.
- Temperature and humidity conditions can inhibit or promote the growth of bacteria and activate or deactivate viruses.
- Lower air exchanges in dwelling units where radiant heating (electrical or hydronic) leads to a build-up of moist air and odours resulting from occupant respiration and activities, such as cooking and smoking.
- Activities common to hospitals, such as opening doors, moving staff and patients, temperature differentials and the stack effect, are all accentuated by vertical openings such as chutes, elevator shafts, stairwells and mechanical shafts. This mix of activities and diverse building features made it difficult to undesirable air flow between rooms and floors.
- Group homes are commonly found in altered use single-family homes; As such they can experience any and all of the same problems and concerns.

⁷ Includes contracted and government treatment centres

III.D.2.6 Specialized medical facilities

Specialized medical facilities include dental care facilities and outpatient services, such as day-surgery facilities. They may be a free-standing unit, part of an acute-care facility, or part of a medical facility, such as a medical office or clinic. These facilities are likely to include reception and waiting areas, treatment and operating room, denture laboratories, and workrooms where supplies are stored and instruments are cleaned and sterilized (ASHRAE, 2011).

- **Concerns**

- Many common dental procedures generate aerosols, dusts and particulates and may contain microorganisms (both pathogenic and benign), metals, such as mercury fumes, and other substances including silicone dusts and latex allergens
- Lab procedures have been shown to generate dusts and aerosols containing metals
- Nitrous oxide is used as an analgesic or anesthetic gas in many facilities

III.D.2.7 Industrial workplaces

A detailed discussion of industrial settings is outside the jurisdiction of environmental public health, except in circumstances where contaminants are emitted or carried off site and create a public health nuisance. Industrial workplaces where there is manufacturing or chemical processing are regulated by Alberta Workplace Health and Safety. However, IAQ in administrative offices or workspaces and public spaces in buildings where there are industrial activities are within EPH jurisdiction. The reader should refer to *Chapter I Introduction to indoor air quality* of the manual for clarification of EPH jurisdiction and authority.

III.E Investigation specifics for ventilation systems

The general ventilation system can be thought of as the lungs of a building or facility. The occupants rely on the system for comfort, ventilation, temperature, odour and humidity control. If the system is properly designed and maintained⁸, it can be capable of resolving 80 per cent of the indoor air problems in facility. However, if that system is poorly designed or maintained, it can be responsible for 50 % to 60% of building generated IAQ problems (Burroughs and Hansen, 2004).

It should be noted that a dilution ventilation control strategy actually allows contaminants to be released into the general air of the building; whereas, local exhaust ventilation (LEV) does not (George, DiNardi and Handy, 1997, p.848).

Mechanical ventilation systems are not the only strategy for contaminant control. Ventilation is only one element of an effective IAQ program. The other elements that should also be considered are as follows (CHMC, 1996, p.B2):

- Source removal (store chemicals outside the living areas)
- Substitution (select natural fabrics and low emitting construction materials)
- Source containment (store chemicals in an airtight cabinet connected to an exhaust system)
- Local exhaust system (use of local ventilation exhaust systems to capture gas or vapour emissions directly from the source)
- Source control (sub-slab depressurization to control methane gas or radon entry)

While general or dilution ventilation may be an appropriate solution for some IAQ problems, the following conditions would make general ventilation less effective and more expensive (Burton, 1995, p.199):

- Toxic contaminants, such as formaldehyde (HCHO) and tobacco smoke
- Hazardous contaminant concentrations as in the case of HCHO, CH₄
- Emissions that vary with time, such as smoking outdoors instead of indoors
- Buildings located in severe climates or environmental conditions
- Outdoor air is more contaminated than indoor air
- Existing HVAC system is not capable of treating the air

⁸ Although it is beyond the scope of this manual to go into the design of HVAC systems, system-related problems are second only to operations and maintenance concerns.

III.E.1 Local exhaust ventilation (LEV) system

In terms of controlling exposure to gasses, vapours and particles in typical commercial, institutional or industrial settings, a LEV system is a primary and more effective means of capturing and removing airborne contaminants at their source in the building.

The LEV system is primarily designed to capture or contain contaminants at their source before they escape into the room environment. A typical system is made up of the following components (see Figure III.E-1):

- **Process hood**

The “process hood” is the point where airborne contaminants are captured at the source in a process. In essence, the hood is the device that is designed to capture, enclose or receive the contaminants.

- **Duct**

A duct is the formed pathway for conveying airborne contaminants from the hood through the ventilation system that includes an air-cleaning device and into the outdoors. The air velocity through the ductwork must be sufficient not only to carry the airborne contaminants but also to prevent the contaminant particles settling.

- **Cleaner**

An air cleaner is a device that is used to remove the contaminant from the airstream before being discharged into the outdoor environment.

- **Fan**

The fan is the unit that moves air through the LEV system. Exhaust fan selection is based on a number of factors including:

- Type of fan

Typically, a centrifugal fan is used in LEV applications. However, a backward-curved blade centrifugal fan will most likely be used for LEV systems that move gas streams without heavy particle concentrations.

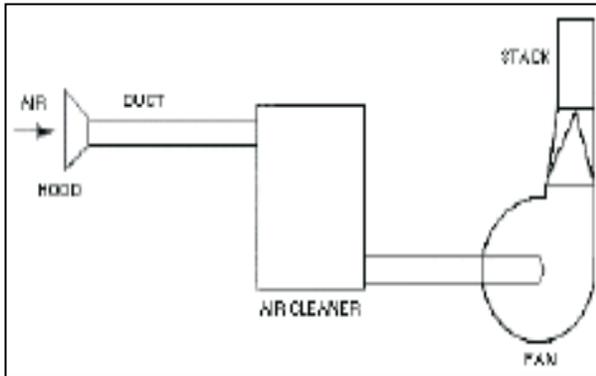
- Fan selection

Other factors including the LEV system design flow rates and pressures and fan inlet diameters will determine fan selection.

- **Stack**

A stack is the formed pathway that is used to discharge the airstream into outside and away from the building wake. The location of the exhaust stacks relative to fresh air intake is of critical.

Figure III-E.1 LEV components



Source: OSHA, 1999

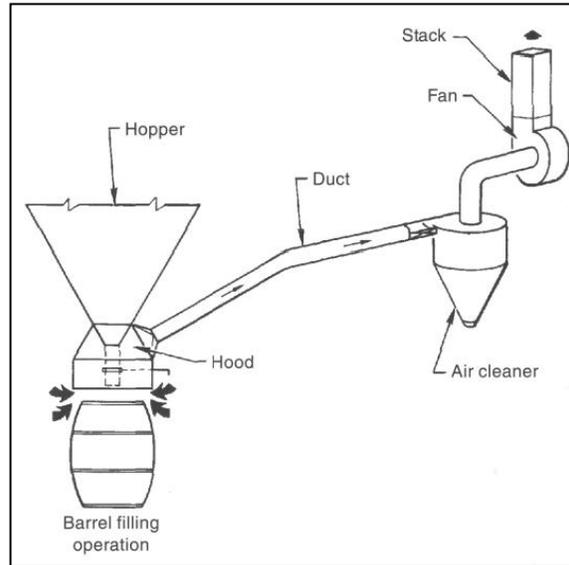
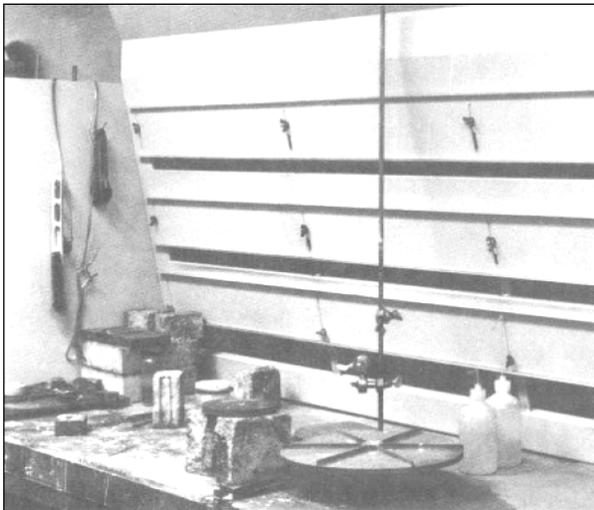
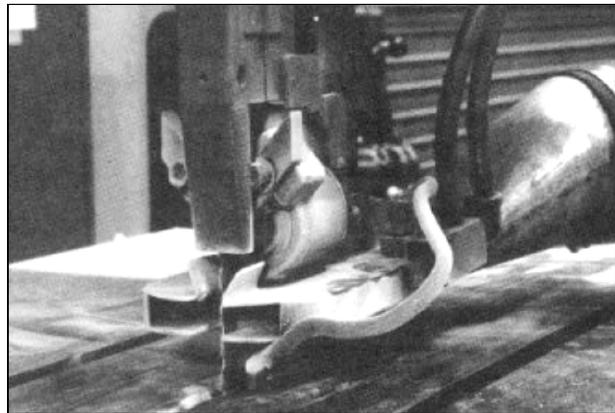


Figure III-E.2 Slot hoods across a soldering bench



Source: McDermott, 2001, p.70

Figure III-E.3 Capturing hood on a bandsaw



Source: McDermott, 2001, p.70

The primary advantage of LEV systems is that they remove contaminants rather than just dilute them. It should be noted that even with local exhaust system installation, some of the airborne contaminants may still be in the air. These residue contaminants are because of uncontrolled sources or less than 100 per cent hood collection efficiency.

In large commercial kitchens and in some commercial activities, such as light manufacturing, LEVs are interlocked with make-up air units. Large commercial LEVs potentially can generate significant negative pressure and air flow in rooms and also affect air flow in adjoining areas. To mitigate this, LEVs are interlocked with engineered make-up air units that mitigate the generation of negative pressure and air flow by supplying conditioned outdoor air into the room to replace the air being exhausted.

Local exhaust systems may be more difficult to design than dilution systems. The hoods (contaminant pickup points) must be properly shaped and positioned to control the contaminants, and the fans and ducts must be designed to draw the correct amount of air through the hoods (McDermott, 2001).

Before LEVs are recommended as a mitigation strategy, other source control considerations should be examined (McDermott, 2001):

- **Source control**

This involves looking at ways to reduce the amount of contaminant released into the air.

- ▶ Practice preventive maintenance by repairing leaks or controlling other factors that may increase contaminant emission. For instance, ensure that fuel storage containers are capped, sealed and stored in a cool area away from other combustible materials.
- ▶ Substitute less toxic materials for those that are currently in use:
 - ◇ Replace carbon tetrachloride solvent with less toxic solvents.
 - ◇ Substitute artificial abrasives in abrasive blasting or cleaning operations to reduce exposures to free silica.
- ▶ Change the process to reduce the release of the contaminant emission. For example, use water spray when cutting concrete pipe to prevent dispersion of dust without ventilation.

- **Exposure pathway modifications**

This method looks at modifying the route by which a contaminant travels from a source to the breathing zone (exposure pathway). Modifications include:

- ▶ Lengthening the exposure pathway by increasing the distance between the source and the person or occupant. The dilution rate is influenced by drafts and other air motion, and the contaminant concentration decreases with increased distance from the source.
- ▶ Interrupting the exposure pathway with physical barriers to impede the movement of contaminated air toward people or occupants.
- ▶ Isolating the process or occupant by moving one or the other to a different room.

- **Other controls**

- ▶ Adapt procedures that would minimize exposure.
- ▶ Use personal protective equipment, such as respiratory protection devices, such as air-purifying or atmosphere-supplying respirators. Generally, respirators are used for routine tasks only when engineering controls or work procedures do not reduce exposures to acceptable levels.

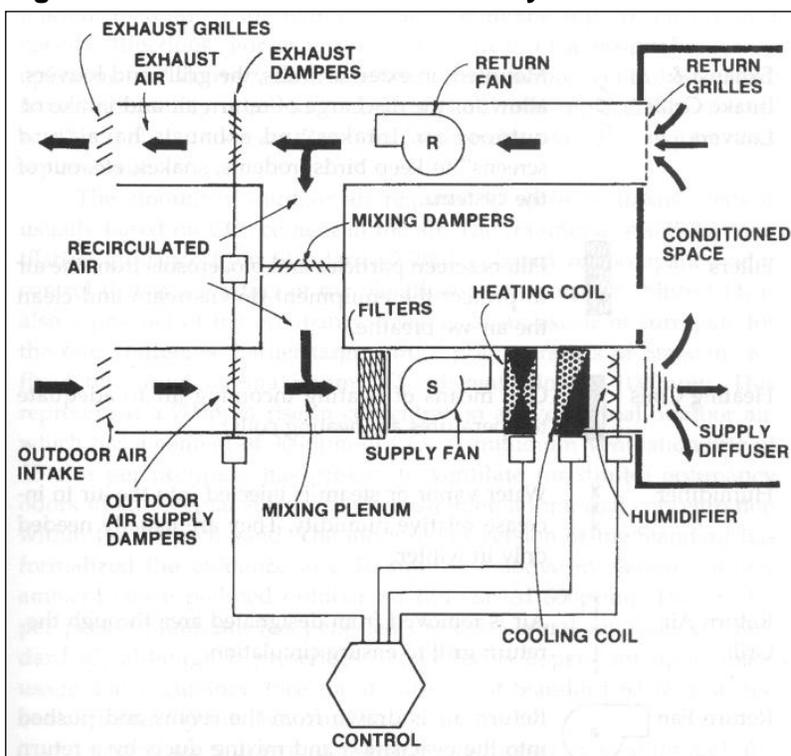
LEV is an engineering control that is used to keep airborne contaminant exposures to an acceptable low level. In some cases, the need for ventilation for certain materials or tasks is explicitly stated in a regulation or best practice (welding on cadmium, lead, or other toxic materials). It is also important to do post-monitoring or air-sampling measurements to confirm the desired reduction in air contaminant level.

III.E.2 HVAC system

The quality of air in residential, institutional or commercial buildings is an important issue for building and facility managers, mechanical engineers, and health professionals. Heating, ventilating and air conditioning (HVAC) systems can play an important role by providing fresh air and circulation to maintain satisfactory indoor air quality (IAQ) and comfort. However, there are many factors that can affect IAQ: total air flow, amount of outdoor air provided, temperature, humidity, air motion in the occupied space, and the presence of odours or other contaminants⁹ in the outdoor and re-circulated air (McDermott, 2001).

A typical HVAC system and its air-handling components are shown in Figure III.E-4. The main purpose of the system is to provide a comfortable environment for the majority of building's occupants by providing heating or cooling, outside air, filtration, air distribution and air diffusion (Burroughs and Hansen, 2004).

Figure III.E-4 Mechanical ventilation system



Source: Burroughs and Hansen, 2004, p.167

Many HVAC problems, such as heavy lint and debris that build-up in the ductwork and obstruct the outdoor air intake, are readily detectable by a visual inspection. Note that any malfunction in a HVAC system from worn bearings in the fan to dirty coil fins can affect the system's ability to provide satisfactory indoor air quality. All air systems have the capability to provide outdoor air to the building; that is, to replace indoor air and to dilute contaminants. The amount of air exchange required may be dependent on the type

⁹ For example, carbon monoxide, organic vapours, respirable particulate matter, airborne microorganisms, radion (and its progeny), and carbon dioxide.

and function of the facility. For example, hospital operating rooms, delivery rooms and research laboratories, where contamination control is critical, may require total air replacement (Burroughs and Hansen, 2004). Otherwise, the amount of outdoor air required to serve occupant needs is based on the CO₂ content in the air¹⁰. The more recent version of the ASHRAE Standard has fixed the CO₂ guidance to a 700 ppm rise above measured outdoor ambient level¹¹.

The outdoor air and the re-circulated air are mixed in the “mixing plenum”. Any dirt in this area may be picked up, carried and distributed in the ventilation system and into the occupied space.

III.E.3 General ventilation air systems

- **Air systems**

Air systems basically fall into two categories: constant volume or variable air volume. Both these air systems may use chilled water from a central plant or be outfitted with damper controls or heat pump coils (Burroughs and Hansen, 2004).

5. Constant volume

Constant volume air systems require and distribute a fixed amount of air at all times.

- ▶ Single zone

In single zone applications, air is moved to one or more locations in the building via ducts. A single thermostat is used to monitor and control the amount of heating or cooling in the air system. The fan controls the flow rate (Figure III.E-4). This type of system is typically found in auditoriums, dining halls, gymnasiums and other large open spaces.

- ▶ Multi-zone

In multi-zone applications, there is one constant volume fan which supplies heated or cooled air to several individually controlled zones¹² (see Figure III.E-5). The amount of hot or cold air varies and is controlled by the individual zone’s thermostat. This type of system is typically found in large commercial or institutional buildings.

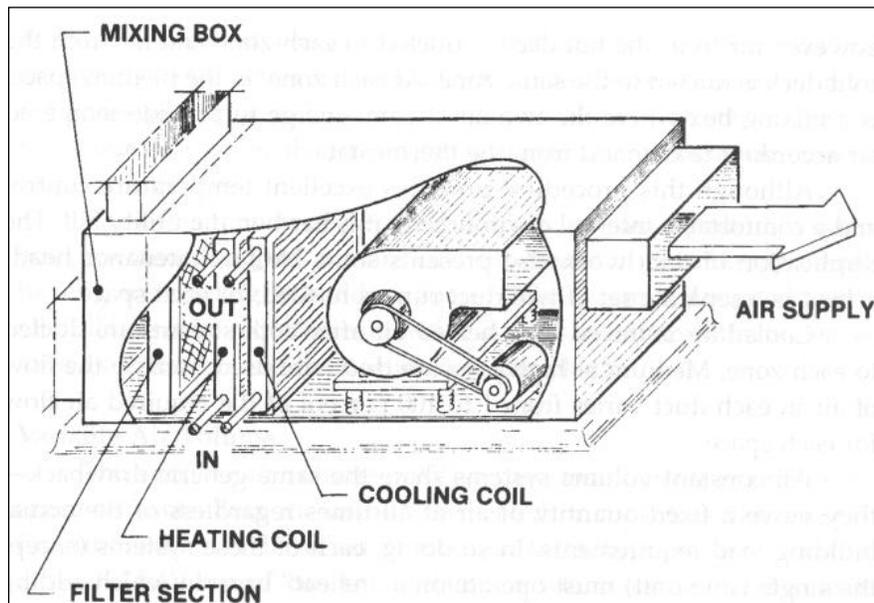
At each zone, the hot and cold air streams merge and are mixed in the mixing plenum box to provide the tempered air according to the demand from the thermostat (see Figure III.E-6).

¹⁰ The traditional ASHRAE ventilation guidance was based on an occupancy odour control, which was a product of the occupants’ bioeffluents. Since CO₂ is also an occupant product, CO₂

¹¹ Note: polluted outdoor air can exceed 600 ppm. serves as a surrogate for the other effluents (Burroughs and Hansen, 2004, p.169).

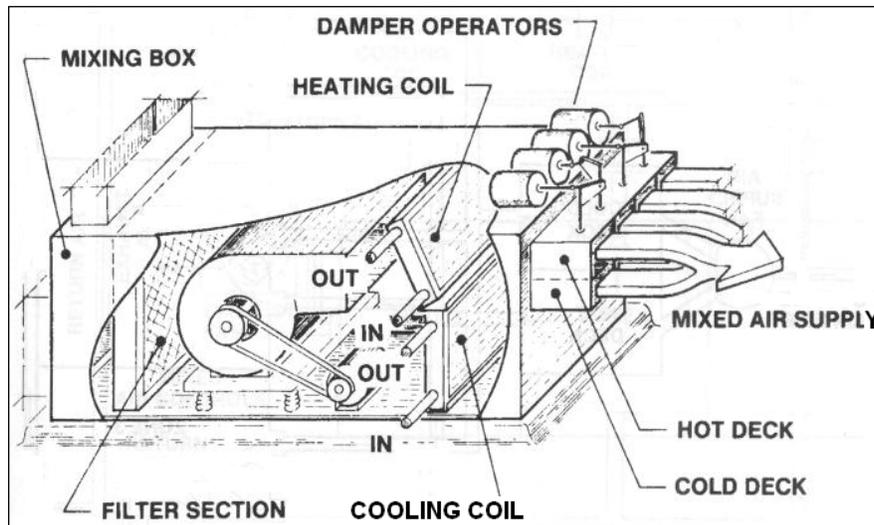
¹² Each zone has its own thermostat unit.

Figure III.E-5 Single zone constant volume air system



Source: Burroughs and Hansen, 2004, p.175

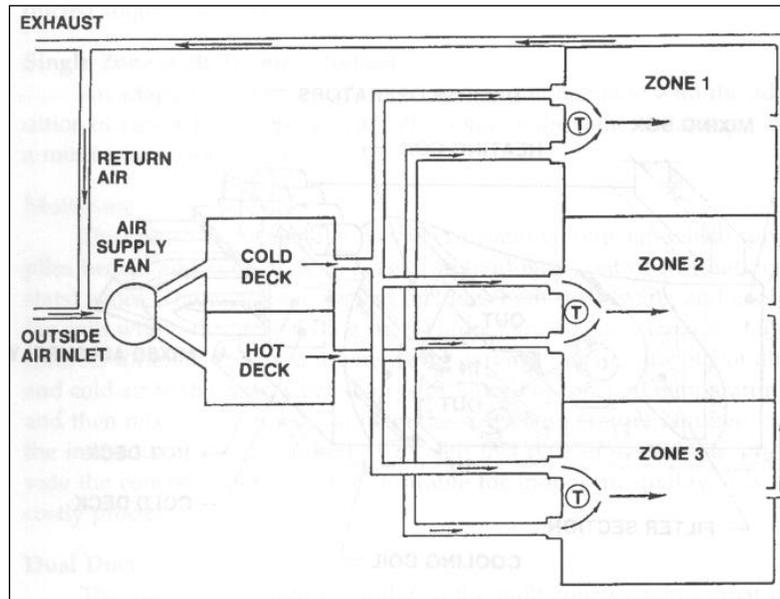
Figure III.E-6 Multi-zone constant volume air system



Source: Burroughs and Hansen, 2004, p.175

Dual duct air systems are similar to the multi-zone system except that air from the hot deck and cold deck are separately ducted to each zone. At each zone, the hot and cold air streams merge and are mixed in the mixing plenum box to provide the tempered air according to the demand from the thermostat (see Figure III-E.7).

Figure III.E-7 Dual duct system

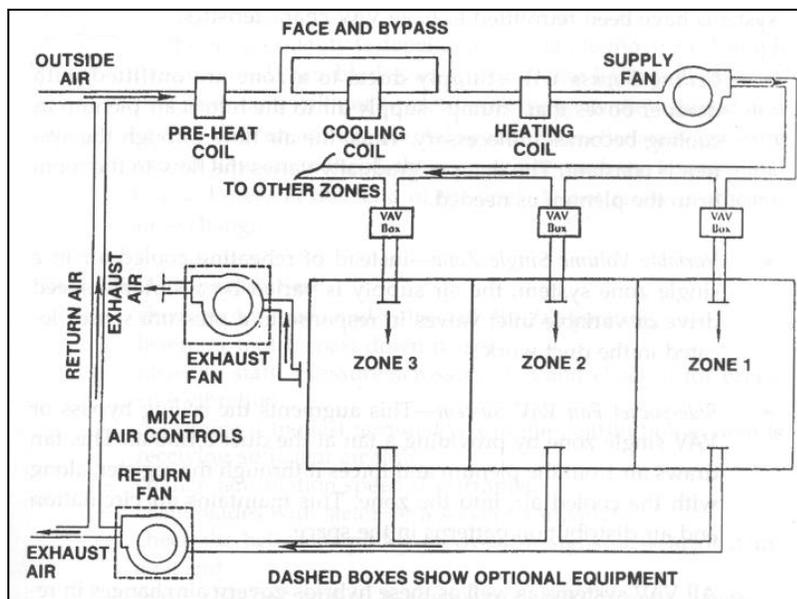


Source: Burroughs and Hansen, 2004, p.176

6. Variable air volume (VAV)

In VAV and hybrid systems, the temperature in air space is regulated by controlling the amount of heated or cooled air flowing through the system. The conditioned air is delivered at medium –to–high pressure to the room through VAV boxes. The dampers in the VAV boxes restrict the flow according to the demand from the thermostat (see Figure III.E-8).

Figure III.E-8 Variable volume air system



Source: Burroughs and Hansen, 2004, p.176

III.E.4 Heat transfer

Heat transfer occurs at the heat-exchange section of the air handling unit. There are several heating and cooling media that are used for this purpose, including water, steam, refrigerant and electric.

A generic description of the water and air heating-and-cooling systems is described below¹³.

- **Water systems**

Water coils are the most common component for transferring heat with circulating air. There are two types of water systems that are used in the ventilation system (Burroughs and Hansen, 2004):

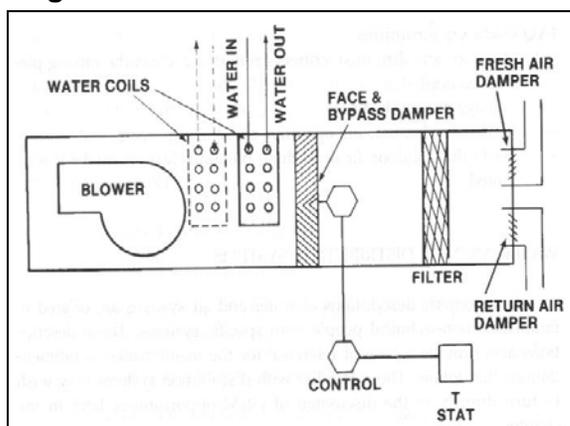
- Unit ventilator

In unit ventilators, water moving in the coils of the unit ventilator is not controlled. However, the amount of air moving through the coil is controlled by the “face and bypass damper”. The percentage of fresh air intake is controlled by the “fresh air damper” and the “return air damper”, which, in turn, may be determined by thermostat or other temperature controls for that building (see Figure III.E-9).

- Fan coil unit

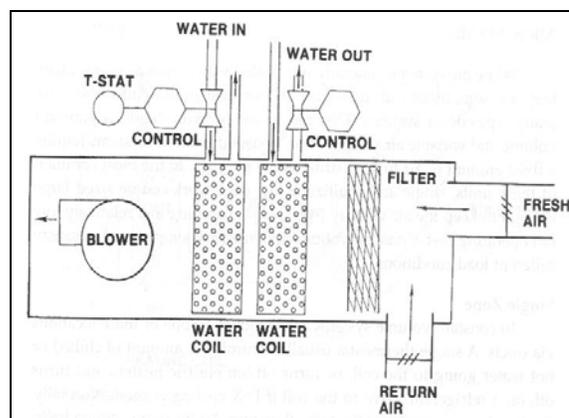
There are no dampers or controls inside the fan coil unit. This unit is controlled by a water valve, which reacts directly to the thermostat setting (see Figures III.E-9 and III.E-10)¹⁴. Blower motor speed control is commonly used as the fresh air is controlled by the damper in the fresh-air duct.

Figure III.E-9 Unit ventilator



Source: Burroughs and Hansen, 2004, p. 173

Figure III.E-10 Fan coil unit

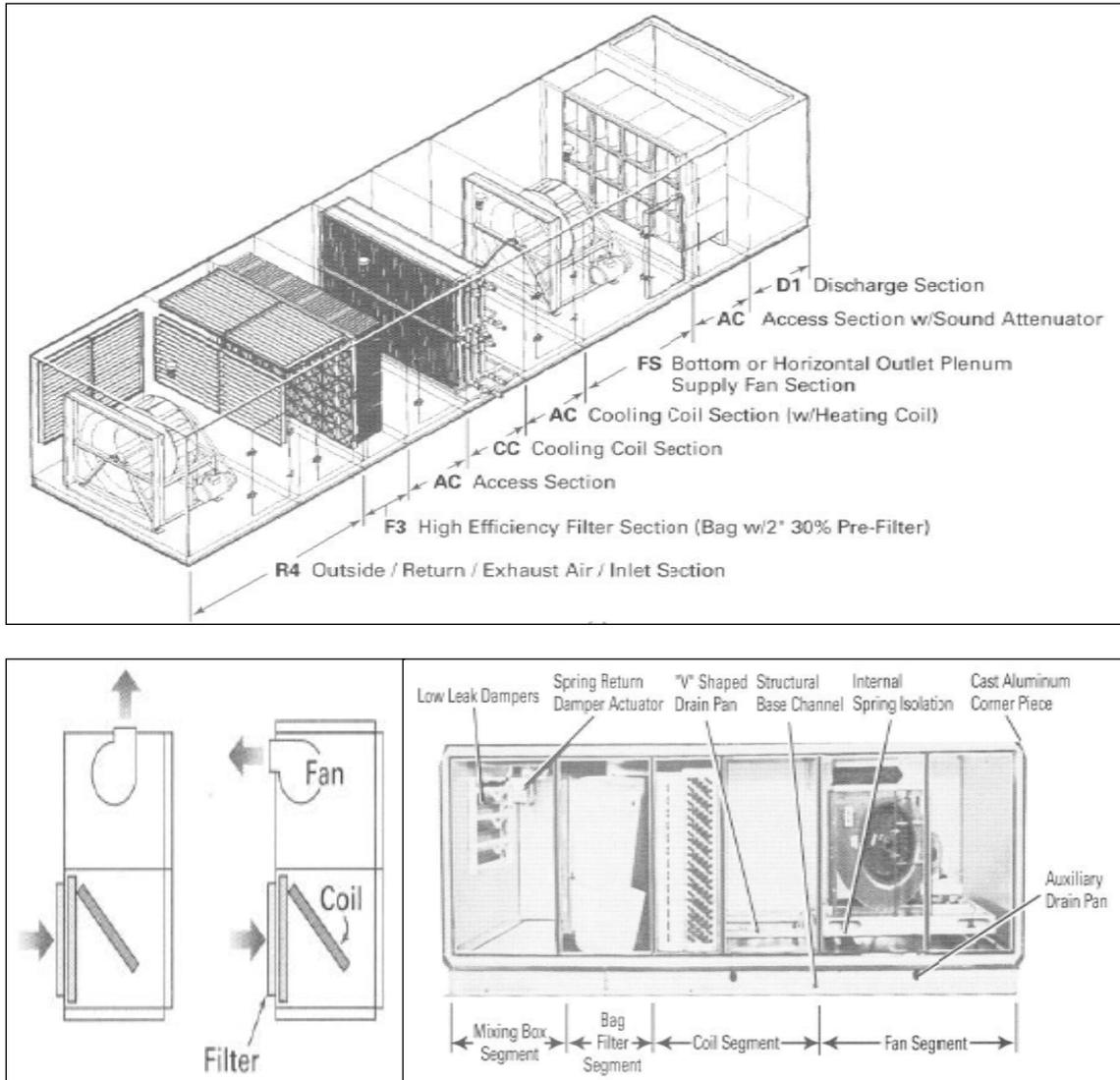


Source: Burroughs and Hansen, 2004, p. 173

¹³ There are many types of air systems, but only two basic types of water systems.

¹⁴ Burroughs and Hansen (2004, p. 172) noted that adjustments to the thermostat should be made in small increments. Too great or rapid a change in thermostat settings leads to temperature over-correction.

Figure III.E-11 Basic commercial fan coil unit



Source: Janis and Tao, 2009, p. 166.

Note: The upper drawing represents a built-up horizontal air handling unit, showing one return-air fan with mixing dampers, combination filters, and cooling and heating coils; one supply air fan with a sound-attenuating section; and a discharge plenum.

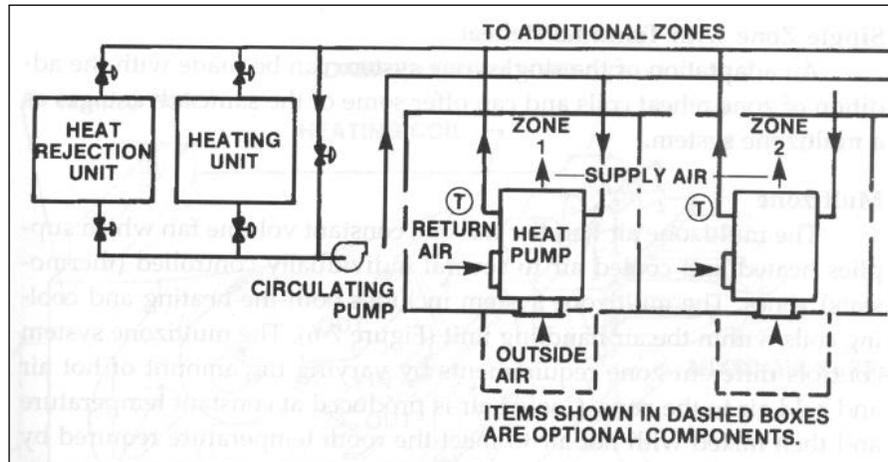
The lower left-hand drawing represents a basic fan-coil unit configuration that may be in a vertical or horizontal mount configuration.

The lower right-hand drawing represents a packaged horizontal air-handling unit with a single supply-air fan, one return-air inlet, and one air-supply outlet.

- Water-source heat pumps

A water loop is interjected between the pump and the outdoor air supply. Heat is pumped to or from that circulating water loop (see Figure III-E.12).

Figure III-E.12 Unitary hydronic heat pump system



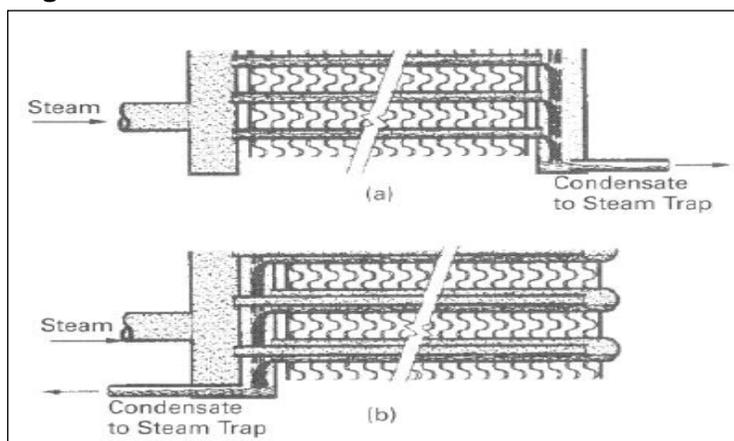
Source: Burroughs and Hansen, 2004, p.173

- Steam coils

There are two types of steam coils (Janis and Tao, 2009, p.168):

- General purpose or conventional steam coils with steam supply and condensate return at the different ends of the coil (see Figure III.E-13)
- Steam distributing coil type¹⁵ in which the steam is distributed evenly from an inner orifice tube within the outer heat-transfer tube.

Figure III.E-13 Steam coils



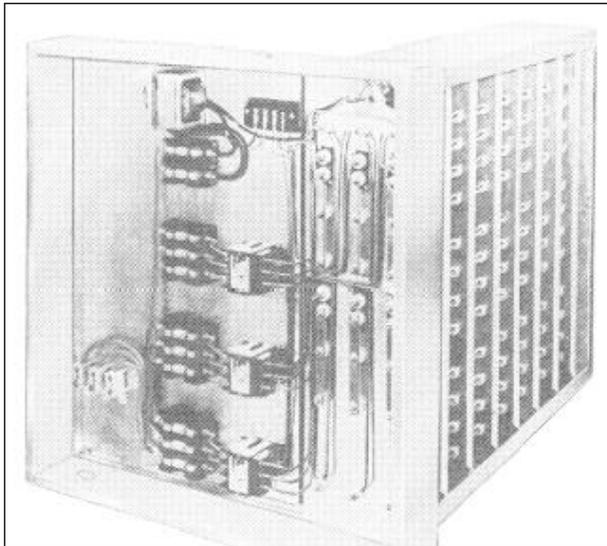
Source: Janis & Tao, 2009, p.168

¹⁵ This design ensures an even temperature distribution across the face of the coil. This is also most effective in preventing the coil freezing in below-freezing temperatures. (Janis and Tao, 2009, p. 168).

- **Electrical coils**

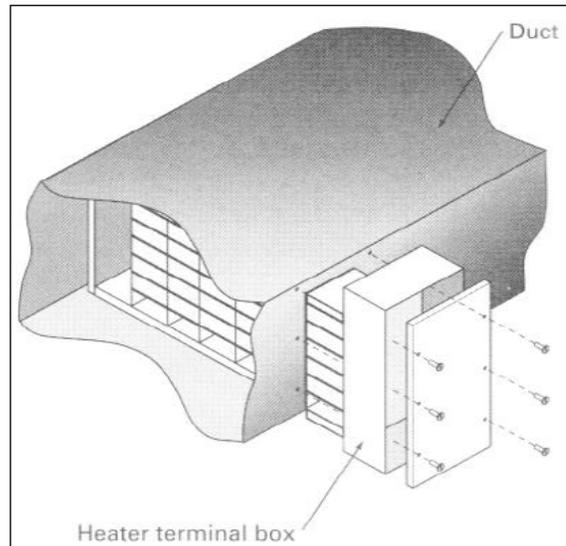
Electric coils have very low resistance to air flow¹⁶. They are designed as part of the air handling unit or may be installed on the ductwork exterior to the air-handling unit (see Figure III.E-134 and Figure III.E-15).

Figure III.E-14 Electric duct heater



Source: Janis and Tao, 2009, p.168

Figure III.E-15 Electric duct heater with slide in construction



Source: Janis and Tao, 2009, p.168

III.E.5 Cooling systems

Cooling systems in large buildings may be designed using several methods, including vapour compression, absorption refrigeration and evaporative cooling (via direct refrigerant coils, chilled-water coils, or evaporative coolers).

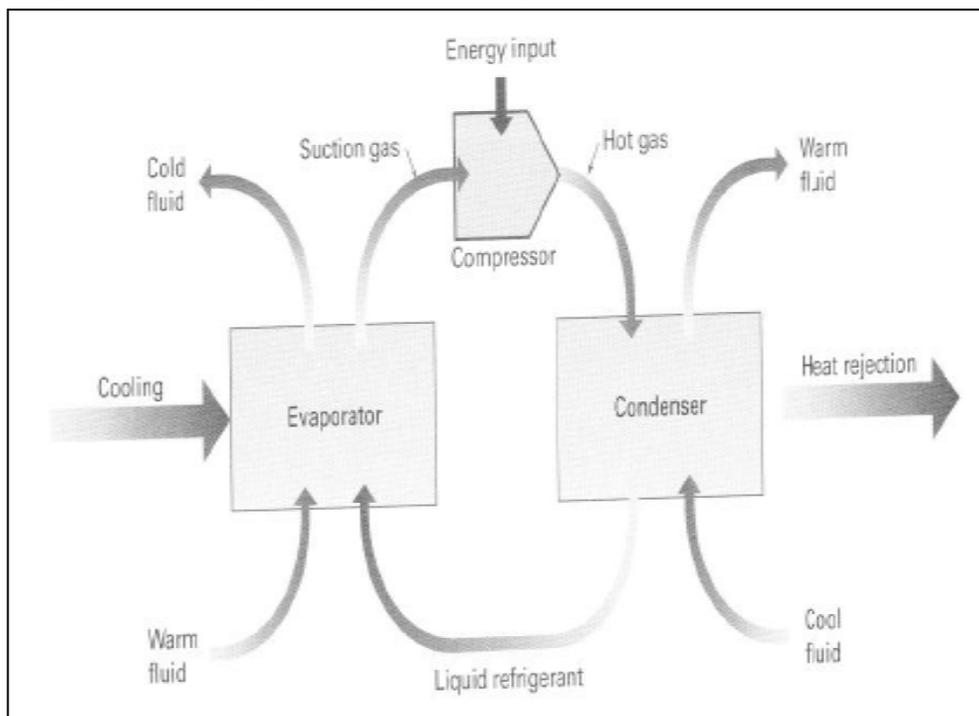
3. Vapor compression cycle (VCC)

The refrigeration process most often used in HVAC systems is called the vapour compression cycle. This process involves boiling and condensing “refrigerant” fluids at temperatures that will produce a cooling effect. In this process, warm air is passed across a refrigerant filled cooling coil. The heat of the warm air is absorbed by and used to heat the refrigerant. Therefore, the air is cooled and the refrigerant is boiled, or evaporated (Janis and Tao, 2009).

The vapour-compression cycle (Figure III.E-16) returns the refrigerant gas to its liquid state. For this condensing cycle, the refrigerant is drawn from the evaporator by the suction of the compressor so the pressure of the refrigerant is low; therefore, raised at the discharge point of the compressor (Janis and Tao, 2009).

¹⁶ In air handling unit with high flow velocities, water or steam coils are used instead of electrical coils.

Figure III.E-16 Vapor compression cycle



Source: Janis and Tao, 2009, p.108

- **Absorption refrigeration cycle (ARC)**

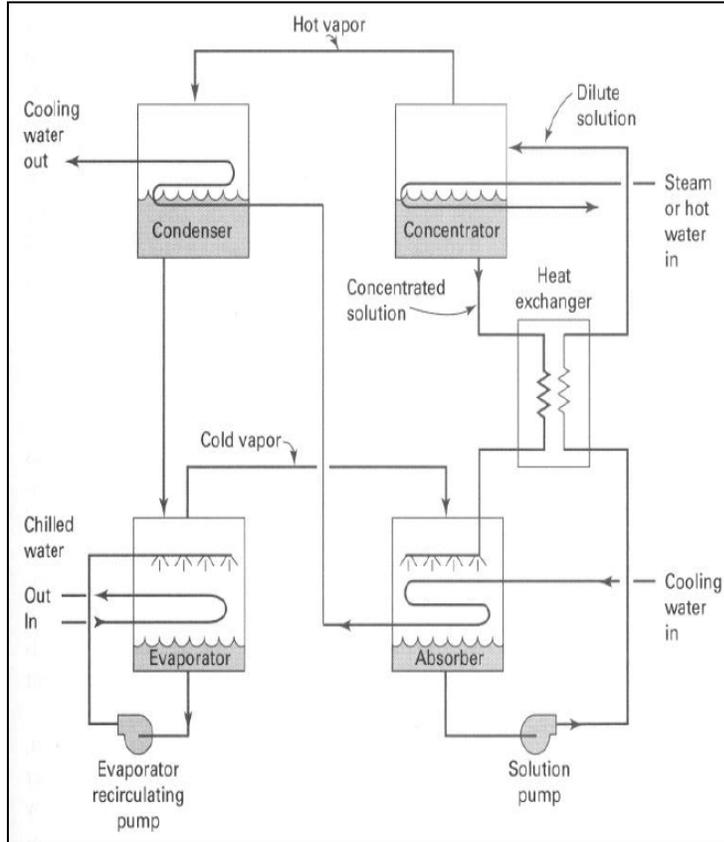
In the ARC (Figure III.E-17), water is used as the refrigerant. As with VCC, the refrigerant is boiled in an evaporator that absorbs heat from the air that is being cooled. The water vapour produced in the evaporator is conducted to a chamber that contains a strong solution of a hygroscopic chemical, such as LiBr. That solution absorbs the water vapour, which then becomes liquid. This part of the ARC is similar to condensation in the vapour compression cycle. As the solution becomes more dilute, it must be regenerated by removing water. This is accomplished in the concentrator chamber, which uses heat to boil off excess water and strengthen the solution (Janis and Tao, 2009).

- **Evaporative cooling**

This is an economical alternative or supplement to vapour compression or absorption refrigeration. The process involves passing the air through a water spray or wetted medium. The air is cooled and humidified for direct use in interior spaces, or indirect use to cool another airstream via an air-to-air heat exchanger (see Figure III.E-18).

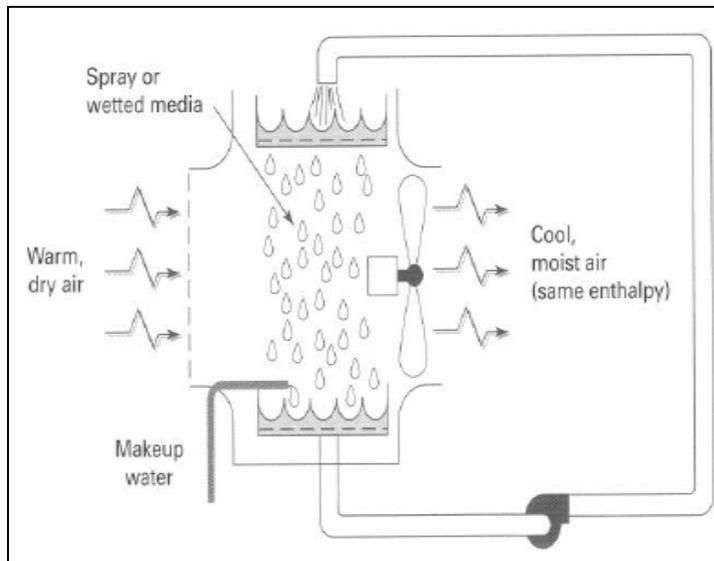
It should be noted that evaporative cooling is also part of many systems that use vapour compression or absorption refrigeration. A typical large system will include a cooling tower to produce condensing water during warm weather.

Figure III.E-17 Absorption refrigeration cycle



Source: Janis and Tao, 2009, p.109

Figure III.E-18 Evaporative cooling

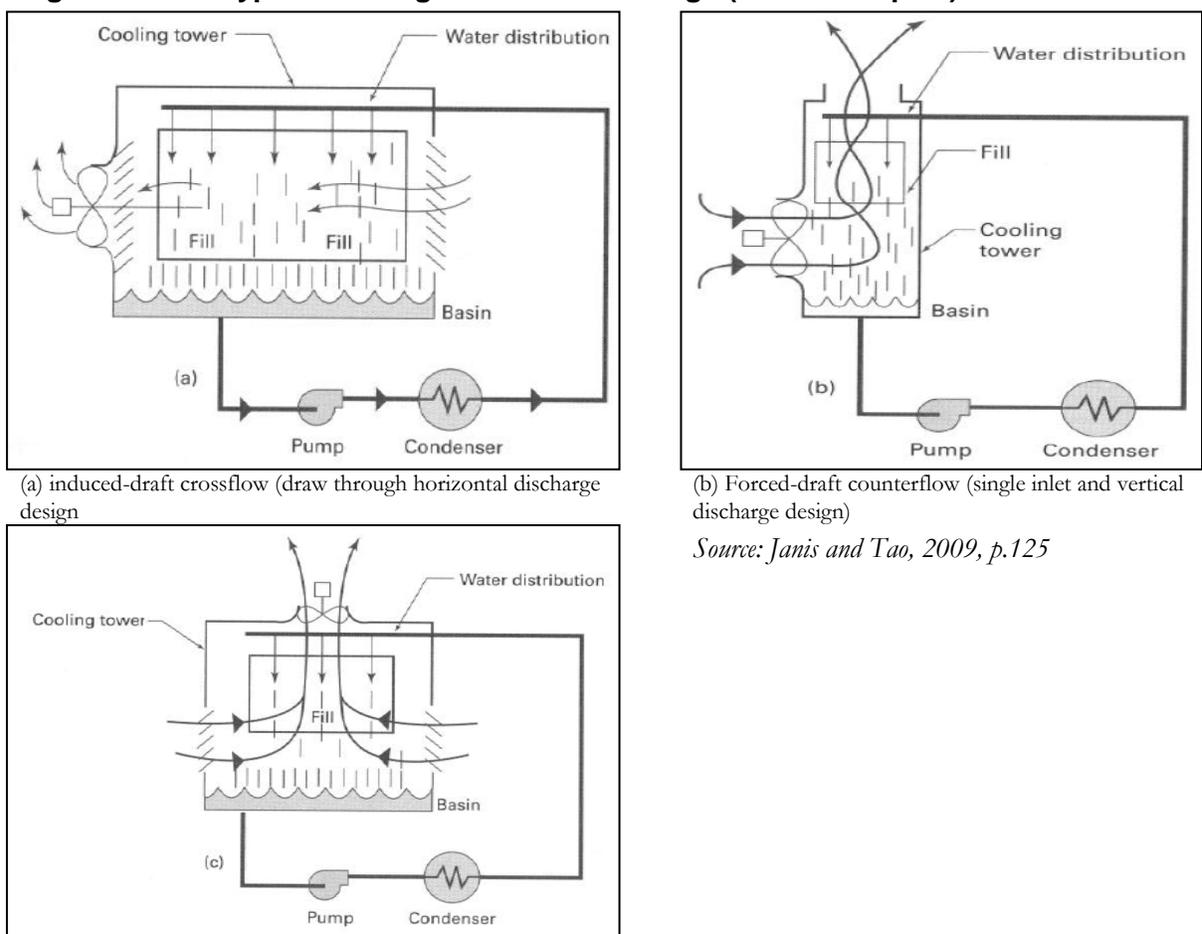


Source: Janis and Tao, 2009, p.110

Most large cooling systems are served by chilled water. According to Burrows and Hansen (2004), cooler plants “with elevated chilled water temperatures can contribute to indoor air problems. Adjusting chilled water temperatures upward as the load decreases can push relative humidity up” to 65 to plus-85 per cent in occupied spaces. This higher humidity increases the likelihood of microbial growth.

Cooling towers produce water at an appropriate temperature for condensing by evaporation. Evaporation happens by water flowing over a fill material in the tower. There are three basic ways to move air through a cooling tower: (a) induced-draft crossflow, (b) forced-draft counterflow and (c) induced-draft counterflow (Janis and Tao, 2009). Free circulation of air is needed for cooling tower operation.

Figure III.E-19 Typical cooling towers for buildings (three examples)



(a) induced-draft crossflow (draw through horizontal discharge design)

(b) Forced-draft counterflow (single inlet and vertical discharge design)

(c) Induced-draft counterflow (double inlet and vertical discharge design)

Source: Janis and Tao, 2009, p.125

For example, as a general rule, the minimal clear air passage that is needed for:

- Induced-draft towers is equivalent to the tower intake height
- Forced-draft towers is equal to 1.5 times the tower width

In addition, discharge from the tower should be unimpeded. Violations of these guidelines can cause circulation of humid discharge into the inlet or impede the air

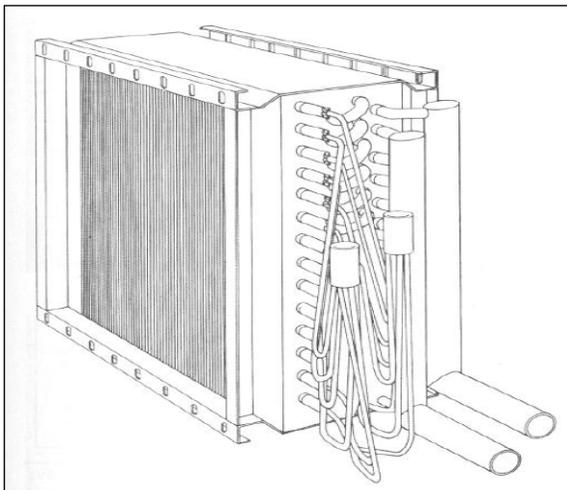
flow. Further, both effects will result in performance degradation (Janis and Tao, 2009).

Discharge air from towers is humid and may contain droplets of water with high mineral concentrations and water treatment chemicals. Surfaces that are exposed to those water droplets may become corroded, soiled, or discoloured (Janis and Tao, 2009).

- **Direct expansion (DX) coils**

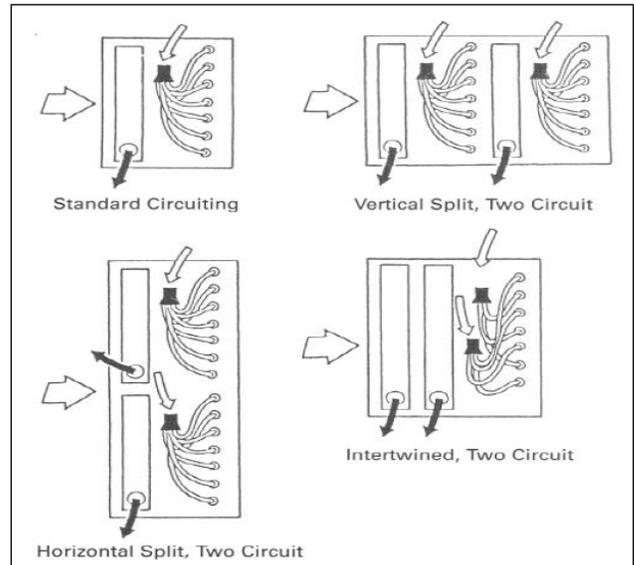
DX coils use a refrigerant, such as Freon, as the cooling medium. The cooling coil is designed to allow the refrigerant to vaporize in the coil, thereby absorbing the heat from the air. As shown in Figure III.E-20 and Figure III.E-21, the DX coil consists of a refrigerant header and many distribution tubes and configurations (Janis and Tao, 2009, p.169).

Figure III.E-20 Typical DX coil construction



Source: Janis and Tao, 2009, p.170

Figure III.E-21 Refrigerant tube circuiting



Tubes may be single-circuited for small coils, or horizontally or vertically split for even distribution of the refrigerant

Source: Janis and Tao, 2009, p.170

III.E.6 Roof-top units

III.E.6.1 Roof-top air handling units (AHUs)

Roof-top AHUs are available in any of the already discussed configurations; however, they are more common for servicing smaller zones (Spengler et. al., 2001). These units have staged heating and cooling, typically two stages. The cooling system will usually be refrigerant-based and each cooling stage will be completely separate with its own compressor (Spengler et. al., 2001).

Roof-top AHUs are found in commercial settings, primarily in small strip malls and one or two storey buildings. However, AHUs can also be found in large malls that service individual commercial bays or retailers.

These units are exposed to the elements and can accumulate pools of water as reservoirs for biological contaminants. Also, the exposure to the elements can decrease the service life of such systems.

When inspecting roof-top AHUs, inspectors should assess the cleanliness of the area around the outdoor air intakes and the intake grill, including the position of the intake louvres. Closed louvres or “sealed” louvres suggests that the AHU is being operated to predominantly recycle return air and minimize the intake of clean outdoor air, which likely would generate occupant complaints about stale, stuffy air. Side wall covers can be removed to check the condition and cleanliness of the interior, fans and filters.

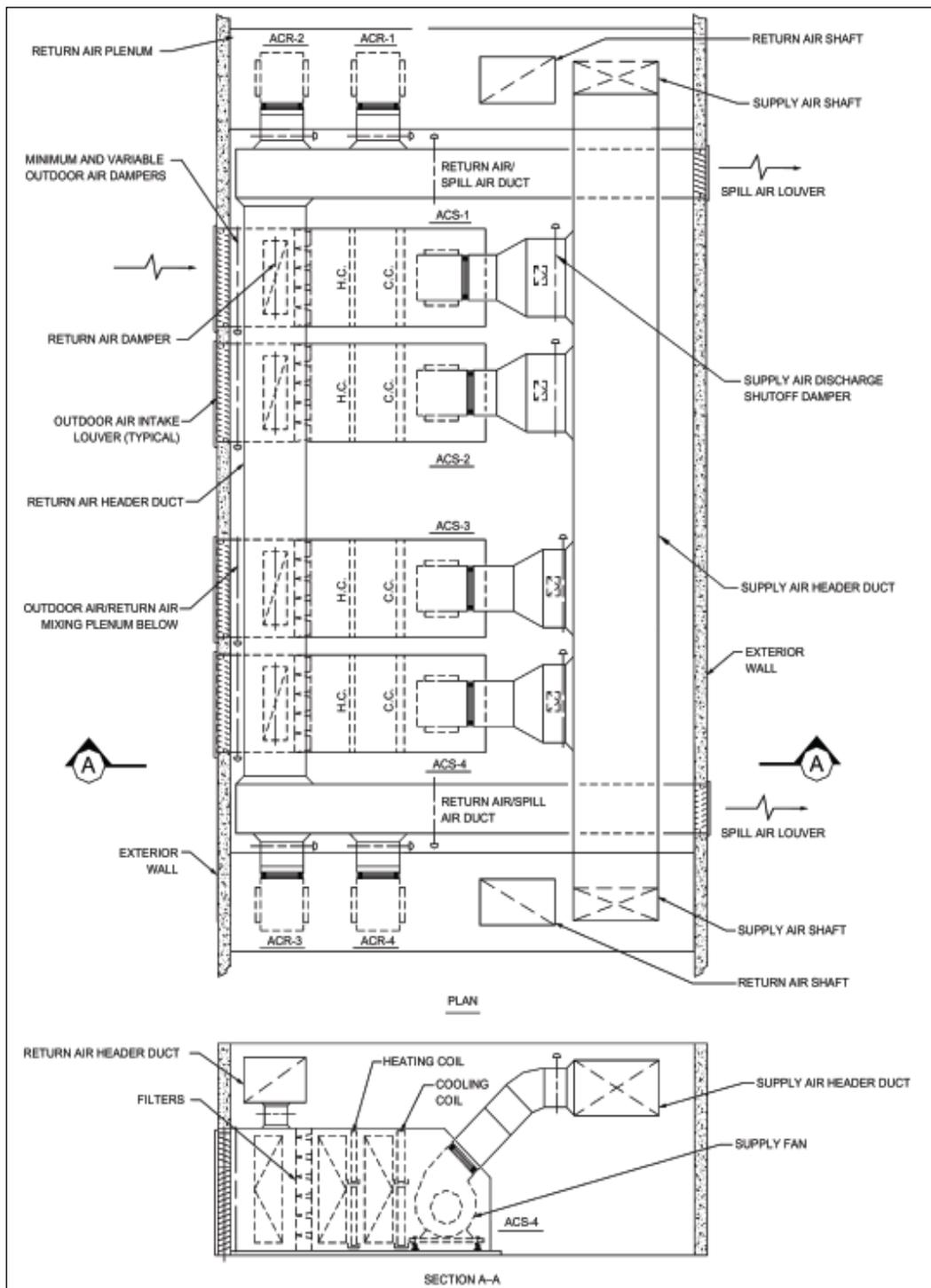
III.E.6.2 Building mechanical rooms

Multi-storey office buildings, hospitals, recreation centres, libraries, large retail malls and apartment towers may have mechanical rooms for domestic hot water boilers and centralized HVAC systems for heating and cooling. Mechanical rooms can be found on penthouse floors, in basements and on floors half way up large towers. Walk-in AHUs are common in mechanical rooms.

Figure III.E-22 provides a sample layout for a penthouse mechanical room. Assessing the configuration of supply-and-return air ducts on the outside of the AHU will also aid in understanding of the system. Inspectors can access the interior of AHUs through access hatches to assess the condition and cleanliness of the interior, air filters and heating and cooling exchangers. Assessing the configuration of return-air, exhaust-air and outdoor-air-intake louvres can help determine if excessive amounts of recycled return air are in the system. Louvre configurations that suggest insufficient outdoor air or excess recycled return air may also suggest failure to meet the minimum building code requirement of outdoor air. Such a condition may generate occupant complaints about headaches, fatigue and stale and stuffy air.

Carbon dioxide monitoring in occupant spaces may help confirm a hypothesis of insufficient outdoor air in occupant spaces. In mechanical rooms equipped with carbon dioxide sensors for supply, return and exhaust air, inspectors can check the sensor displays to ensure there is an adequate supply of outdoor air. Inspectors also can request to see operation, maintenance and repair records, such as the filter replacement cycle.

Figure III.E-22 Example layout of penthouse mechanical room



Source: ©ASHRAE (2011 ASHRAE HANDBOOK – HVAC Application (SI Edition)), (Chapter 4 – Tall Buildings), (2011).

III.E.6.3 Unit heaters (optional)

A unit heater is a self-contained heating unit usually mounted in the corner of the ceiling or in a limited access area. These units are used to heat the immediate surrounding area. The delivery of the conditioned air can be either passive (radiative) or active (fan-driven). Direct-fired gas units include a flue for discharging combustion gases outside.

Unit heaters are usually found in industrial applications, such as warehouses, commercial bays and areas where light construction and maintenance activities are underway.

III.E.6.4 Natural ventilation

For residential premises, natural ventilation may allow for cross ventilation of the building. However, in larger commercial, institutional and industrial buildings, open windows may interfere with the controls of air conditioning systems. For example, in a health center, several perimeter offices may be served by a single variable air volume (VAV) terminal unit (see Figure III.E-23 and Figure III.E-24); that is, controlled by a single thermostat in one of the offices. Therefore, if a window was opened in the office with the thermostat, then that office's temperature will not be the same as adjacent spaces, and good temperature control throughout all offices will not be possible. Further, operable windows can work against the control of building air flow and pressure relationships (Janis and Tao, 2009).

Figure III.E-23 VAV terminal box and air terminals

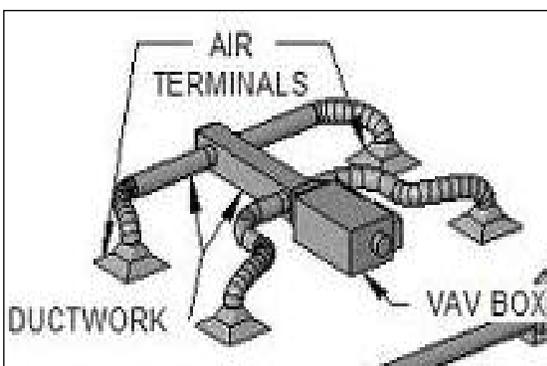


Figure III.E-24 VAV terminal box



III.E.6.5 Inspecting a HVAC system

Inspecting HVAC systems is complicated. There are many types of systems for residential, commercial, institutional and industrial use. As a recommended strategy, first look at the HVAC system as a whole, and then look inspect the system's individual components and conditions. After the inspection is completed, assess the “big picture” of the HVAC system.

III.E.6.6 Checklist

The first step in an HVAC inspection process is to identify the system's equipment and components (CDA, 2005a). The following checklist may be helpful this identification process.

- Is the heating system a furnace or boiler?
- What is the fuel source: gas, propane, oil or electric?
- What is the distribution method (ducts and registers: pipes radiators and baseboards; radiant piping; or electric radiant?)
- How is the combustion air supplied?
- Is there an outdoor or fresh air intake supply?
- Is there a return air system?
- Is there a return-air exhaust to the outside?
- Identify local contaminant sources, such as cooking ranges, fire places, clothes dryers; and humid areas including bathrooms. How and where is air exhausted to the outside through a chimney, stack, or sidewall vent?
- What safety controls should be in place? Can they be located?
- What operating controls do you expect to find? Are they there?
- What is the efficiency of the system whether conventional, mid-efficiency, or high-efficiency? There are different components and controls depending on the efficiency of the HVAC system.

III.E.6.7 Inspection guidelines

After identifying the HVAC system components, look at each of the following components.

- Air intake
- Gas furnace
- Heat exchanger
- Regulator vent
- Filters
- Electronic air filters
- Insulation on ductwork
- Return air grills and supply air diffusers
- Humidifiers
- Condensate lines
- Mixing plenum
- Fans
- Dampers
- Heating and coiling coils
- Air flow patterns
- Ductwork
- Terminal boxes and diffusers
- Heating plants
- Roof-top AHUs
- Mechanical rooms
- Unit heaters

1. Air intakes

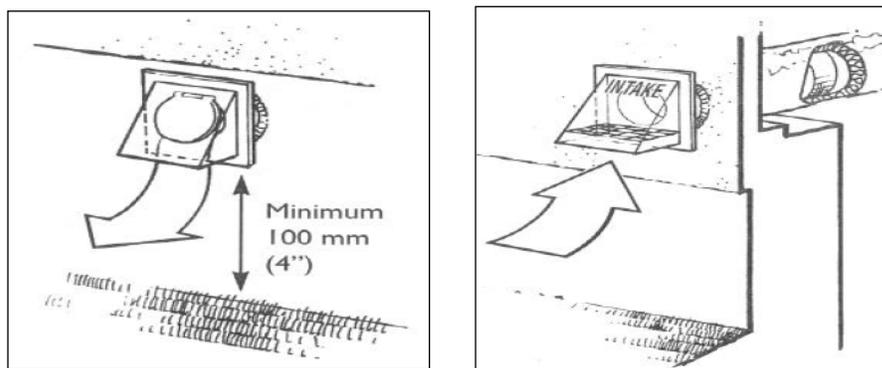
Ask the following questions: Is the air flow restricted? Are the diffusers open and unobstructed? Are they adjusted to avoid drafts? Is the exhaust system operating correctly? Are the air intakes unobstructed and operating correctly? Are the air intakes bringing the building's own exhaust back into the facility?

◦ Exterior hoods

▶ Exhaust hoods

Backdraft dampers should be present in all exhaust ducts (except HRVs). For residential premises, the outlet of the damper should be located at least 10 cm (4 in.) above finished grade. Exhaust outlets should not be terminated in enclosed spaces, such as garages, attics, soffit spaces, crawl spaces and under decks¹⁷. Check to make sure that the operation of the damper is smooth and closure is airtight (CMHC, 1996).

Figure III.E-25 Residential exterior hoods (exhaust versus intake)



Source: Canada Mortgage and Housing Corporation (CMHC). *Complying With Residential Ventilation Requirements In The 1995 National Building Code*. All rights reserved. Reproduced with the consent of CMHC. All other uses and reproductions of this material are expressly prohibited.

▶ Intake hood & ducts

The primary purpose of the HVAC system is to provide fresh air to the building. It is essential to avoid locating the air supply ports near pollutant sources and drawing contaminants into the living space (CMHC, 1998). Check outdoor air intake locations to see if there is any possible sources of contamination that is located near that intake (Burroughs and Hansen, 2004):

- ◊ Re-entry of building exhaust
- ◊ Odours and contamination coming in from garbage dumpsters or compactors
- ◊ Contaminants from bird droppings
- ◊ Combustion contamination from indoor garages, loading docks and parking lots

¹⁷ Moisture from the exhaust air will condense on the building materials or elements in cold weather.

- ◇ Exhaust from other buildings and pollution from stagnant water.
In addition, check to see if there is any evidence of water penetration at or around the intake hood area; if there is, recommend that:
 - Wet insulation should be replaced with dry waterproof insulation
 - Install an indirect drain, or change the damper design if necessary (Burroughs and Hansen, 2004, p.170).

For residential premises, check to see if the air intake hood is located:

- ◇ ≥ 45 cm (18 in.) above finished grade and the depth of expected snow accumulations
- ◇ ≥ 90 cm (36 in.) away from gas vents, oil fill pipes, exhaust outlets and appliance vents
- ◇ At a distance from contamination source including automobile exhaust and building exhaust

Further, these hoods should be accessible for cleaning (not under decks) as they will pick up debris and lint. In addition, there should also be a corrosion resistant rodent and bird screen or grille on the hood opening (CMHC, 1996, p.D5).

Check the ducts carrying unconditioned outdoor air. Ducts should be insulated and have a vapour barrier to mitigate condensation on the duct surfaces.

- **Fresh air intakes**

Fresh air intakes deliver fresh outdoor air to the indoor environment. The air is usually driven by a fan. This air may be conditioned as it passes through the conditioning unit and is mixed with return air from the occupied space.

Schools must absolutely have both a fresh air intake and a combustion air intake. Commercial buildings are also expected to both air intakes. But older construction and portable school structures may not have the dual air intakes because of grandfathering under the building code. In such case, the PHI or EHO can recommend or require separate air intakes for both fresh air and combustion air.

The fresh air intake fan is required to operate continuously when the school or commercial business is in use and occupied to meet the fresh outdoor air delivery requirements specified in the building code and by ASHRAE.

2. Gas furnaces

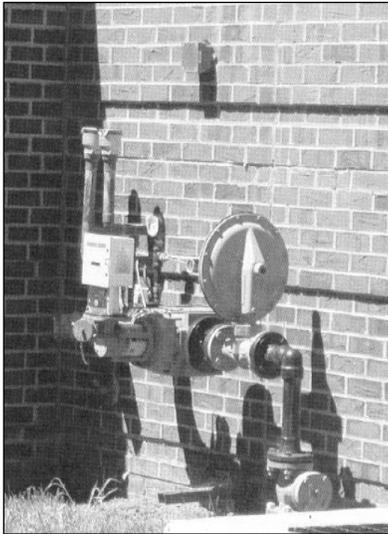
Check the following components of a conventional gas furnace are as follows (CDA, 2005a):

- Fuel storage and delivery systems
- Gas piping
- Combustion air
- Furnace air intakes
- Cabinet
- Exhaust venting of heating units
- Exhaust vent connector
- Connections and supports

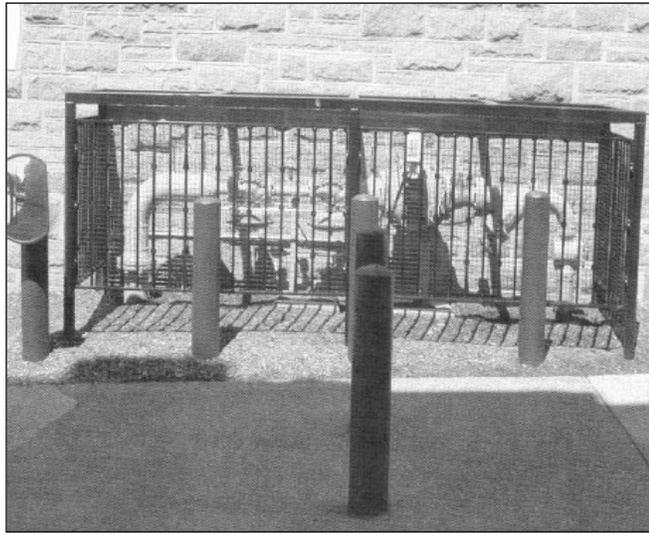
- **Fuel storage and delivery system**

This system includes the fuel system, piping and combustion air (without touching the furnace) Find the gas meter. Pay attention to things like rust, mechanical damage, access, and location (Figure III.E.26). For example, ice may accumulate on the regulator and valve of a gas service line & Outdoor Meter (Residential) - Ice accumulation on the (see Figure III.E-27).

Figure III.E.26 Gas service lines and meters



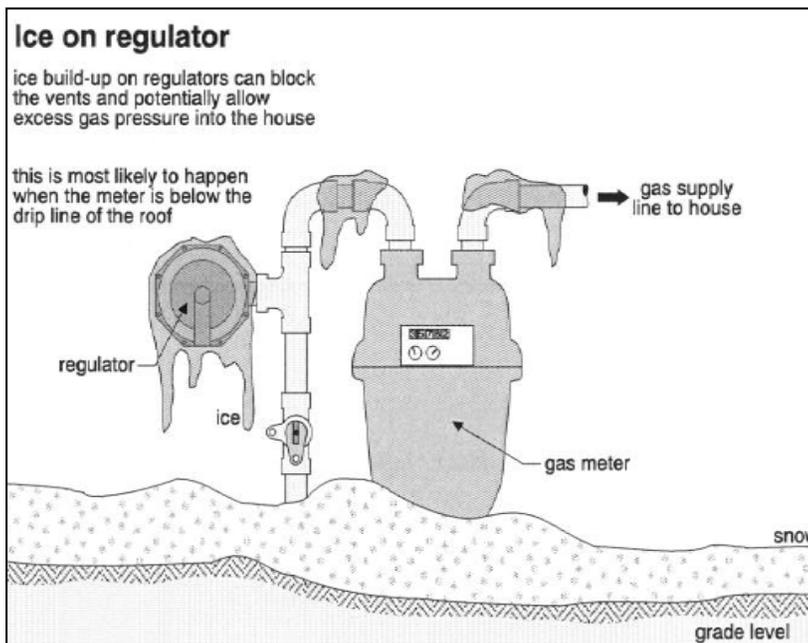
Source: Janis and Tao, 2009



Source: Janis and Tao, 2009

Note: bollards and other provisions may be required for protection from damage and tampering.

Figure III.E-27 Ice on gas meter & regulator



Source: CDA, 2005a

Gas meters and regulators may be located below the edge of a roof, and; therefore, exposed to a significant amount of snow or water.

Ice can obstruct the vents on the regulator. This situation may lead to a potential failure of the regulator, resulting in excessively high-pressure gas entering the building's gas-supply line.

If the meter is iced up or buried under snow, advise the tenant or owner of this situation, and recommend that utility company check the meter and serviced it, if necessary.

- **Gas piping**

Examine the gas piping including the material, support for leaks, rust and poor connections. For appliances, look for the shutoff valve and drip leg.

For example, gas piping and valve (residential) – gas leak

Gas leakage may be a result of a number of conditions:

- ▶ Poor connections, which may be caused by mechanical damage, ice, rust, earth settling or heaving, or vibration
- ▶ Inadequate support of the horizontal metal gas piping¹⁸
- ▶ Leak in the gas valve

A gas leak may lead to an explosion if there is an ignition source present or nearby.

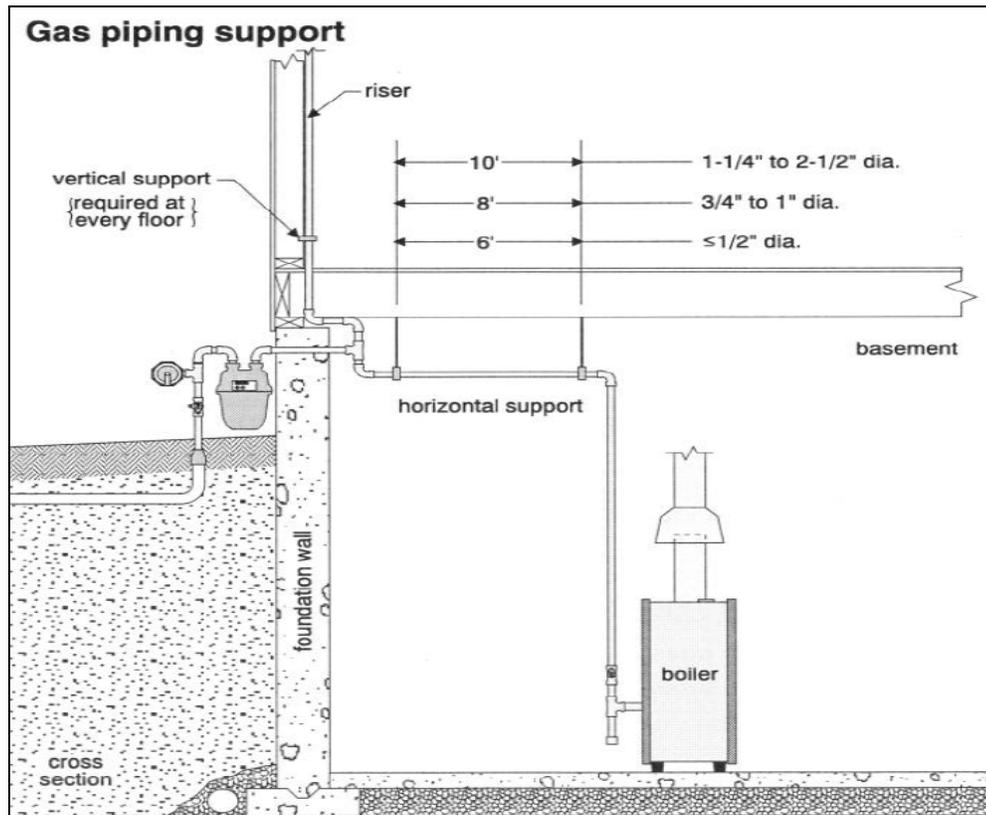
Reduced sulphur compounds are added to natural gas to help people smell natural gas leaks. These compounds have odour thresholds in the low ppb range. If the odour leads you to suspect a possible natural gas leak, and other possible sources have been considered, immediately dial 911 if the occupant has not already done so. The 911 dispatcher will connect you with ATCO Gas.

Depending on the inspector's assessment of the situation, ask the occupants not to use any electrical or electronic devices including the telephone, but instead leave the building. Once outside the building, the occupants can either call the gas company directly or dial 911. For personal safety, the inspector should suspend, leave the building and not return until proven safe to continue.

Also, look for missing or ineffective support brackets (see Figure III.E-28). Also, check for materials stored on top of or hanging from pipes. Gas piping should not be used support storage.

¹⁸ Inadequate support, such as two few, broken or ineffective brackets, may be because of poor installation, the brackets being removed or damaged. Poor piping support may result in gas leakage.

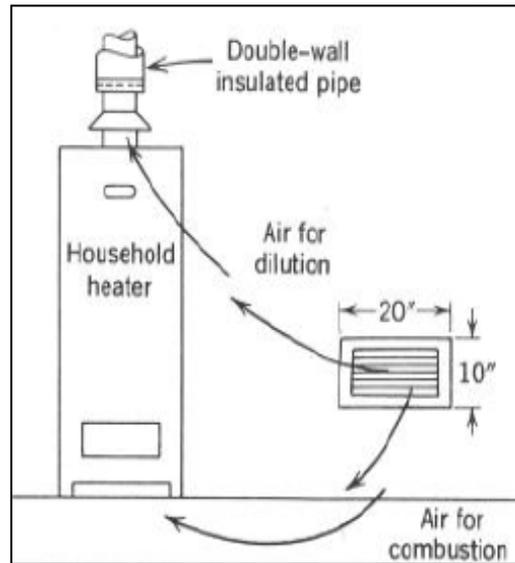
Figure III.E-28 Gas piping support



◦ **Combustion air**

Where is the furnace getting its combustion air from? Is there an insulated duct starting at an exterior wall and terminating at or close to the furnace. Furnaces should have two insulated ducts starting at an outside wall. One duct to bring fresh outdoor air into the ducted system of the furnace, to replace interior air lost to the outside through leakage and exhaust systems. The other is the combustion air duct referred to earlier. Both ducts must be insulated as evident by double wall pipes (see Figure III.E-29).

Figure III.E-29 Unobstructed air intake to furnace



Source: Salvatore, 1972, p.83.

- ▶ Low- and mid-efficiency furnaces may have the combustion air duct terminate close to the furnace. Is the duct opening unobstructed and tamper-free?
- ▶ Inspect the outside intake grills, are they clean and unobstructed? Are they in an area free of potential contaminant sources? Not located in proximity to exhaust discharges associated with clothes dryers, bathrooms, gas-fired fireplaces, high efficiency furnace discharges?

Combustion air intakes provide air to the combustion chamber of the furnace for the purpose of combusting fuel for heating through a heat exchanger. The intakes, which are either passive or active (fandriven), are required to prevent and mitigate the back-drafting of combustion gases into the room or building.

Schools must absolutely have both a fresh air intake and a combustion air intake. The dual intakes are also recommended in commercial applications. Both intakes may not be found in older construction and older school portable classrooms. Although such situations may be grandfathered under a previous building code, they may be considered unacceptable if they are creating a nuisance condition under the Public Health Act. In such cases, the inspector assessment of the situation may result in a recommendation or requirement that there be a separate intake.

○ **Furnace air intakes**

For low and med efficiency furnaces, the opening for drawing combustion and dilution air into the burner is called the draft hood and it should be clear and unobstructed and should not be compromised by rust, storage, furnace modifications, or mechanical damage (Figure III.E-28) (CDA, 2005a). For high efficiency furnaces, combustion air is ducted directly into the burner area.

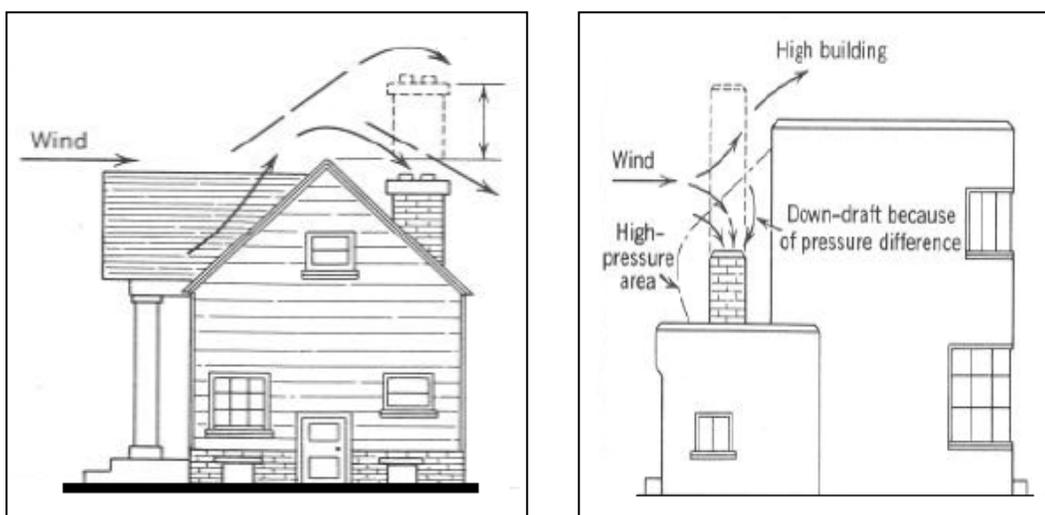
- **Cabinet**

Are there any panels missing? Look for evidence of rust, damage and scorching. Assess the findings as they relate to IAQ.

- **Exhaust venting of heating units**

Proper exhaust venting ensures the removal of all the combustion products through a designated channel or flue to the outside air. Figure III.E-30 shows chimney conditions that may result in back-drafts. The flue or vent should extend high enough above the building or other neighbouring obstructions so that the wind from any direction will not strike the flue or vent from an angle above horizontal.

Figure III.E-30 Chimney conditions that are apt to back-draft



Source: Salvatore, 1972, p.83.

Exhaust vent connector

Find and follow the exhaust vent connector. This is the exhaust duct that goes from the furnace to the chimney or main exhaust stack. Look for evidence of rust, poor slope, too-long length, poor support, poor connections, inadequate combustible clearances, poor manifolding and the vent connector extending too far into the chimney, spillage at the draft hood and obstruction. (Figures III.E-31 and Figure III.E-32).

To exhaust gases outdoors, some furnaces run an exhaust breech or exhaust flue through the return air plenum of the furnace before joining the vent

Figure III.E-31 Vent connector slope extends too far into the chimney

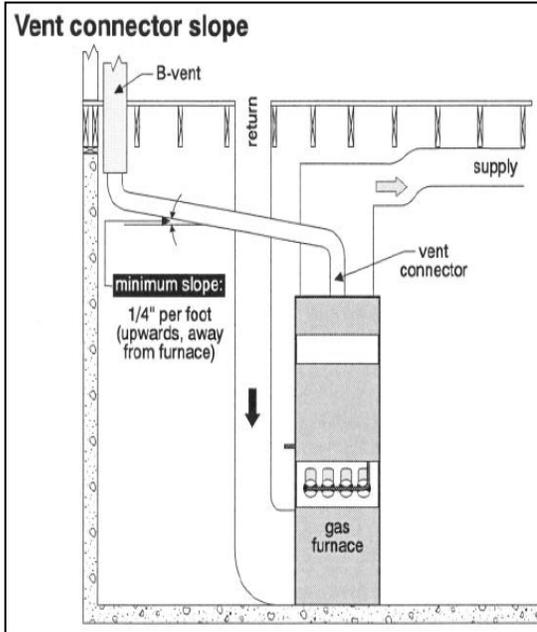
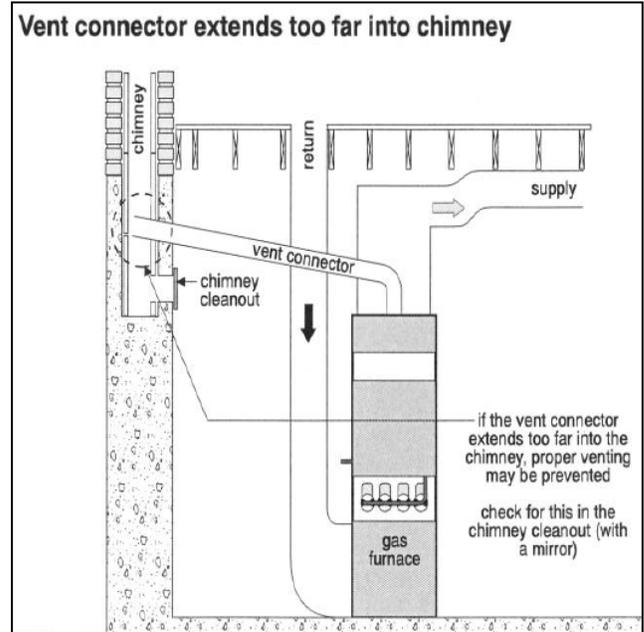


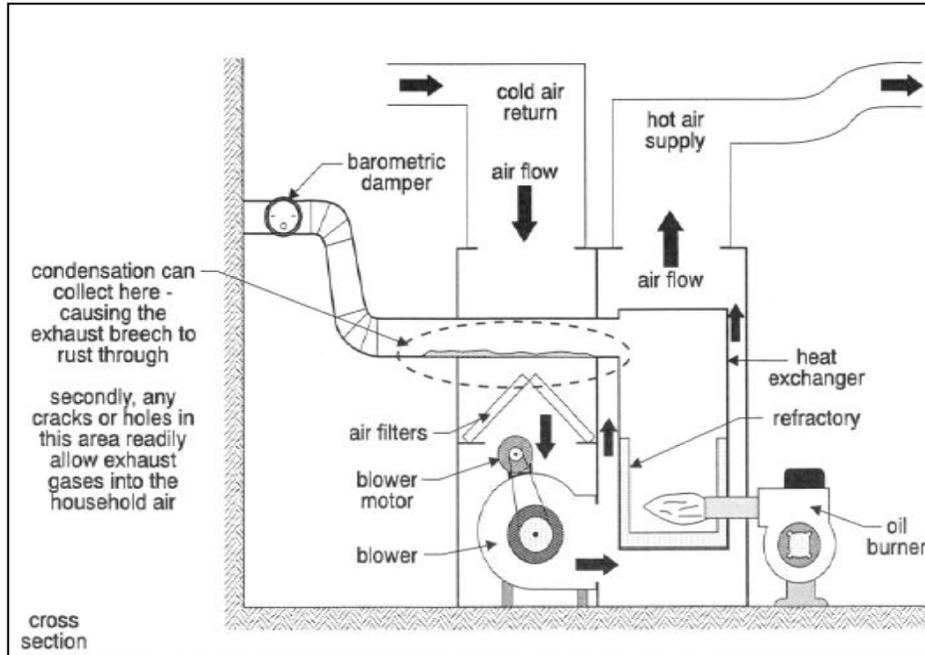
Figure III.E-32 Vent connector extends too far into the chimney



Source: CDA, 2005a, p.145

To release exhaust gases outdoors, some furnaces run an exhaust breech or exhaust flue through the return air plenum of the furnace before joining the vent connector (see Figure III.E-33).

Figure III.E-33 Exhaust breach through cold air return



Source: CDA, 2005a, p.148

The purpose of this design was to improve energy efficiency by transferring heat that would otherwise be lost up the chimney. This formed a “secondary heat exchanger.” The side effect was that this extra cooling of the exhaust gases could result in condensation problems in the exhaust flue, vent connector or chimney. The condensation could run back into the furnace and rust the exhaust flue, or heat exchanger (as shown in Figure III.E-33). Cracks or holes may develop and allow exhaust gases into the household air.

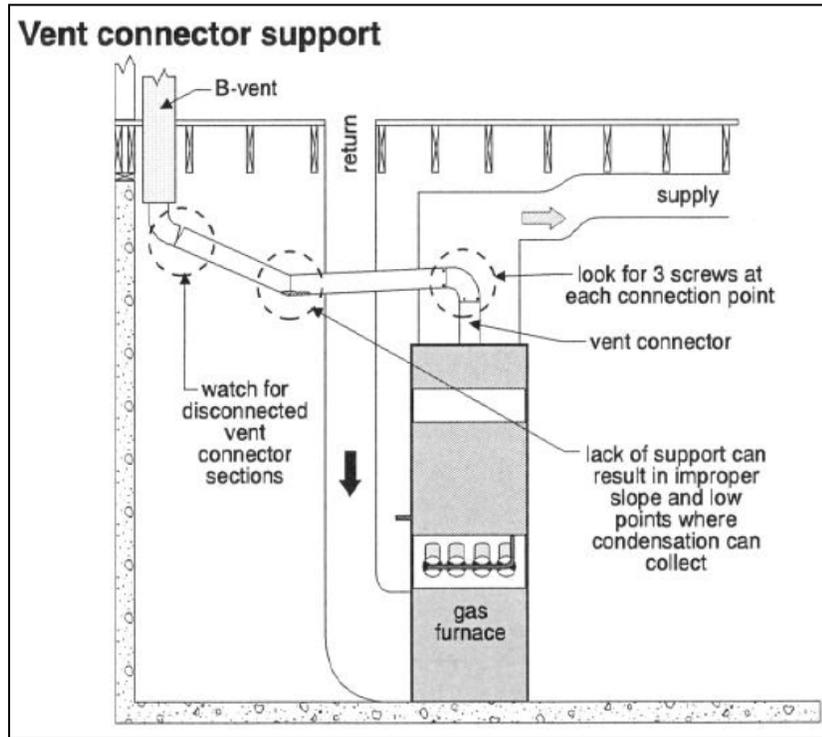
° **Connections and support**

While poor connections are an installation issue, the result is leakage of combustible gases into the building.

Check the entire circumference of each connection. Watch for disconnected vent connections (Figure III.E-34 and Figure III.E-35).

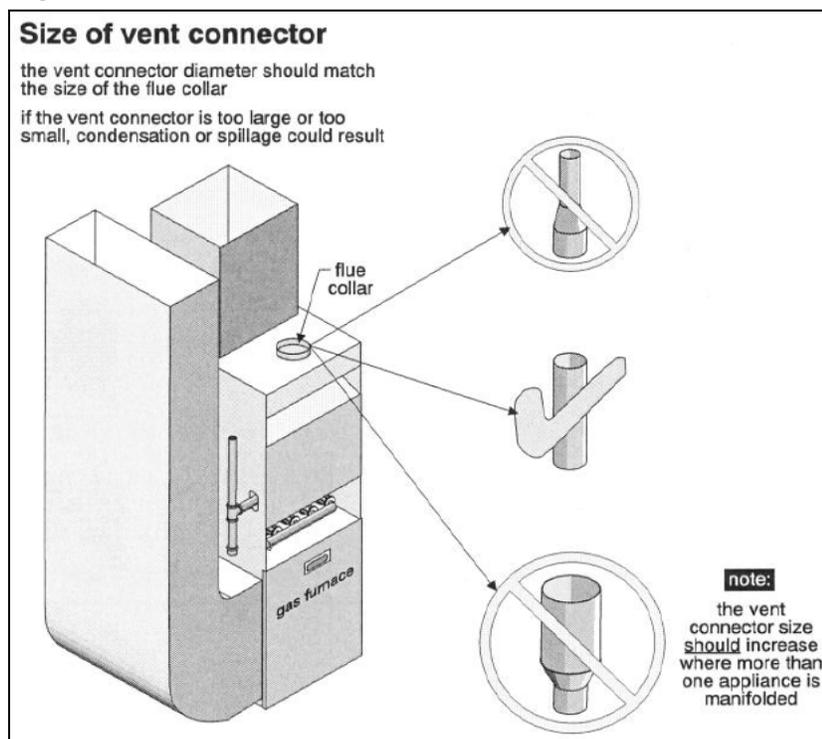
Vent connector should be the same size as the flue collar on the appliance. Where there is more than one appliance, the size of the vent connector should increase. Further, for multiple vent connectors to the same chimney flue, the smaller appliance vent connector should be above the larger appliance. For example, a gas water-heater’s vent connector is above the gas furnace vent-connector).

Figure III.E-34 Poor vent connector support & connections



Source: CDA, 2005a, p.145

Figure III.E-35 Vent connector



Source: CDA, 2005a, p.144

► Draft hood

While the furnace is operating, there should be no spillage from the draft hood¹⁹. Keep in mind that there may not be any spillage on the day of the inspection, but there could be spillage under different weather or building depressurization²⁰ conditions; therefore, the test is considered non-conclusive. Spillage of combustible products may suggest:

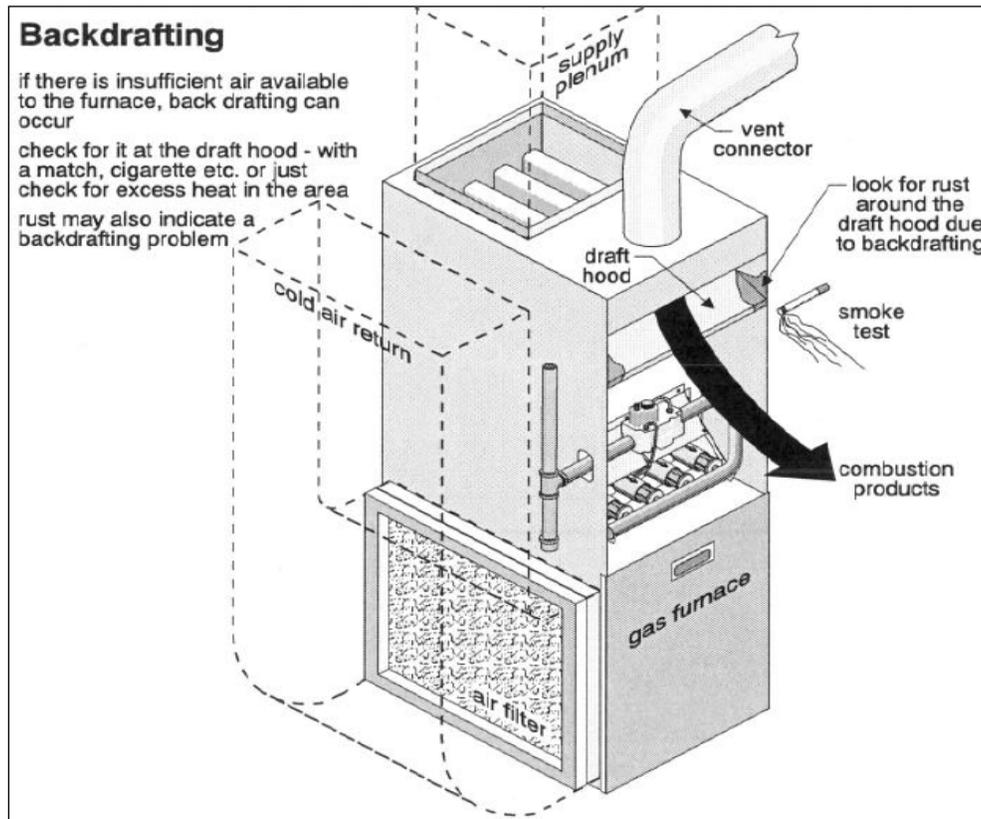
- ◇ Inadequate combustion or dilution air
- ◇ Mismatch in the sizing of the chimney or vent and the size of the appliance
- ◇ Negative air pressure in the house
- ◇ Obstruction or downdraft condition on the chimney
- ◇ Poor slope of the vent connector
- ◇ Excess vent connector length
- ◇ Poor manifolding of multiple appliances
- ◇ Vent connector extends too far into the chimney.
- ◇ Advise the occupier of the finding and recommend servicing by a qualified HVAC operator.

Spillage can be assessed using a smoke pencil (incense sticks can be used in a pinch) or CO monitor. To simulate a worst case scenario for back-drafting (Figure III.E-36), turn on any exhaust fans or clothes dryers in the area and increase the thermostat settings on the hot water tank so it requires combustion air and also on house/zone thermostats so that there is a demand for heating (and combustion air). Allow some time for equilibration, and observe if smoke from the pencil flows away from the hot water tank exhaust canopy or the draft hood of the furnace. Either suggests a back-drafting risk. Rust-coloured stains on the exhaust ducting show that back-drafting is occurring.

¹⁹ If the furnace started, there may be a little spillage in the first couple of minutes. This is not a problem. Once the furnace is warmed up, the spillage should stop.

²⁰ Depressurization occurs when the amount of air being mechanically vented from a house or space in a house exceeds the amount of air which is being mechanically supplied to the house or area. Clothes dryers, central vacs, exhaust fans, stop-top barbecue exhaust, the defrost cycle of some HRVs and furnace fans may cause local or whole house depressurization.

Figure III.E-36 Back-drafting



Source: CDA, 2005a, p.148

3. Heat exchangers

The heat exchanger is critical because it separates the combustion products from the house air (see Figure III.E-37). If the heat exchanger fails, combustion products may enter the house. If there is less than complete combustion, then these products may contain carbon monoxide.

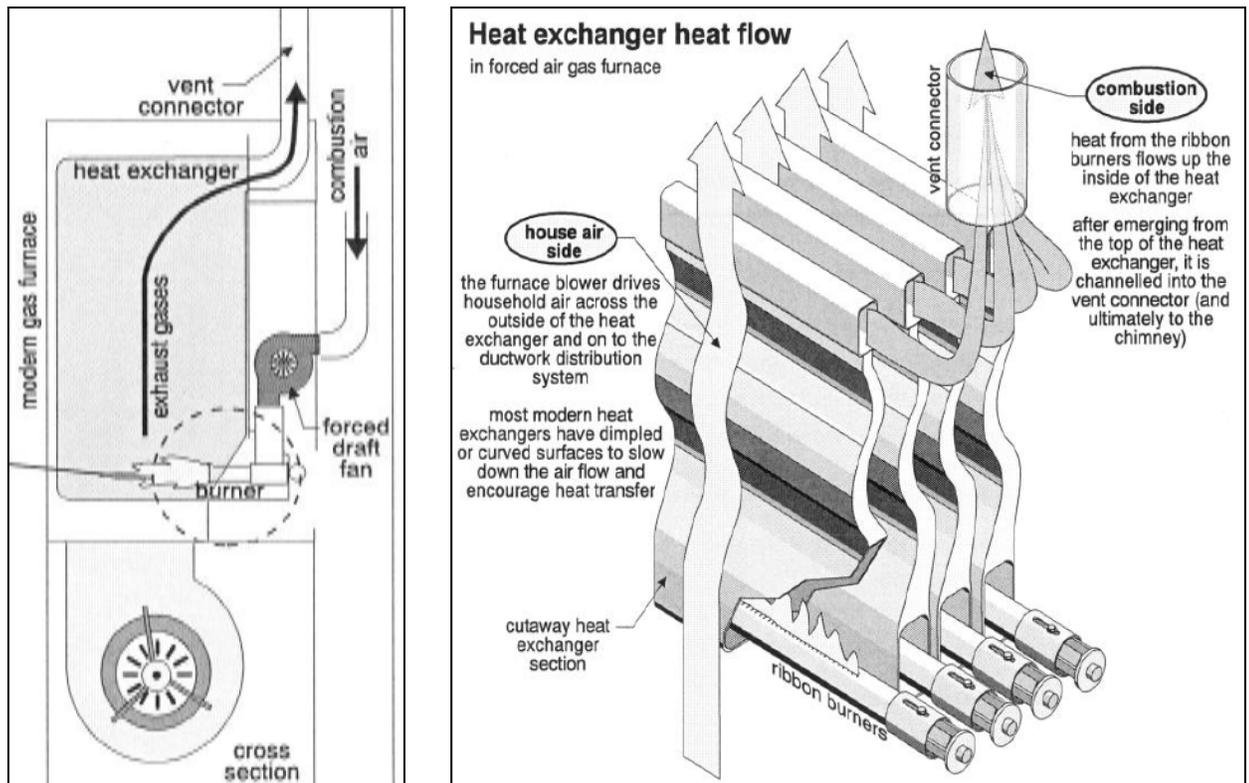
An inspector should not be doing an assessment of the heat exchanger. If occupant systems or air monitoring shows elevated CO levels, it is recommended that a gas company, plumber, or service technician be contacted for this assessment. If indoor CO levels are elevated above 25 ppm, it is recommended that 911 be phoned.

When the burner is “on”, watch the flame. The flame should be steady and should not be disturbed when the house fan comes on. A flame blown or sucked to one side or the other may there is a hole or crack in the exchanger (CDA, 2005a). Refer the building owner or occupant to a qualified HVAC specialist.

4. Regulator vent

A gas leak at the regulator vent means the diaphragm may have a hole in it. This possibility should be checked by a qualified service technician.

Figure III.E-37 Heat exchanger



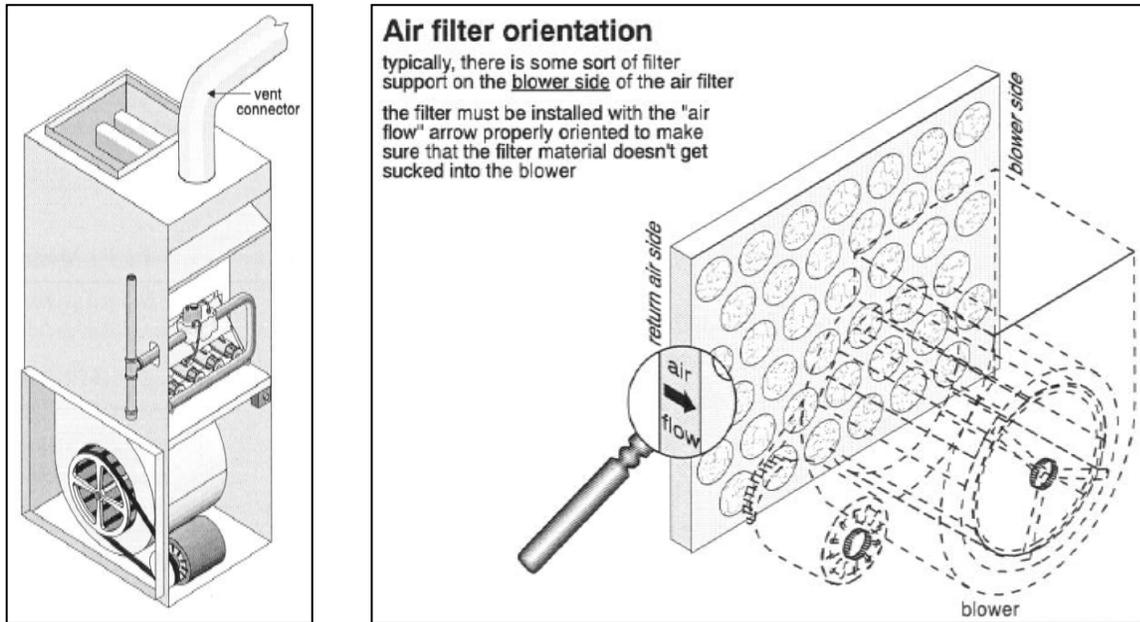
Source: CDA, 2005a, p. 79 & 98

5. Filters

Filters may be classified according to the following criteria (Janis and Tao, 2009):

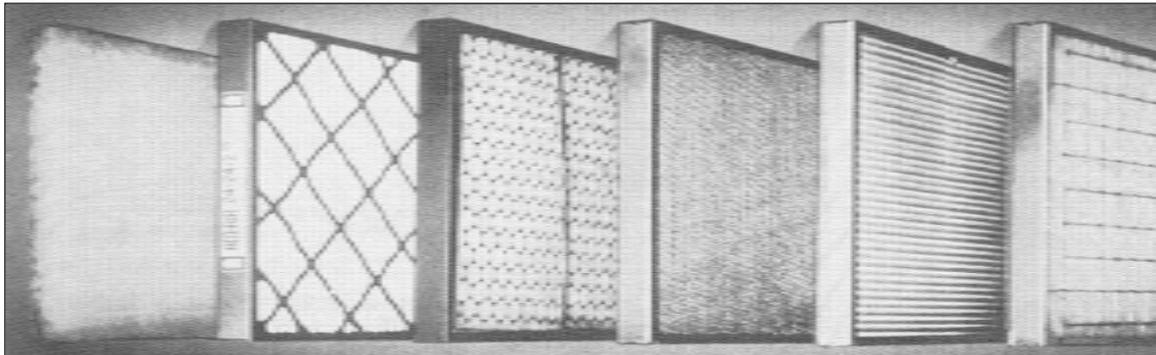
- Filtration principle by the medium or electrostatic precipitation
- Impingement, either dry medium or viscous impingement
- Configuration, flat or extended surface (pockets, V-shaped or radial pleats)
- Service life, either one-time use or renewable
- Performance (low, medium, HEPA or UEPA)
- Special features, such as odour absorption and disposal of radiative material.

Figure III.E-38 Air filter orientation with respect to the blower



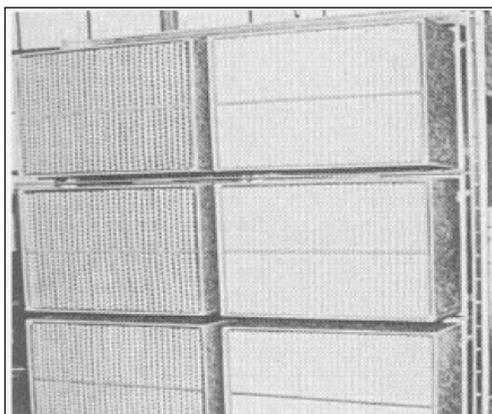
Source: CDA, 2005a, p. 167 & 169

Figure III.E-39 Examples of low efficiency filters



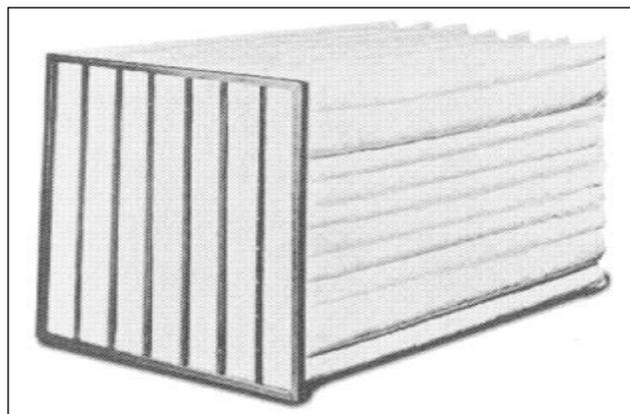
Source: Janis and Tao, 2009, p.171

Figure III.E-40 HEPA filters in a rack



Source: Janis and Tao, 2009, p.171

Figure III.E-41 Medium efficiency, extended surface bag filter



Source: Janis and Tao, 2009, p.171

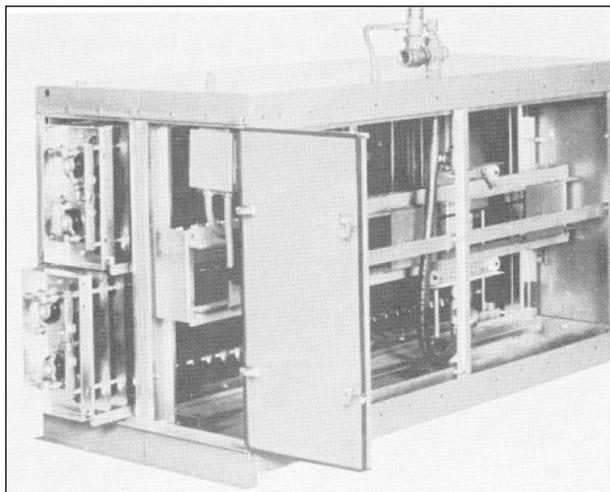
Ask the following questions: Are the filters accessible and properly serviced? Do the filters fit the openings? Are they sealed and installed properly?

- Check to see if a filter is present or missing, dirty, installed backwards, the wrong size, loose, collapsed or wet²¹. If a filter was installed backwards, explain the issue to the client and recommend having the filter cleaned or replaced, being careful to properly install the new filter. Do not continue to use a filter that was installed backwards because all the trapped dirt will be released into the furnace (CDA, 2005a).
- If the filter does not fit the openings, this can increase air velocity around and across the filters, which, in turn, can increase the static pressures. Check to make sure that the filter is appropriate for the HVAC system. Check to see if the filter frames have proper gaskets or are caulked.

Recommend inspection, regular replacement and removal of used filters from the conditioned space or mechanical room to avoid re-occurrence of odour (Burrows and Hansen, 2004).

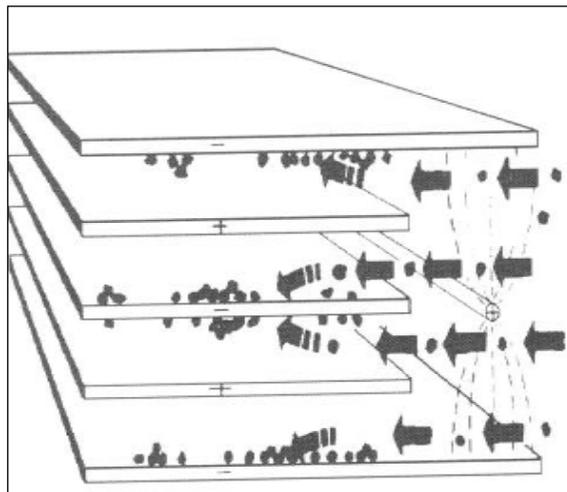
Appendix A1 Chemical factors: gases provide an overview of filter applications for the various buildings and applications.

Figure III.E-42 Electrostatic filter that is used in a commercial facility



Source: Janis and Tao, 2009, p.172

Figure III.E-43 Principle of electrostatic filter operation



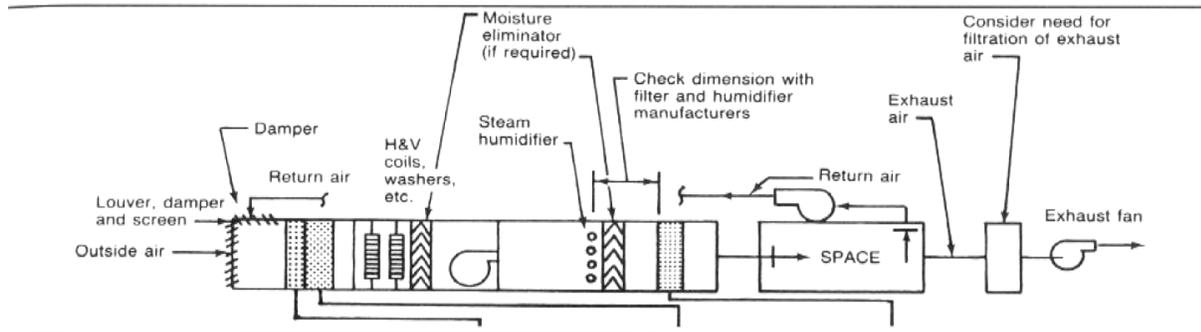
Dust and fumes are positively charged at 14,000 V, then enter a second electric field where they are attracted to the collector plates

Source: Janis and Tao, 2009, 172

²¹ Filters, already contaminated with organic materials, when wet may serve as reservoirs for microorganisms when wet

Figure E Application of air filters in air-handling systems

Source: Janis and Tao, 2009, p.173



Application	System Designator ^a	Prefilter	Prefilter 2/Filter	Final Filter	Application Notes		
Warehouse, storage, shop, and process areas, mechanical equipment rooms, electrical control rooms, protection for heating and cooling coils	A1	None	None	50 to 85% arrestance	Panel type or automatic roll	None	Reduce settling of larger particles. Protect coils from dirt and lint.
	A2	None	None	25 to 30% dust spot	Pleated panel or extended surface	None	
Special process areas, electrical shops, paint shops, average general offices, and laboratories	B1	None	None	75 to 90% arrestance, 35 to 60% dust spot	Extended surface, cartridge, bag type, or electronic (manually cleaned or replaceable medium)	None	Average house-cleaning. Reduces lint in airstream. Reduces ragweed pollen >85% at 35%. Removes all pollens at 60%, somewhat effective on particles causing smudge and stain.
Analytical laboratories, electronics shops, drafting areas, conference rooms, above-average general offices	C1	75 to 85% arrestance, 25 to 40% dust spot	Extended surface, cartridge, or bag type	>98% arrestance, 80 to 85% dust spot	Bag type, cartridge, or electronic (semiautomatic cleaning)	None	Above-average housecleaning. No settling particles of dust. Cartridge and bag types very effective on particles causing smudge and stain, partially effective on tobacco smoke. Electronic types quite effective on smoke.
	C2	None	None	>98% arrestance, 80 to 85% dust spot	Electronic (agglomerator) with bag or cartridge section	None	
Hospitals, pharmaceutical R&D and manufacturing (nonaseptic areas only), some clean ("gray") rooms	D1	75 to 85% arrestance, 25 to 40% dust spot	Extended surface, cartridge, or bag type	>98% arrestance, 80 to 85% dust spot	Bag type, cartridge, electronic (semiautomatic cleaning)	95% DOP disposable cell	Excellent house-cleaning. Very effective on particles causing smudge and stain, smoke and fumes. Highly effective on bacteria.
	D2	None	None	>98% arrestance, 80 to 95% dust spot	Electronic (agglomerator) with bag or cartridge section	None	
Aseptic areas in hospital and pharmaceutical R&D and manufacturing. Cleaning rooms in film and electronics manufacturing, radioactive areas, etc. ^b	E1	75 to 85% arrestance, 25 to 40% dust spot	Extended surface, cartridge, or bag type	>98% arrestance, 80 to 85% dust spot	Bag type, cartridge, electronic (semiautomatic cleaning)	≥99.97% DOP disposable cell	Protects against bacteria, radioactive dusts, toxic dusts, smoke, and fumes.

^aSystem designators have no significance other than their use in this table.

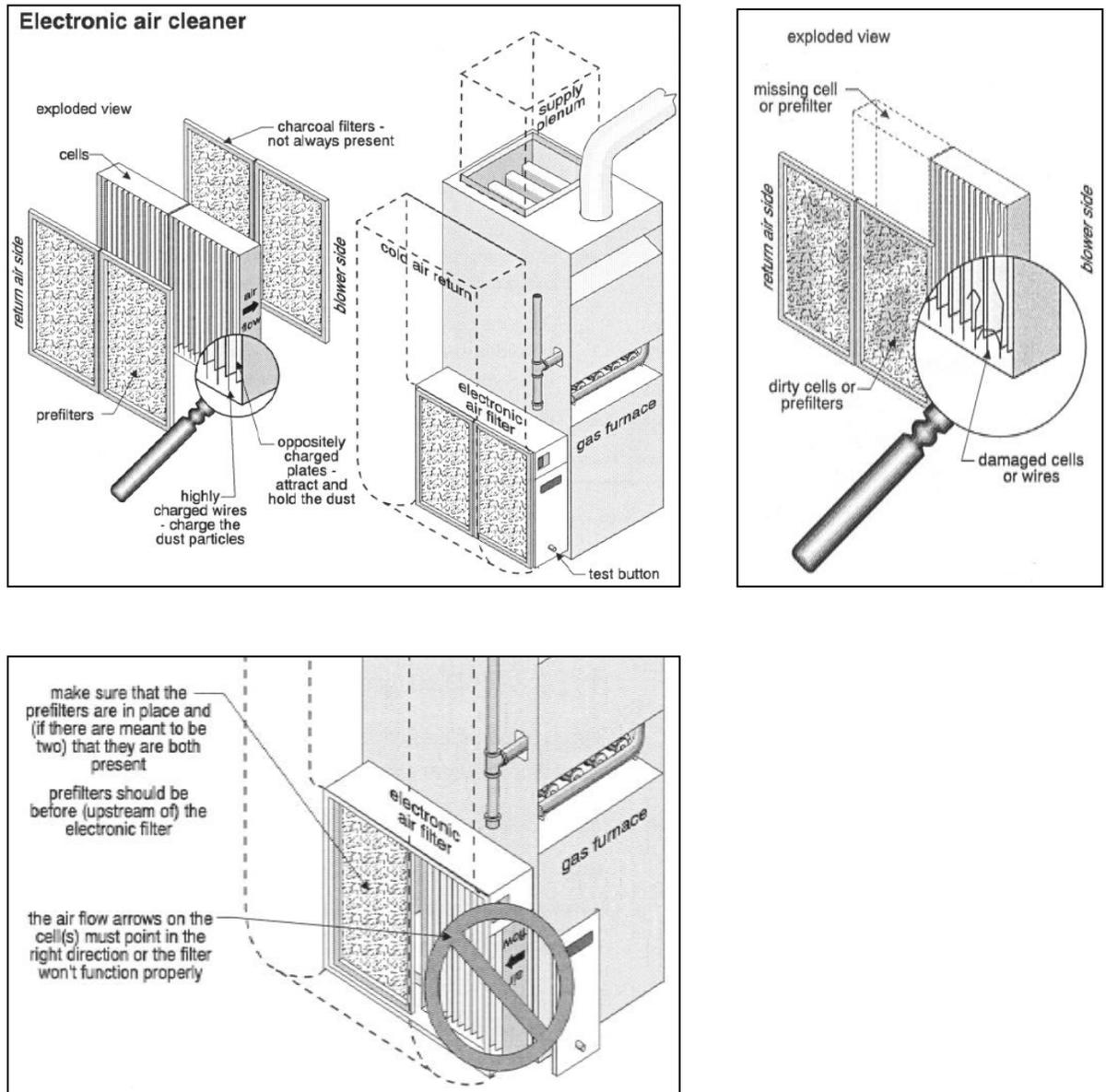
^bElectronic agglomerators and air cleaners are not usually recommended for clean room applications.

Source: Reprinted by permission from ASHRAE (www.ashrae.org).

6. Electronic air filters

These air filters are more efficient than a conventional mechanical filter. These units operate with an electrostatic charge which attracts dust particles to the plate because of the particles' opposite charge. These filters need to be cleaned often because they collect more dirt than mechanical filters.

Figure III.E-44 Electronic air cleaner used in a residential building



Source: CDA, 2005a, p.171, 173, & 174

Problems that may be encountered with electronic cleaners include dirt build-up, missing components, damaged cells, inoperative unit, improper orientation and improper wiring. Electronic air cleaners (Figure III.E-44) should not be energized when the furnace fan is not pulling air through the furnace. Look for the indicator

light on the air cleaner cabinet. If the furnace fan is operating, then the power light should be on; otherwise, the power light should be off.

There are two ways to test whether the air cleaner is working:

- Tap the duct just upstream of the air filter. This will dislodge dust from the duct walls and into the air stream. You should be able to hear cracking and popping sound.
- Use the test button located on the air cleaner to generate the crackling or popping sound (CDA, 2005a).

7. Insulation in ductwork

Check to see if the material is wet. Porous insulation inside the air handling and fan coil ventilation equipment may provide substrate for microbial growth if the material is damp. Insulation within ductwork, if found, should be covered. There should be no exposed insulation inside the duct work.

8. Return air grills and supply air diffusers

The supply air ducts can be examined by lifting the floor diffuser and using an inspection mirror and flashlight to look down the length of the duct. We do not expect the ducts be clean, but excessively dirty ducts are not acceptable. Also, ducts directly below floor diffusers should not be used to assess the duct, because floor debris easily falls into this area. The occupant could be required to clean the area below the floor diffuser if dirty, as it is caused by the activities of the occupant in that space.

9. Humidifiers

A water humidifier serves two purposes: improving IAQ quality and maintaining comfort levels. Regarding IAQ, humidifiers scrub organic dusts from the air stream. It should be noted that the use of water, i.e., sprayed or steamed, provides an opportunity for microorganisms to amplify on the wet surfaces in the HVAC system. For example, steam humidifiers may create condensed water in the duct work (Burroughs and Hansen, 2004). With respect to maintaining comfort levels, the purpose is to bring humidity levels up to acceptable indoor standards.

In residential homes, there are several types of humidifiers.

- **Tray with evaporative pad**

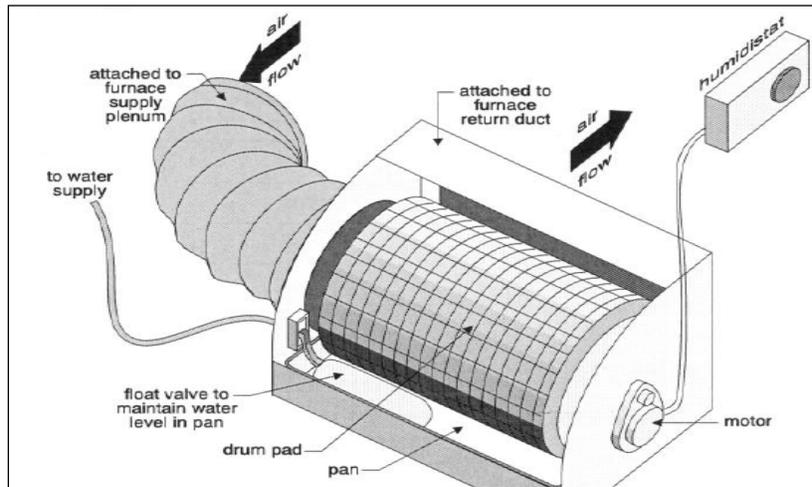
The least expensive ones consist of a tray with evaporative pads. According to CDA (2005a), some of these units are designed so that the tray sits inside the plenum; that is, directly over the heat exchanger. On other units, the tray may sit outside the plenum beside the furnace. These units tend to leak and drip onto the heat exchanger and eventually cause premature rusting of the heat exchanger and furnace failure.

- **Drum humidifiers**

A drum humidifier, the most common type of humidifier, runs on a small motor that turns a foam or fabric mesh-covered drum through a tray of water. A float valve maintained the water level in the tray. A tube is connected to the water supply plumbing pipe. A humidistat is usually mounted beside a thermostat or on

the return duct close to the humidifier. Drains or overflows may be present on the device to protect the furnace from damage because of water leakage. This humidifier is usually mounted on the return air plenum of the furnace with a bypass duct to the supply plenum (CDA, 2005a).

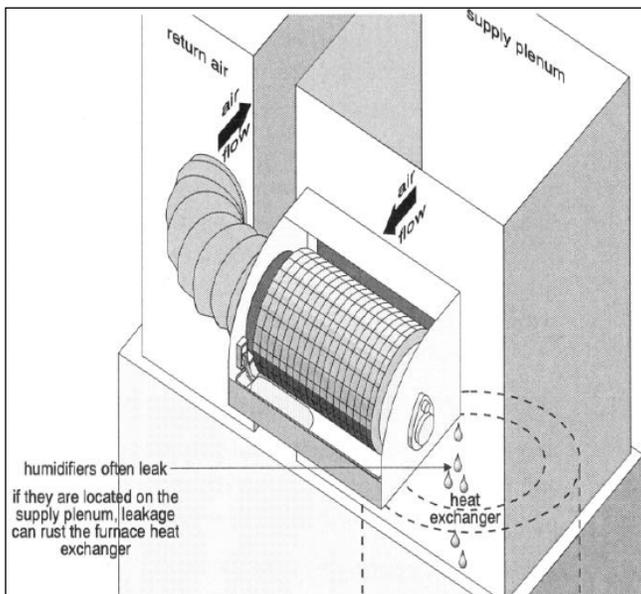
Figure II.E-46 Example of a drum type humidifier



Source: CDA, 2005a, p.182

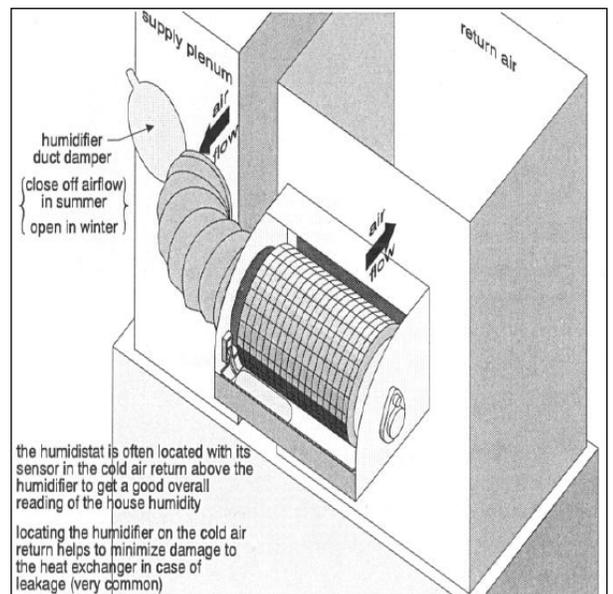
Er

Figure III.E-47 Drum humidifier above heat exchanger



Source: CDA, 2005a p. 178

Figure III.E-48 Air flow through a drum humidifier



Source: CDA, 2005a p. 180

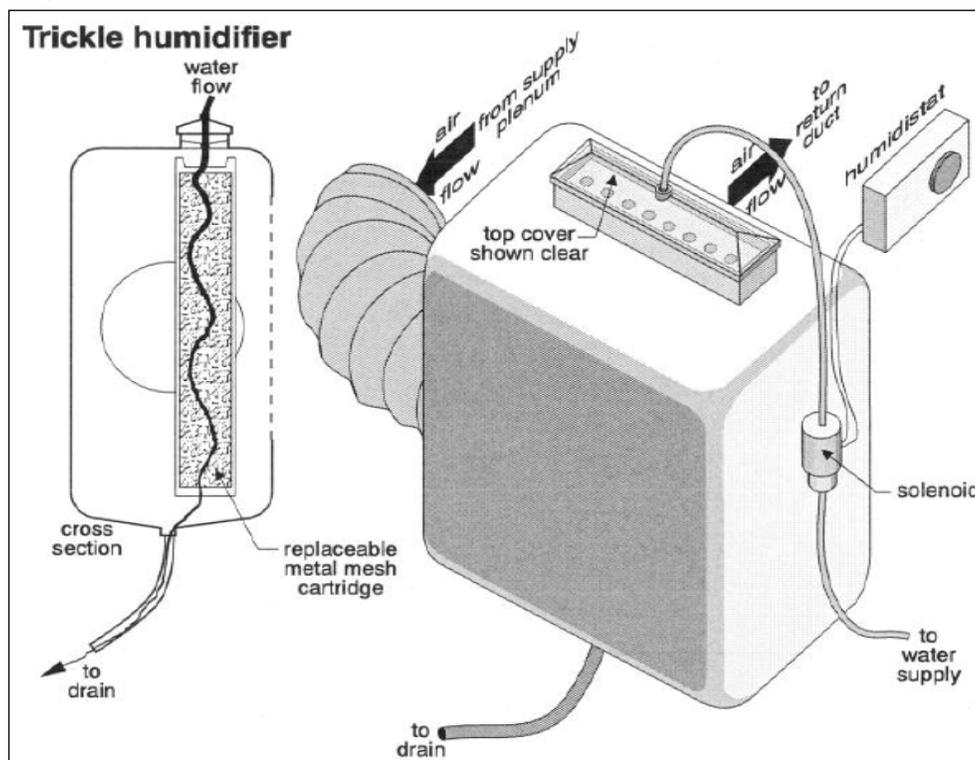
- **Spray humidifiers**

These humidifiers use a series of nozzles and a pump to generate and introduce a mist or steam²² into the air stream. These humidifiers require drains to carry away excess water.

- **Trickle humidifiers**

Trickle humidifiers (Figure III.E-49) use a solenoid valve to control water flow through an expanded metal mesh. As the water trickles down the mesh, it evaporates into the air. This type of device is more reliable than the other humidifiers (CDA, 2005a).

Figure III.E-49 Trickle humidifier



Source: Kardon, Hansen and Casey, 2007, p.134

- **Flow-through humidifiers**

In flow-through humidifier, the water is released at the top of a humidifier bed where air passes through. Water is then collected at the bottom in a tray and discharged to the sanitary system. There are no reservoirs for biological problems but the bed itself can be a problem.

The problems that are related to the drum-type and trickle humidifiers include:

- ▶ Lack of duct damper
- ▶ Water leakage

²² Some spray humidifiers use heating coils to generate steam.

- ▶ Clogged pads, mesh or nozzle
- ▶ Inoperative motor, solenoid valve, or pump
- ▶ Dirt and scale build-up
- ▶ Poor installation location

Maintenance requirements to mitigate biological contamination of humidification systems include (CDA, 2005a):

- ▶ Overflow drain lines are free-flowing and clear of debris, scale, or algae build-up
- ▶ Downstream duct insulation is dry. But if the duct insulation is wet, then recommend replacing the duct insulation
- ▶ Humidifier sprays, grids and pans are free of scale build-up and are not plugged. If you observe deficiencies, recommend regular monitoring and maintenance, such as emptying and cleaning the pans when the humidifier is not operating

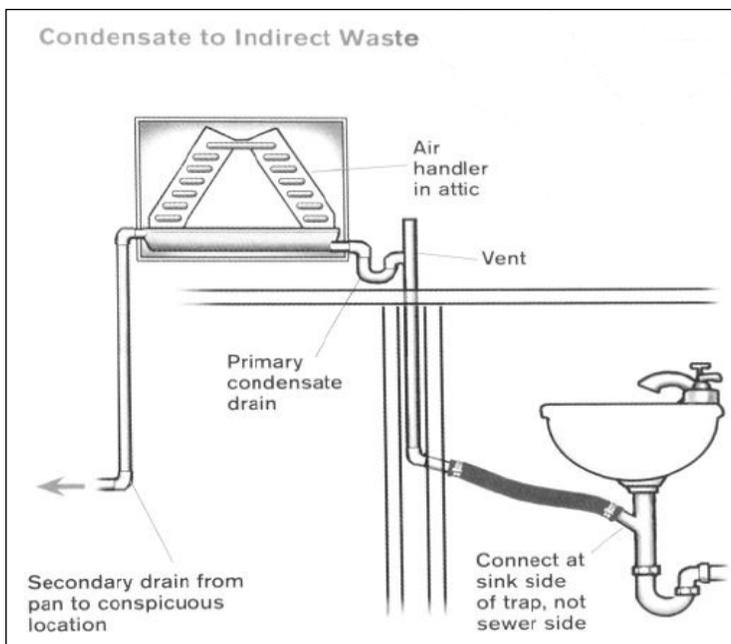
10. Condensate Lines

Can you follow the condensate lines? Where do they discharge? Is there a neutralizer? (see Figure III.E-50).

Check to see if there are stagnant water build up in the drain pans.

Is there water in the “P-trap?” Often, with air-handler units that are installed in the ceiling space, the water in that P-trap may have evaporated or dried up, allowing bad-smelling gas to enter and disperse within the localized indoor environment.

Figure III.E-50 Condensate line & p-trap for an above ceiling air handler unit

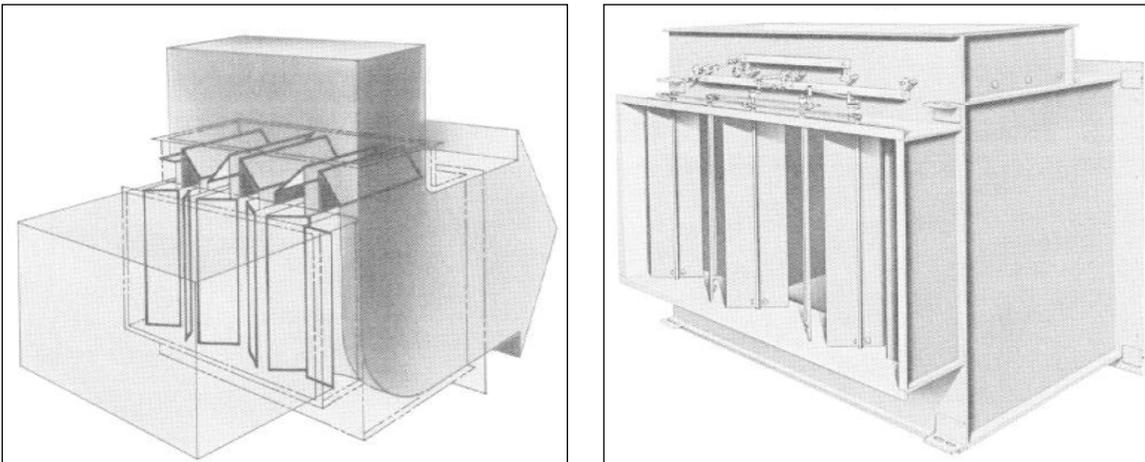


Source: Kardon, Hansen and Casey, 2007, p.134

11. Mixing Plenum

- During an inspection, do the following:
 - ▶ Look for any dirt, dust, or debris build-up in the mixing plenum. Recommend cleaning the mixing plenum as needed.
 - ▶ Look for any signs of moisture or standing water that may be present in the plenum. Trace the source. Recommend the necessary mitigation actions or controls, such as sealing the plenum against any leakage to solve that problem.
 - ▶ Verify that the dampers are operative. Recommend servicing or repair, if necessary.
 - ▶ Verify that the outdoor air is reaching the plenum. Clear the air intake if warranted.

Figure III.E-51 Typical air-mixing box in a commercial building



Source: Janis and Tao, 2009, p.174

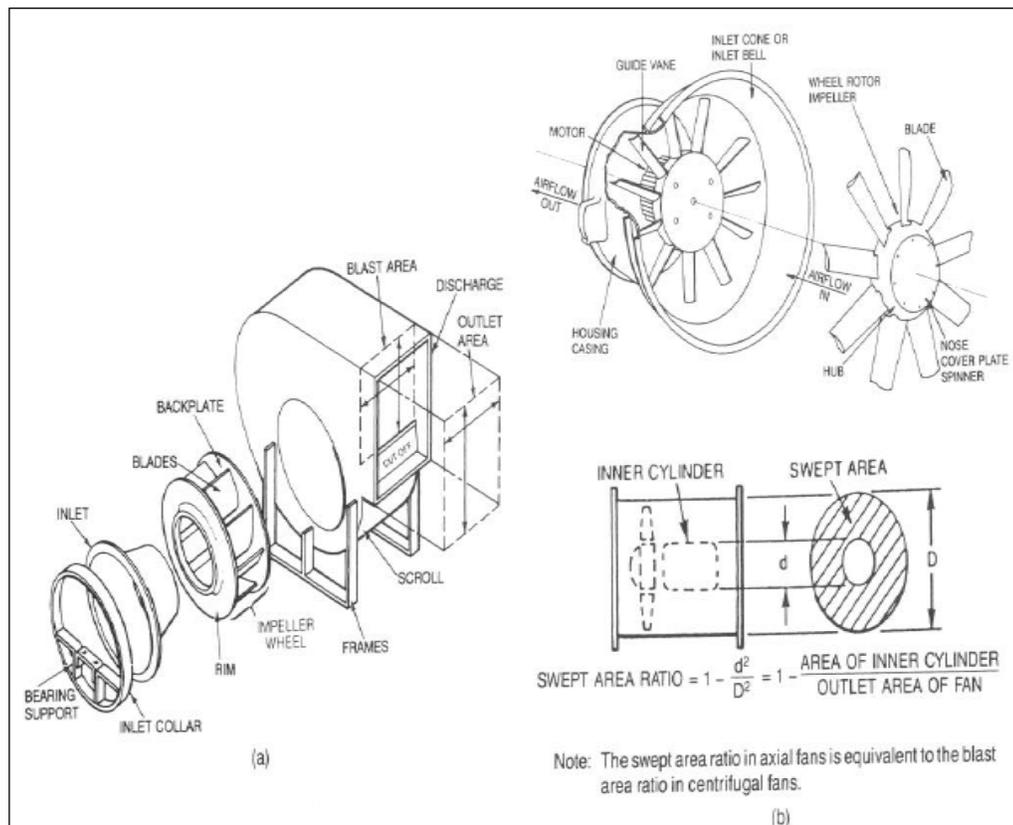
12. Fans

IAQ in the building is dependent on the fan moving air through the system. Fans will not work as effectively or run at their normal speed if the fan blades are dirty or belts are worn or stretched (Burrows and Hansen, 2004). When the static pressure and air flow are reduced, the air may not reach the areas at the end of the line. Therefore, do not receive sufficient air exchange. See Figure III.E-52 to see the components and construction of a fan.

Fan concerns and recommendations:

- If the blades or compartment are dirty, recommend that the blades and compartment be cleaned on a regular basis, such as annually.
- When inspecting the fan, first make sure that the power is shut off. Look for cracks, signs of wear and damage to the belt. Any obvious damage or wear to the belt, including a slipping or misaligned belt, should be reported for servicing

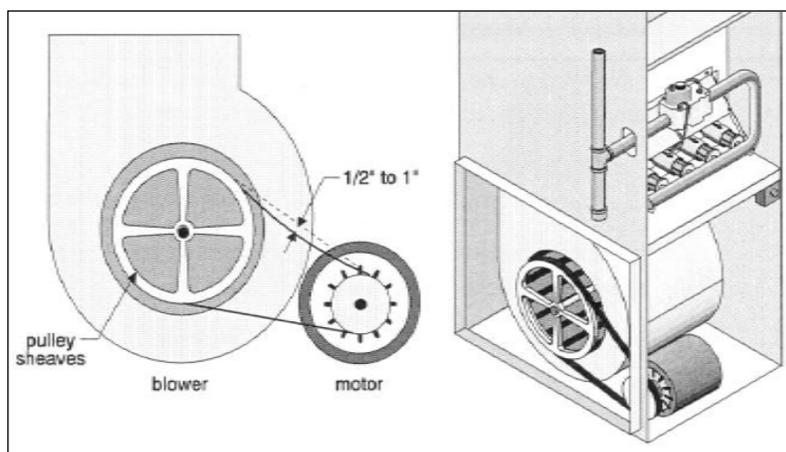
Figure III-E-52 Typical construction and components of fans



Source: Janis and Tao, 2009, p.176

- Verify that the belt tension is appropriate (see Figure III.E-53). It is recommended that fan-belt tension be assessed by a professional. You should be able to push the belt in about half an inch to an inch; that is, at the halfway point between the pulleys, depending on the fan unit. If the fan belt is too loose, it will slip. This slippage will be accompanied by a squealing noise.

Figure III.E-53 Gas furnace fan belts



Source: CDA, 2005a, p.167

- A fan belt may slip if the pulley flanges are loose or misaligned; this can be corrected by adjusting the sheaves of the pulley. On the other hand, if the belt is too tight, the bearings may wear excessively and the motor may overheat. Recommend adjusting belt tension the belt as needed. Proper adjustment of the belt is important (CDA, 2005a; Burrows and Hansen, 2004).
- As the HRV system ages, failure of the supply side fan motor has been identified as one of the most common components that are likely to fail. This could lead to increased problems with back-drafting of combustion equipment. Regular seasonal servicing of the HRV system would reduce the average length of time before this deficiency is identified and resolved (CMHC, 1998).
- Check to see if the furnace fan is operating. If the fan is not operating, the mechanical provision of fresh air to living areas will be inadequate.

13. Dampers

Dampers are located throughout the ventilation system including outdoor and return air systems, and bypass ducts.

As mentioned before, dampers affect the air intake and the amount of air recirculated and exhausted. Therefore, when the dampers are loose or not opening, the air flow is not controlled. This can create the following effects (Burrows and Hansen, 2004):

- Indoor air temperature have unacceptable temperature swings
- Either too little or too much fresh air will result in unsatisfactory indoor air quality,
- Damper linkages will need servicing or repair

14. Heating and cooling coils

Heating coils warm the air to assure comfortable conditions for the building's occupants. Control problems may be the result of:

- Coil design
- Dirt build-up on the coil
- Malfunctioning heating valve
- Faulty or poorly adjusted control system

Cooling coils cool and humidify the air supply. Cooling coil must be drained properly to avoid and mitigate biological growth. Non-porous surfaces where moisture collection has promoted microbial growth and should be cleaned and disinfected²³.

If it is possible to observe heating or cooling coils during an inspection of the heating or cooling coils, make sure that:

- The coils (fins) are clean.

²³ Care should be taken to ensure that surfaces are clean and dry before activating air handling units.

- Condensate drains and drain pans are clean and operating without standing water (Burrows and Hansen).

For other heating coil problems, consider the following:

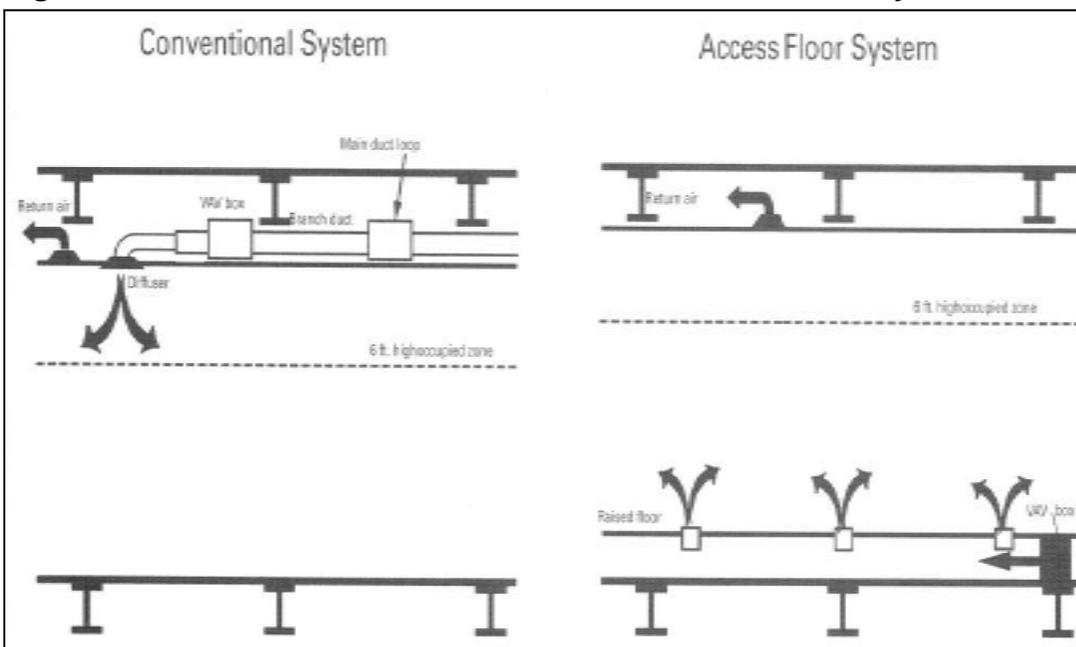
- Heating -oil discharge temperature is too high or too low, which may mean that there is a problem with the temperature control system
- Air is still being heated despite the water or steam being closed, which could mean that the valve is not closing tightly. In that case, recommend servicing by a qualified HVAC operator (Burrows and Hansen, 2004).

15. Air flow patterns

There are two ways that air is delivered into the occupied zone: overhead distribution or access-floor system (see Figure III.E54).

Note: The upward movement of air has the advantage of carrying indoor air pollutants including odours and small particulate matter directly to the exhaust duct rather than allowing them to mix in the overall space.

Figure III.E-54 Ductworks – overhead versus floor distribution systems



Source: Janis and Tao, 2009, p.193

16. Ductwork

(Figures III.E.55, III-E.56 and III.E-57)

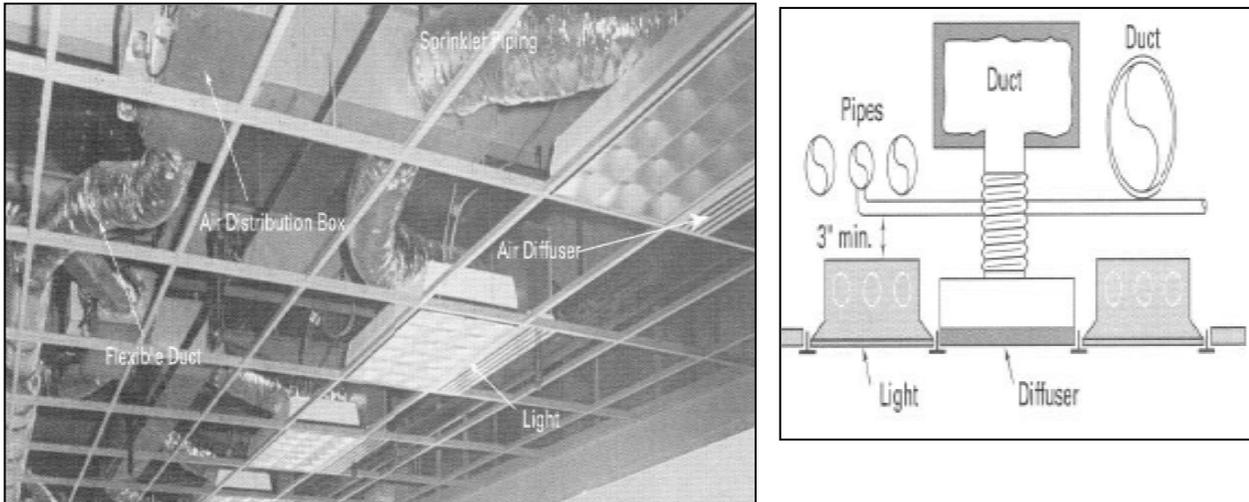
Poorly maintained ductwork can add pollution. With that in mind, do the following:

- Look for any dirt, dust or debris build-up in the ductwork. Recommend cleaning the ductwork, if needed. According to Burrows and Hansen (2004), the “cleaning of duct work, whether lined or not, is a difficult task, and may have dubious value, or in some cases negative impact....” Systems should be carefully evaluated before assuming that duct cleaning will automatically increase air

quality. Further, dirty air conveyance systems are usually a symptom of dirty supply air.

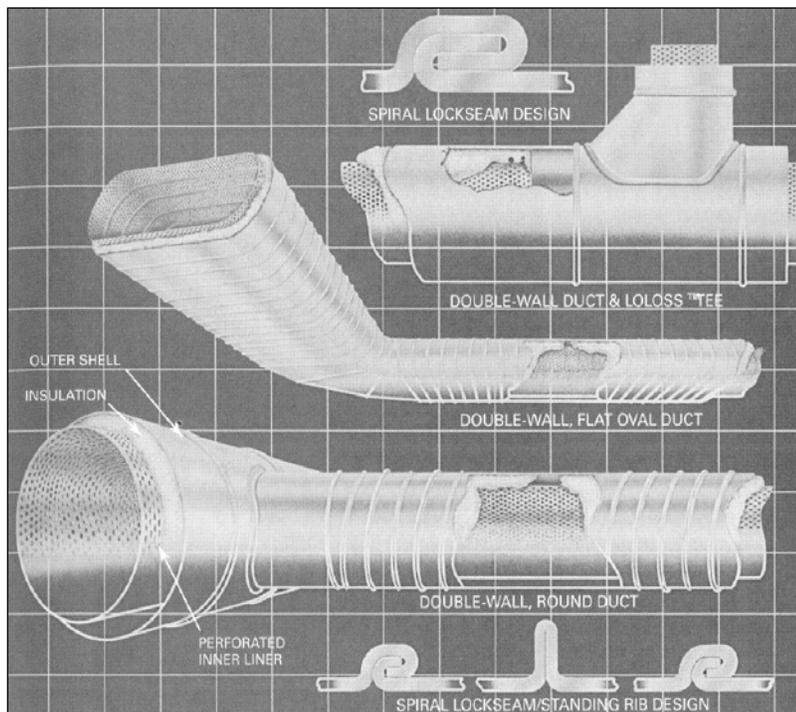
Therefore, cleaning should not be undertaken without an understanding of and remedial action regarding the root cause of the condition. Both NAIMA and EPA urge caution when determining the need and selecting contractors to perform that work.

Figure III.E-55 Components including ductwork in the ceiling space



Source: Janis and Tao, 2009, p.185

Figure III.E-56 Double-wall flat and round ducts.

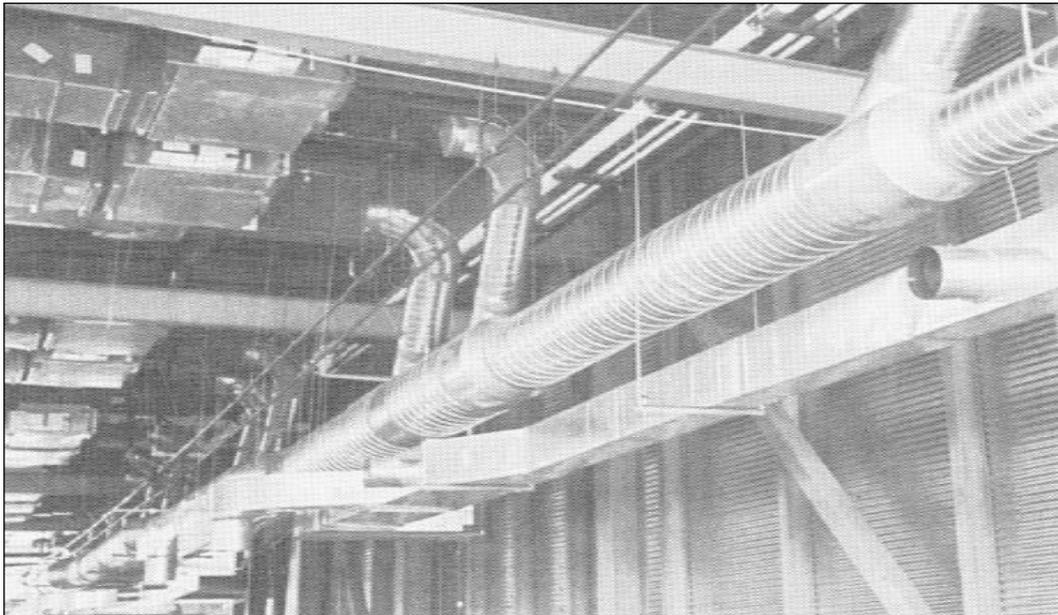


The perforated inside duct is separated from the outside duct by an acoustic insulation material

Source: Janis and Tao, 2009, p.183

- Look for any signs of moisture or standing water that may be present in the ductwork. If there are signs of moisture or standing water, trace the moisture source. Burrows and Hansen (2004) also made the following additional recommendations:
 - ▶ Repair areas where water where has collected or leaked.
 - ▶ Maintain relative humidity below 60 per cent (average) in all occupied spaces and low velocity air plenums.
 - ▶ Once contamination has occurred through dust or dirt accumulation, or moisture-related problems downstream of the heat exchange components, consider if additional filtration downstream is necessary before air is introduced into occupied areas²⁴.
 - ▶ Clean and disinfect²⁵ non-porous surfaces where moisture collection has promoted microbial growth.
 - ▶ Look for any pinched or collapsed flexible ducting.
- Look for collapsed interior liner. Collapsed interior liner will hinder or suppress air flow from the supply side of that ductwork.

Figure III.E-57 Assembly of high-pressure or velocity round ducts and low-pressure rectangular ducts



Source: Janis and Tao, 2009, p.182

²⁴ Referral to a qualified HVAC specialist is recommended at this point.

²⁵ Care should be taken to ensure that surfaces are clean and dry before reactivating air handling units.

17. Terminal boxes and diffusers

Dust plays or accumulation near the diffusers may not be from upstream ductwork. That build-up may be because of charged particles in the room. Look for any obstructions at the terminal boxes and diffusers. If the units are jammed, air flow is restricted. Recommend cleaning the terminal boxes and diffusers. If the room is perennially not warm enough on a dual duct system, leakage may be occurring. Refer the building owner to a qualified HVAC specialist.

18. Heating Plants

External heating plants produce combustion contaminants because of incomplete combustion. The level of the contamination generated is dependent on the:

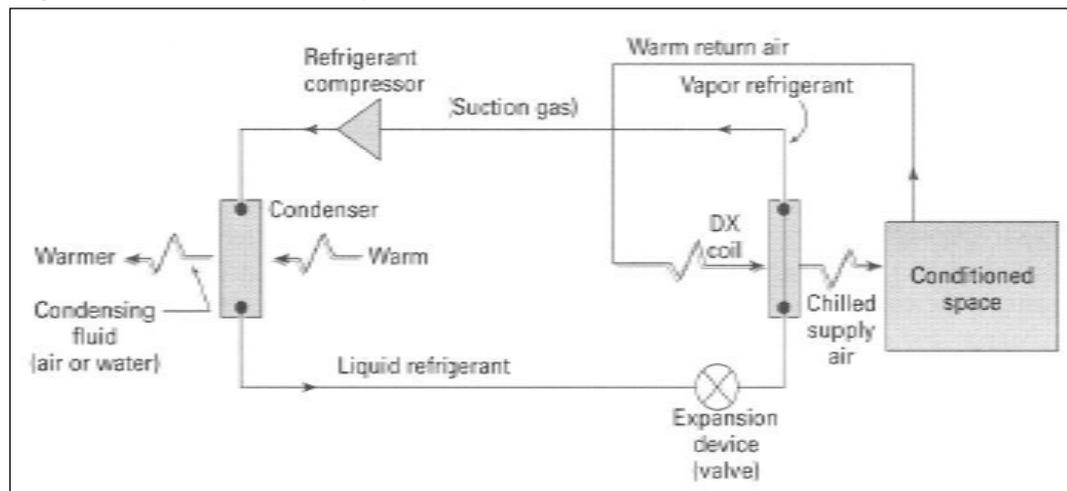
- Combustion characteristics of the burners and furnace
- Type of fuel used
- Burner operating mode (Burrows and Hansen, 2004)

Boiler stack emissions may enter the building through intake cross contamination. Burrows and Hansen (2004) offered the following recommendations:

- Check heating plants in the fall and during the heating season
- Seal cracks

Check burner settings and make sure burner parts have not deteriorated to avoid high CO (g) emissions

Figure III.E-58 Basic DX system components



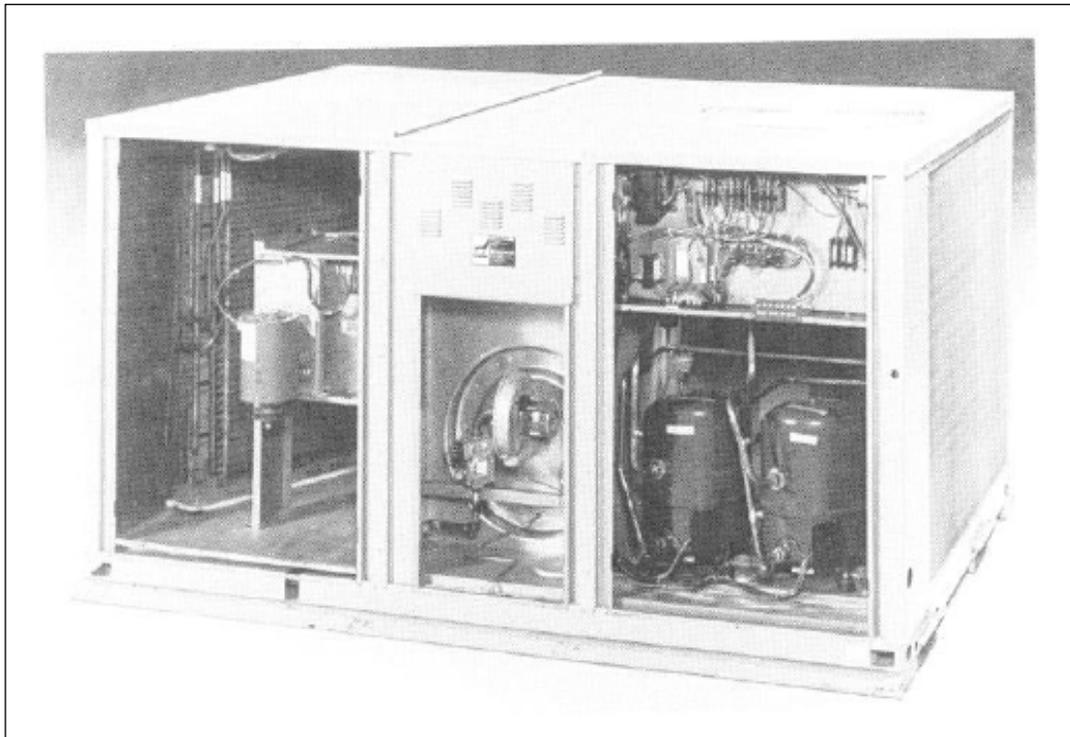
Source: Janis and Tao, 2009, p.113

19. Roof-top AHUs

The components of the roof-top AHU can be any combination of the various systems described earlier in this chapter, as such the inspection specifics will be similar to those already noted. However, to inspect a roof-top AHU, the inspector must gain access to the roof-top of the building and access to the AHU components through access panels. There is one major difference with inspecting roof-top AHUs: the surrounding outdoor environment provided a greater influence on IAQ.

There are added concerns with the outdoor environment of such units. They are much more easily accessed by pigeons, seagulls or bats, seeking crevices that provide harbourages. There is also a greater potential for water to pool near the intakes of the unit, providing reservoirs for biological contamination.

Figure III.E-59 Typical roof-top model of an air-cooled cooling and heating unit consisting of all indoor and outdoor components



Source: Janis and Tao, 2009, p.124

20. Mechanical rooms

Mechanical rooms provide a central location for conditioning and delivering air to occupied spaces throughout a building. Figure III.E-22 provides an example layout of a penthouse mechanical room. To inspect ventilation and air conditioning equipment within the AHU, the PHI or EHO will need to gain access to the inside the AHU through hatches. An assessment of the configuration of supply and return air ducts on the outside of the AHU will also facilitate an understanding of operation.

Once inside the AHU, inspectors can assess the condition and cleanliness of the interior, air filters and heating and cooling exchangers. The configuration of return air, exhaust air and outdoor air intake louvres can be assessed for an estimation of whether excessive amounts of return air are being recycled into the system. Louvre configurations that suggest insufficient outdoor air is being brought in or excess amounts of return air are being recycled, may also suggest that the building code requirement for the minimum supply of outdoor air is not being satisfied. Such a condition may generate occupant complaints of stale and stuffy air, headaches and fatigue because of the excessive recycling of polluted indoor air. Carbon dioxide monitoring in occupants spaces can be used to provide evidence or support of the hypothesis of insufficient outdoor air being delivered to occupant spaces. Some mechanical rooms are furnished with carbon dioxide sensors in supply, return air and exhaust air to ensure the adequate delivery of outdoor air, which the inspector can read on displays. The inspectors can request access to operation, maintenance and repair records, such as the filter replacement cycle.

21. Unit heaters

As mentioned previously, these units are self-contained small heating units that have an influence on a local area only. There will be some form of heater (one of the various heating technologies already discussed) and a delivery system. The delivery can either be passive (radiative) or active (fan-driven). The inspection techniques for these units will be similar to those above; however, the unit will be much smaller and will have a limited area of influence. These units are usually ceiling-mounted, so a ladder will most likely be needed to conduit an inspection.

III.E.7 Microbiological agents & activity

According to Burton (1995), four conditions must be met for microbiological agents to be a realistic problem:

1. Reservoir – There must be a reservoir or suitable environment; such as standing water in a cooling drain pan, or in the ductwork itself.
2. Nourishment source – There must be a source of nourishment, such as organic dirt in the cooling drain pan, filter or ductwork.
3. Amplification – There must opportunity for the microorganisms to grow.
4. Pathway – There must be a pathway for the aerosolized micro-organisms to reach the human receptors, perhaps through water dripping off the cooling coil onto the ductwork.

If microbial agents are suspected, look for stagnant water in the ventilation system. The visual presence of mould and slime confirms that microbes are a problem.

Microbiological contamination may be result from (Burton, 1995):

- Contaminated cooling coils, humidifiers and air washers
- High velocity air passing through contaminated wet cooling coils
- Use of porous fibre insulation inside air handling and fan coil ventilation equipment
- Contaminated sound liners in supply ductwork
- Stagnant water in drain pans
- Excess humidity, typically greater than 70 per cent
- Build-up and recirculation of human shed bacteria and viruses
- Transfer of virus and bacteria on human-origin aerosols via coughing or sneezing
- Use of cool water room humidifiers
- Condensation runoff from windows into unit ventilators
- Flooding of any type in the building
- Water breach through the building envelope
- Locating outdoor air intakes near external bioaerosols sources, such as garbage dumpsters and cooling towers
- Inadequate preventative maintenance. The visible presence of fungi on the surfaces of mouldy ceiling tiles, humidifiers, diffusers and air supply ducts requires investigation and remedial action regardless of the airborne spore load (Health Canada, 1995).

III.F Conclusion

In IAQ investigations, once the type, extent and locations of symptoms have been established, determining the cause is a step-by-step process (McDermott, 2001), i.e., one that may involve:

- Obtain sufficient information about the building's HVAC system including its components, layout, and function
- Inspect the system may require a review of its controls, damper operation, and cleanliness of the system internal components
- Carryout air sampling to measure the levels of contaminants that may be involved
- Verify that ventilation air flow and, if appropriate, infiltration exchange rates , air motion, temperature and relative humidity are within acceptable criteria
- Involve a medical practitioner if the symptoms and conditions warrant it

Chapter IV

Management of indoor air quality investigations

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IV. Management of indoor air quality investigations

IV.A. Introduction

For public health inspectors, the goal of indoor air quality (IAQ) investigations is to obtain sufficient information to identify, evaluate, and control or manage IAQ problems. The most effective approach for IAQ control is to prevent a problem from occurring. Therefore, a proactive approach is ideal for controlling and managing indoor air quality in buildings. In this chapter, different IAQ control strategies and management principles shall be briefly discussed.

IV.A.1 IAQ control approach

Ideally, the following two goals of indoor environmental control should be met:

- Prevent or minimize toxic exposures
- Provide for occupant comfort and well-being

Building design and management principles should be applied throughout each of the four stages of a building's lifecycle:

- Design phase
- Construction phase
- Long-term occupancy
- Adaptive re-use and disposal

Given the fact that Environmental Public Health is not involved with the design, construction, adaptive re-use or disposal of a building, this chapter will only discuss the IAQ control and management concerns from a long-term occupancy perspective.

Generally, there are two basic strategies for controlling occupant exposure to indoor air contaminants:

- Source control; that is, eliminating occupant exposure to the contaminants
- Exposure control, that is, minimizing but not eliminating occupant exposures by methods of dilution or air cleaning (IOM, 1993)

IV.B. Source control

Source control as a risk management tool can be effective throughout a building's life cycle including design and construction phases, occupancy and adaptive re-use, and eventual demolition. This principle applies to both commercial and residential buildings.

In theory, source control is easier than other IAQ methods because contaminants are controlled before they are distributed into the general air of the building. Some of the factors that influence source control methods are the physical and chemical characteristics of the contaminants, and nature of the contamination in the indoor environment. Therefore, efforts to prevent or mitigate IAQ problems should include the identification and control of pollutant sources. The following control measures can be used at the source (Godish, 2000)

- **Source elimination**

The most effective and only method of indoor air contaminant control at the source should be to completely eliminate the source of the contamination.

- Example 1: A painter is undertaking painting activities in a strip mall. Several business owners from that area are complaining of headaches and other health problems. The painting activities can be stopped and the painter can be removed from that area. However, in reality, complete elimination can be very challenging. In these cases, source reduction may be a more appropriate tool.
- Example 2: During a housing inspection that was prompted by a "mould housing" complaint from the tenant. Specifically, mould was observed on the ceilings in the kitchen, dining room, washroom and hallway. In addition, there was evidence of water stains on one section of the wall in the hallway. An inspection of the roof revealed not only 16 tires on the rooftop but also past and present attempts to seal the seams between the metal sheets on the roof. In this case, the source of the roof leak needs to be resolved first, and then the mould-contaminated areas, such as interior walls and ceilings, need to be cleaned or, if necessary, replaced.
- Example 3: Prohibit smoking indoors or limit smoking to areas from which air can be exhausted and not recirculated throughout the building.

- **Source substitution**

This refers to measures or management approaches that prevent or exclude the use of contaminant-producing processes, materials, furnishings and equipment in indoor settings. Alternative technologies, processes or materials can be used to effectively manage IAQ problems using source substitution.

- Example 4: Materials that emit significant levels of formaldehyde can be replaced with formaldehyde-free products. Building materials, such as particleboard flooring, MDF and pressed wood cabinets, can be removed and replaced with solid wood materials.

- **Source modification**

An indoor contaminant source can be treated to prevent or eliminate contaminant releases.

- Example 5: If there is asbestos present in a building, this man-made mineral fibre should be enclosed or sealed so as to prevent exposure.

- **Source reduction**

By reducing the concentrations of hazardous substances at the source, the PHO can minimize the production or release of these substances into the air. Therefore, source reduction can effectively reduce public health risks and assure people of a healthier environment and community (NACCHO, 1995). Emissions from indoor sources can be minimized or reduced by applying coatings or sealers that act as a diffusion barrier.

- Example 6: In an office environment, the use of printers or photocopier machines is associated with the release of different VOCs into indoor air. Emissions can be minimized by selecting low-emission equipment or servicing existing equipment, however, printers and photocopiers, vital for office work, cannot be removed. Therefore, if possible, it may be better to relocate contaminant-producing equipment to unoccupied, better ventilated or exhaust-only ventilated spaces.

For additional information on contaminant specific control measures, refer to *Chapter III Investigation of indoor air quality* of the manual. Source control can be a cost effective approach to protecting indoor air quality. Refer to the ventilation section of this chapter (IV.B.1) for a brief description about ventilation as an IAQ control strategy.

IV.B.1 Ventilation

Industrial ventilation including local exhaust generally involves the use of supply and exhaust ventilation to control emissions, exposures and chemical hazards in industrial workplaces. However, in commercial and residential premises, general ventilation (non-industrial) systems, commonly known as heating, ventilating and air-conditioning (HVAC) systems are used to control temperature, humidity and odours for the comfort of occupants (OHSA, 1999b).

IV.B.1.1 Ventilation & IAQ issues

It should be reinstated that inadequate or improper ventilation is the cause of about half of all IAQ problems¹ (see Figure IV.B-1 and Table IV.B-1) (OSHA, 1999a; IOM, 1993). The physical causes that are usually associated with problem buildings include (IOM, 1993):

- Design inadequacies including equipment problems
- Operational inadequacies, such as inappropriate control strategies, lack of maintenance and housekeeping, and ineffective load management of building systems

¹ The other contributors to IAQ problems include: (a) contamination from inside or outside the building; (b) microbial contamination; (c) contamination from the building fabric; and (d) other (including unknown) sources

This is illustrative of two of the most common problems (IOM, 1993)

- The complexity of the control system is not within the comprehension of the current building operators
- The implementation of overly aggressive energy-saving strategies has compromised the ability of the control strategies to provide acceptable indoor environmental quality.

Figure IV.B-1 Primary sources of IAQ problems

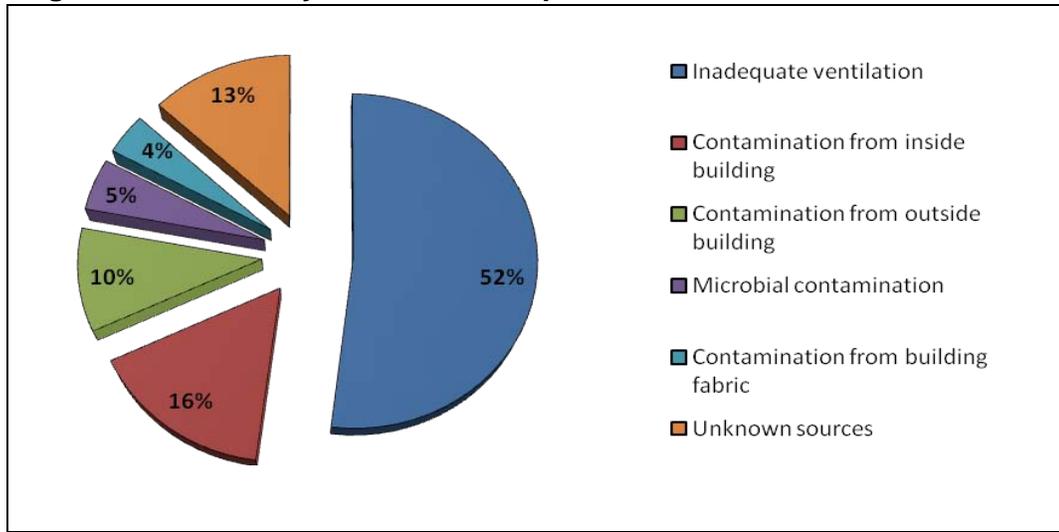


Table IV.B-1 Frequencies of occurrence of physical causes of problem buildings reported

Problem category	Physical causes	Frequencies of occurrence (%)
Design	• System problems	64 – 75
	• Inadequate outdoor air	46 – 75
	• Inadequate air distribution to occupied spaces (supply & return device)	
	• Equipment problems	57 – 65
	• Inadequate filtration of supply air	60 – 63
	• Inadequate drain lines and drain pans	38 – 45
	• Contaminated duct work or duct linings	16 – 20
Operations	• Malfunctioning humidifiers	
	• Inadequate control strategies	90
	• Inadequate maintenance	75
	• Thermal and contaminant load charges	60

Source: IOM, 1993

Indoor air contaminants can be transported by or originate from the ventilation system² through wet filters, wet insulation, wet undercoil pans, cooling towers or evaporative humidifiers. In addition, outside air for ventilation or makeup air for exhaust systems

² E.g., wet filters, wet insulation, wet undercoil pans, cooling towers, or evaporative humidifiers

may also bring contaminants into the building, such as emissions from a neighboring wood burning stove or vehicle exhaust.

In HVAC systems with old filters, the air used for room ventilation may pass through a filter ‘dust cake’, which, in essence, is a build-up of contaminants including human skin scales, fungal spores, pollen, tobacco smoke components and other atmospheric dust and debris. Filters that become moist or wet can become significant sites for micro-organism growth, especially, fungi³. Protecting filters from moisture and carefully and periodically replacing filters⁴ are key to controlling potential allergen emissions from filters in a HVAC system (IOM, 1993).

Dust and debris in supply-air duct systems can be expected to be most abundant near elbows and turning vanes, in addition to zones where air flow is restricted. That build-up can become significant “especially in HVAC system with inefficient filters, where filters do not fit properly in filter frames, or in poorly designed filter banks where significant volumes of air can bypass the filter bank (IOM, 1993)”.

IV.B.1.2 Ventilation - IAQ control strategy

A well-designed and properly maintained HVAC system will exclude most atmospheric aeroallergens, such as pollen and fungi, from interior spaces (see Table IV.B-2 and Table IV.B-3)⁵. In contrast, a poorly designed and maintained HVAC system may amplify or promote the growth of fungi and actinomycetes in wet niches of the system. Further, pollen and fungi may enter through the air conveyance system itself or through infiltration of the building envelope when the HVAC is improperly operated or maintained (IOM, 1993).

To examine how ventilation can be used as a IAQ control strategy, Figure IV.B-2⁶ provides a simple, one-compartment contextual model of a ventilation control system for a uniformly mixed-occupied space (IOM, 1993). In that model, the net generation rate (N) of indoor air contaminants⁷ may be reduced by increasing the removal rate of air contaminants by diluting them in the indoor air via the use of supply and exhaust ventilation (IOM, 1993; USEPA 1995).

Ventilation modification is often used to correct or prevent IAQ problems. This approach is effective in a limited number of circumstances where:

- Buildings are under-ventilated
- A specific contaminant source cannot be identified (EPA, 1991)

Most ventilation systems found in homes, commercial, institutional and public buildings operate on the principle of general or dilution ventilation. Air from the outside in various percentages is brought into air-handling systems to dilute and flush out contaminants

³ Fungal populations in filters can amplify 2 to 4 orders of magnitude when incubated at 96% RH for 10 days (IOM, 1993).

⁴ I.e., careful removal of the filter without leaving residue from its dust cake in the system

⁵ It should be mentioned that the majority of commercial and residential systems are not designed to do this.

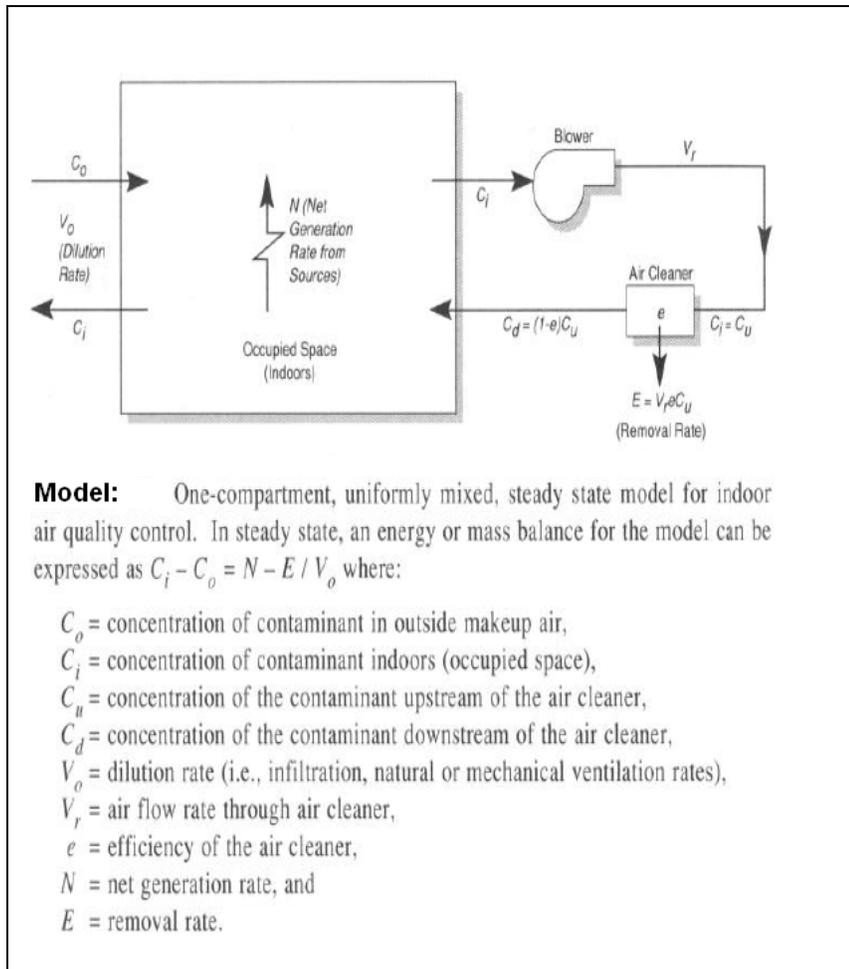
⁶ Source: IOM (1993, p.208).

⁷ E.g., particulates, pollen, microbial agents, organic toxins, volatile organics and reactive chemicals

generated by building sources including building materials, activities and occupants. Therefore, diluting contaminants with outdoor air can be accomplished by:

- Increasing the total quantity of supply air including outdoor air
- Increasing the proportion of outdoor air to total air

Figure IV.B-2 One-compartment, uniformly mixed steady-state model for indoor air quality control

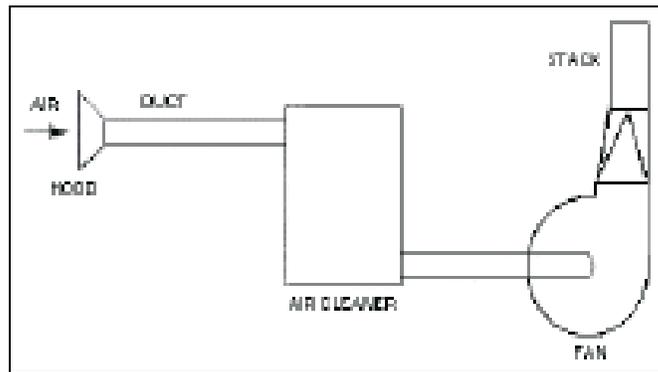


- Improving air distribution throughout the building

It should be noted that general and dilution ventilation can be appropriately used to control contaminants of low toxicity or contaminants that are present in low concentration.

In contrast, local-exhaust ventilation (see Figure IV.B-3, below) is used to control emissions or contaminants that are of higher toxicity or present in higher concentrations. Using or installing local exhaust confines the spread of contaminants by capturing them near the source and exhausting them to the outdoors. Properly designed-and-installed local exhaust results in far lower contaminant levels in the building compared to general dilution ventilation (EPA, 1991).

Figure IV.B-3 Components of a local exhaust system



Source: OSHA (1999b)

- Example 7: Local exhaust fans in the kitchens and washrooms are used to remove excess humidity or unwanted odours and contaminants by discharging them directly to the outside (USEPA, 1995).
- Example 8: Indoor air contamination from activities, such as shoe repair, offset printing, welding, soldering, sanding, painting, paint stripping and some arts and crafts activities are more appropriately controlled using local exhaust ventilation (USEPA, 1995).

It should be emphasized that indoor air quality control and management via ventilation is not the panacea for all IAQ concerns. The application of ventilation is appropriate within a limited context, as discussed above. For some indoor contaminants, such as house dust-mite allergens which are airborne only sporadically and associated with specific human activities, source control is the best option. For other allergens, such as outdoor pollen, removal by filtration is the best option and illustrates appropriate applying ventilation as the IAQ control strategy.

IV.B.1.3 Air cleaners and filters

The ventilation method may be limited by weather conditions or the presence of undesirable levels of contaminants in outdoor air (EPA, 2008; EPA, 1991). Therefore, in these conditions, an air cleaning or filtration device may be useful.

After the release of contaminants either from indoor sources or infiltration from outdoor sources, various measures can be used to control their concentration in transport pathways. With the help of filters and air cleaners, contaminant exposure pathways can be controlled. There are four technologies⁸ that are available to remove contaminants from the air (see Figure IV.B-4 for the dimensional continuum of potential contaminants) (EPA, 1991):

- Particulate filtration
- Electrostatic filtration
- Negative ion generation
- Gas and vapour sorption

⁸ Some air cleaning devices are installed in the ductwork of the building's HVAC system. Portable room air cleaners are used in a single room or specific areas; they are not designed nor intended for whole house filtration (EPA, 1991).

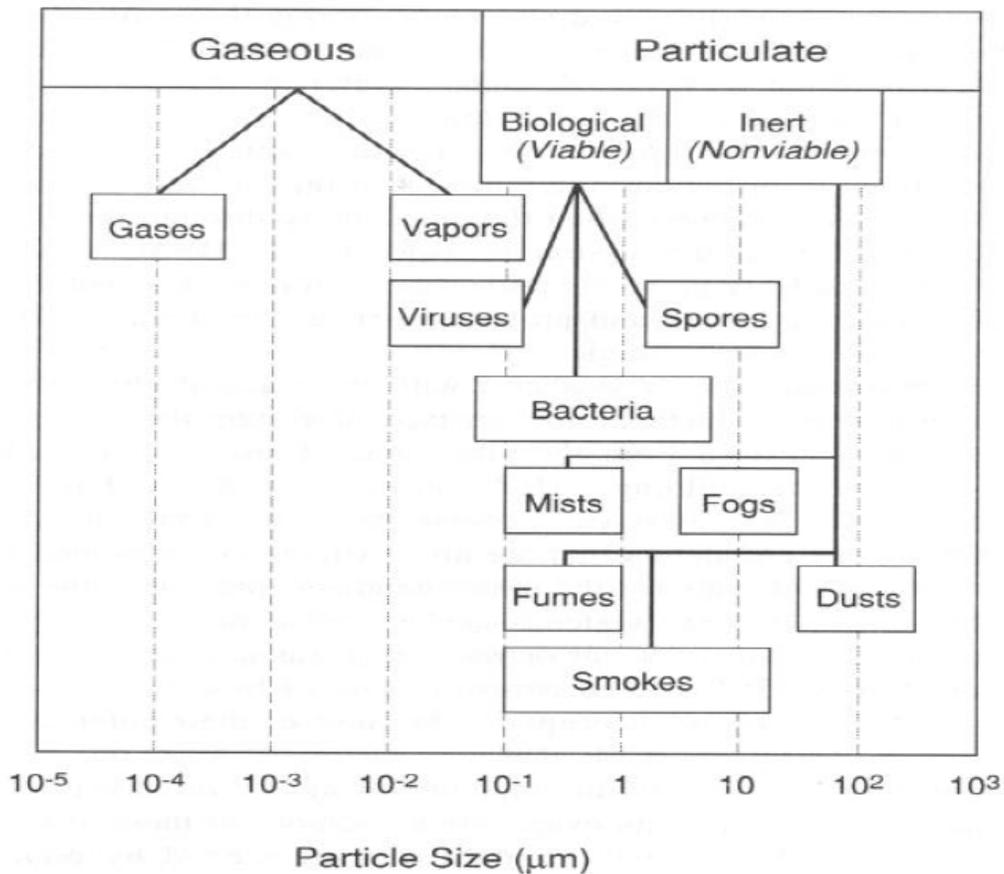
Particulate filtration, electrostatic filtration and negative ion filtration systems remove particulates; gas and vapour sorption removes gases and vapours.

In particle removal, there are two types of air cleaning devices (EPA, 1991):

- Mechanical air filters that remove particles by capturing them on filter materials
- Electronic air cleaners that use electrostatic attraction process to trap charged particles

Particle removal devices as well as gas and vapour sorption devices will be discussed in later in this Chapter.

Figure IV.B-4 Dimensional continuum of potential contaminants



Source: IOM (1993)

- **Particulate filtration**

Particulate filtration is commonly used to reduce the concentrations of airborne particulates⁹ in indoor air. Filter panels are used downstream of blower fans in HVAC systems and residential heating and cooling systems. Most filters have a fibre mat that is oriented perpendicular to the direction of air flow. Cellulose, glass, or in some cases, plastic fibres are used to form the filter bed (Godish, 1989). Air filtration measures can be carried out in non-industrial indoor environments, such as office buildings, schools, commercial establishments, single-family dwellings and multi-unit residential buildings (Godish, 1989; Godish, 2000).

Different varieties of filters and filtration systems are available to remove airborne particles from supply air systems and indoor spaces. For example, filter mats may vary in density and depth, which are important factors in determining a filter's ability to capture airborne particles (see Tables IV.B-2 and IV.B-3) (Godish, 2000).

ASHRAE 52.2, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*, corrected many of the limitations of the previous standard, ASHRAE 52.1, which provided estimates of particulate-capture efficiency without taking particle size into account. The new or updated metric for measuring capture efficiency is called the Minimum Efficiency Reporting Value (MERV). The revised standard provides a method for determining capture efficiencies for filters relative to different particle sizes at specified air-flow rates. The MERV classification system is presented in Table IV.B-2.

For most residential and commercial HVAC systems, filters are primarily installed to prevent dirt and debris from depositing on the heating and cooling coils. These filters are rated in terms of weight arrestance^a (see Table IV.B-3). Unfortunately, these filters show little effectiveness in removing respirable particles from the air moving through that HVAC system (see Tables IV.B-2 and IV.B-3). Filter capacities of filters of varying efficiencies to remove bioaerosols (size: 1 µm to 5 µm) from the indoor airstream are shown in Table IV.B-2.

Roughing or pre-filters can remove 10% to 60% of bacterial particles from the airstream. Medium- and high-efficiency filters including bag filters can remove between 60% and 99% of bacterial particles (IOM, 1993). Keep in mind that the higher the efficiency of the filter, the greater the pressure drop across the filter media within the air distribution system and the greater the reduction in total air flow, unless other adjustments are made to compensate for the reduction in pressure and total air flow¹⁰. Therefore, it is important to select the appropriate filter for the specific HVAC system so that the system will perform as designed.

⁹ Examples of particulate matter: dust, smoke, pollen, animal dander, tobacco smoke, particles generated from combustion appliances and particles associated with tiny organisms (e.g., dust mites, moulds, bacteria and viruses) (EPA, 1991).

¹⁰ .E.g., higher performance fan is installed

Table IV.B-2 MERV classification based on filtration efficiencies and particle sizes¹¹

Filter media	MERV	3 µm – 10 µm	1 µm -3 µm	0.3 µm – 1 µm	0.1 µm – 0.2 µm
Throwaway: disposable fibreglass or synthetic panel filters Washable: aluminum mesh, latex-coated animal hair, or open-cell foam panel filters; woven polycarbonate panel filters, Glass Panel/pleated	1	< 20%			
	2	< 20%			
	3	<20%			
	4	<20%			
Pleated filters, disposable extended surface area, 1-5 in. thick, Typically, cotton polyester blend media; cardboard frames, Cartridge filters: graded density, viscous coated cube or pocket filters, synthetic media; Electret (1 ply)	5	20-35%			
	6	35-50%			
	7	50-70%			
	8	> 70%			
Bag and box filters	9	> 85%	< 50%		
Bag and box filters	10	> 85%	50-65%		
Bag and box filters	11	> 85%	65-80%		
Electret (2 plies), Bag and box filters as described below	12	> 90%	> 80%		
Box filters: rigid style cartridge filters (6-12 in. deep; may use lofty (air laid) or paper (wet laid) media.	13	> 90%	> 90%	< 75%	
	14	> 90%	> 90%	75-85%	
Bag filters in synthetic media (in nominal 24 x 24in. bags are 12-36 in. deep with 8-12 pockets	15	> 90%	> 90%	85 -95%	
Bag filters: nonsupported (flexible) micro-fine fibreglass	16	> 95%	> 90%	> 95%	
HEPA, IEST type A	17			≥ 99.97	
HEPA, IEST type C	18			≥ 99.99	
IEST type D	19			≥ 99.9999	
Ultra Low Penetration Air (ULPA) filters, IEST type F	20				99.999-99.9999%
Super ULPA, IEST type G	> 20				>99.9999%

Source: Modified from McDonald B and Ouyang M (2001), Air Cleaning- Particles, Chapter 9, cited in Spengler et al. (2001).

Table IV.B-3 lists particulate capture efficiencies for various filters using MERV, dust spot and weight arrestance testing. Guidelines are derived from ASHRAE, IES (Institute of Environmental Sciences) and MIL-STD (Military Standard, USA). Examples of typical indoor contaminants that are controlled by different types of filtration are also listed in the table.

¹¹ *Source: modified from McDonald B and Ouyang M (2001), Air Cleaning- Particles, Chapter 9, cited in Spengler et al. (2001).*

Table IV.B-3 MERV classification and filtration efficiency according to ASHRAE 52.1, IEST RP-007 and MIL-STD-282¹²

Filter media	MERV	ASHRAE 52.1 dust spot	ASHRAE 52.1 arrestance	Typical applications and limitations	Typical contaminants controlled
Throwaway: disposable fibreglass or synthetic panel filters Washable: aluminum mesh, latex-coated animal hair, or open-cell foam panel filters; woven polycarbonate panel filters Glass Panel/pleated	1	<20%	< 65%		
	2		65-70%	Protect heat exchanger surfaces from dust and lint, pre-filters for MERV 8-12	Textile and carpet fibers (> 10 µm particles)
	3		70-75%	Window air conditioners	Sanding dust, spray paint dust
	4		75-80%	Minimum filtration, Residential	Pollen, dust, ites
Pleated filters, disposable extended surface area, 1-5 in. thick, Typically, cotton polyester blend media; cardboard frames, Cartridge filters: graded density, viscous coated cube or pocket filters, synthetic media; Electret (1 ply)	5	< 20%	80-85%		
	6		85-90%	Prefilters for MERV ≥ 13	3 to 10 µm particles
	7		> 90%	Industrial workplaces, Inlet air for paint booths	Dusting aids, cement dusts
	8	25-30%	> 90%	Commercial buildings and for better residential buildings	Moulds, spores, hair spray
Bag and box filters	9	40-45%	> 90%	Somewhat effective on fine particles that cause soiling, prefilters for MERV ≥ 15	
	10	50-55%	> 95%	Hospital and general lab ventilation, where hazardous materials are not involved	1-3 µm particles
	11	60-65%			Milled flour, coal dust
Electret (2 plies), Bag and box filters as described below	12	70-75%		Superior residential and better commercial buildings	Legionella, humidifier dust
Box filters: rigid style cartridge filters (6-12 in. deep; may use lofty (air laid) or paper (wet laid) media.	13	80 - 90%	> 98%	Smoking lounges, superior commercial building, analytical labs, effective on fine particles that cause soiling, prefilters for MERV ≥ 17	0.3 to 1 µm particles
	14	90-95%	> 98%		Most face powders, Most paint pigments
Bag filters in synthetic media (in nominal 24 x 24in. bags are 12-36 in. deep with 8-12 pockets)	15	>95%	≥50% MIL STD 282 for 0.3 um part.)		Sneeze droplets, Splatter from cooking oils, Insecticide dust, Copier toner
Bag filters: non-supported (flexible) micro-fine fibreglass	16	N/A	≥ 95% (MIL STD 282 for 0.3 um part.)	Hospital inpatient care, general Surgery	Bacteria, most smoke
High efficiency filters	MERV	IEST RP-007 (0.1-0.2 um)	MIL-STD282 (0.3 um)	Typical applications and limitations	Typical contaminants controlled

¹² Source: modified from McDonald B and Ouyang M (2001), *Air Cleaning- Particles, Chapter 9, cited in Spengler et al. (2001).*

Filter media	MERV	ASHRAE 52.1 Dust Spot	ASHRAE 52.1 Arrestance	Typical applications and limitations	Typical contaminants controlled
HEPA, IEST type A	17	N/A	≥99.97%	Control discharge of hazardous materials such as radioactive and carcinogenic materials	Submicron particles (e.g., from combustion, condensation processes, smoke radon progeny), < 0.3 µm particles <i>(Note: HEPA filters are ineffective against biocontaminants)</i> <i>(see explanation in box on page 15)</i> Very high efficiency on all size particles (efficiency rating at or near most penetrating particle size; higher efficiency for larger and smaller particles, Virus (as individual particles))
HEPA, IEST type C	18	N/A	≥99.99%	Sterile environments for pharmaceutical manufacturing, orthopedic surgery, TB and Immune-compromised patients facilities	
HEPA, IEST type D	19	N/A	≥99.999%		
Ultra low penetration air (ULPA) filters, IEST type F	20	99.999-99.9999%	N/A	Clean rooms such as for semiconductor manufacturing	
Super ULPA, IEST type G	> 20	>99.9999%	N/A		

¹² Source: modified from McDonald B and Ouyang M (2001), *Air Cleaning- Particles, Chapter 9, cited in Spengler et al. (2001).*

◦ **Types of mechanical filters**

Mechanical filters are similar to typical furnace filters (USEPA 1990). Different mechanical air filters are briefly discussed below.

▶ **Dry type panel filters**

They have high porosities and low dust spot^a efficiencies. Therefore, their use is limited to dust-stop filters in HVAC systems and home heating and cooling units. Large particles can be collected by dry-type panel filters by processes such as sieve action, impaction and interception. These filters are used in systems where air velocities ranges from 200 ft/min (fpm) to 700 ft/min (fpm) (60.9 m/min to 213.3 m/min). As filters become soiled, collection efficiency increases. Filter media that are used in dry-type panels are fibreglass, open cell foams, non-woven textile cloths and cellulose fibres (Godish, 2000).

▶ **Extended surface dry type filters**

These filters overcome the pressure drop and air resistance problems that are usually associated with thick, high-density and high-efficiency filtration media. In extended surface type filters, the surface area for particle collection is extended by pleating the filter medium. Extended filters vary in thickness, density, fibre size, media composition, pleats for nominal face area and depth. Filter media used for these filters are cellulose, glass fibre, wool felt or different synthetic fibres. Extended filters are available in different designs. In a typical pleated filter, a panel frame or box holds the filter medium. Extended filters are divided into three efficiency levels:

- ◇ Medium efficiency (40% to 60% dust-spot removal)
- ◇ High efficiency (80% to 90% dust spot removal)
- ◇ Very high efficiency (99.97%). HEPA filters achieve very high particle efficiency (Godish, 2000).

▶ **Viscous-media panel filters**

With these filters, filter fibres are coated with viscous, low volatility oils to increase particle collection and retention. They have high porosities and low resistance to air flow. They have low collection efficiencies for particles commonly detected in indoor air. However, they are highly efficient in collecting fabric dusts and very large particles ($> 10 \mu\text{m}$). The operating velocities range from 300 fpm to 600 fpm (91.4 mpm to 182.8 mpm) (Godish, 2000).

▶ **Renewable-media filters**

This system consists of a slowly moving curtain or a filter unit, which moves according to a timer. It also moves based on pressure drop. When the filter becomes excessively dirty, it moves to take up roll on the bottom of the filter system. When the entire roll becomes dirty, it is removed and replaced. An alarm verifies when the roll needs to be replaced. These filters have high^b arrestance efficiencies between 60% and 90% and low dust spot efficiencies between 20% and 30% (Godish, 2000).

Recent data questions HEPA filter's helpfulness in reducing allergic and asthma symptoms

Although HEPA filters achieve very high particle efficiency, recent experimental data shows that HEPA filters are not that helpful in reducing allergy and asthma in individuals. Current experimental data showed that HEPA filters are not likely to have superior performance than lower-efficiency filters in reducing concentrations of many of the bioaerosols associated with asthma. Even for submicron-size ETS particles, installing a HEPA filter is not necessarily the preferred option.

Therefore, the very common recommendation that allergic and asthmatic individuals should use HEPA filtration is not supported by recent experimental studies. Air cleaners with a lower efficiency rating are likely to be equally effective in reducing the concentrations of most and perhaps all of the indoor-generated particles associated with allergies and asthma (IOM, 2001).

In some specialized applications such as manufacture of semiconductors and other microelectronic products, more efficient filters are used. Filtration experts recommend the use of "Ultra Low Penetration Air" (ULPA) and "Super Ultra Low Penetration Air" (SULPA) filters. According to Institute of Environmental Sciences (IES) standard, ULPA filters have an efficiency of 99.999 per cent for particles in the most penetrating particle size at the specified media velocity. SULPA filters have 99.9999 per cent for the same criteria. The "most penetrating particle size" is defined as that particle diameter for which penetrating through the medium is maximum.

Explanation of terms

^a"Dust spot efficiency" is an indicator of filter performance over a broad range of particle sizes. It measures the performance of medium- to high-efficiency extended media filters and electronic air cleaners. Dust spot efficiency is expressed as percent reduction of the optical density of downstream compared to upstream samples (Godish, 2000).

^b"Arrestance" is a measure of the ability of a filter to collect relatively large particles. Arrestance values are determined by aerosolizing a standard dust mixture upstream of the filtration system. These values are based on the weight of standard dust collected on or in the filter compared to the weight of the standard dust mixture aerosolized upstream of the filter. It is a measure of large particles (> 10 µm) cleaning effectiveness (Godish, 2000).

- **Electrostatic air cleaning devices**

Electrostatic air cleaners use electrostatic forces to remove airborne particles. Three basic electrical cleaning systems are used in the air cleaning process¹³. The three types of electrostatic air cleaning devices are: electronic air cleaners, charged media filters and ion generators.

1. **Electronic air cleaners**

They are used to collect airborne particles in HVAC systems and residential applications. Airborne particles are given a positive or negative charge and then collected on metal plates with the opposite charge. Both single and two-stage electronic cleaners are used in indoor applications. Particles collected on the collection plates lose their original charge and take the charge of collecting surface. They remain attached to the plate and other collected particles by molecular adhesion and cohesion. Electrostatic force diminishes as particle buildup occurs. Electronic air cleaner collection efficiencies depend on particle migration velocity, collection surface area and travel path length and air flow rate. In electronic air cleaners that are used in the indoor applications, the travel path length is usually short, ranging from 6 in. to 12 in. with collection efficiencies that rarely exceeds 95 %. In industrial applications, the travel path is between 20 ft. and 25 ft. with collection efficiencies of 99 per cent (Godish, 2000).

One major disadvantage is the production of ozone (O₃) resulting from high voltage use in electronic air cleaners. In a typical indoor setting, where there is continuous use of an electronic air cleaner, one can smell the sweet odour of O₃ (Godish, 2000).

2. **Charged media filters**

Charged media filters combine both mechanical filters and electrostatic filters. They can be ionizing and non-ionizing. Electret filter consists of a charged media filter. It attracts dust particles onto charged plastic films or fibres called electrets. Both positive and negative charges are produced by the friction of air flowing over the filters. These charges can also be produced as a result of high-voltage imprinting during manufacture. Charged media filters have high particulate removal efficiency. They do not produce ozone. Charged media filters are referred to as single-stage electronic air cleaners (USEPA, 1991). They carry a dielectric filter mat made of glass fibre, cellulose or other fibrous materials supported on or in a grid work of alternatively charged (12,000 V) or grounded members. As a result, a strong electrostatic field is created in the filter medium. When particles approach the filter medium, they become polarized and are drawn towards the filter medium (Godish, 2000).

3. **Ion generators**

Ion generators use static charges for particle removal. They are available as portable units only. They are simple and least expensive devices. They generate ions, which diffuse out into building air and attach to particles and plate out on walls, floors,

¹³ The readers are encouraged to refer to other publications for additional information.

tabletops, draperies and occupants, etc. These systems may soil surfaces (USEPA, 1990).

- ▶ Negative ion generators

In negative ion generators, a stream of negative ions is generated. Then the charge particles are drawn passively to a collecting surface, which contains a positively charged cover. Negative ion generators have been used as health promoting devices for allergy patients. However, there is limited evidence that negative ions may positively affect individual health and relieve allergy symptoms (Godish, 2000; USEPA, 1990).

- **Gas and vapour sorption**

Gas sorption may be installed as part of the air distribution system. It is used to control compounds that behave as gases and vapours¹⁴, such as formaldehyde, sulfur dioxide, ozone, oxides of nitrogen, rather than particles. Gas sorption involves one or more of the following processes with the sorption material¹⁵, such as activated carbon or chemically treated active clays(EPA, 1991):

- Chemical reaction between the pollutant and sorbent
- Binding of the pollutant and the sorbent
- Diffusion of the contaminant from areas of higher concentration to areas of lower concentrations

The performance of the sorption (filter) material will vary with different gases and vapours. Gas and vapour-phase filters are specific to one or a very limited number of airborne pollutants; therefore, they will not reduce pollutant concentrations for which they were not designed for. It should be emphasized that gas sorption is *not* effective for carbon monoxide (CO).

While some air cleaning devices with gas- and vapour-phase filters may remove a portion of the pollutants and thereby mitigate some of the related hazards, at least, on a temporary basis. The effectiveness of these devices may not be demonstrated if there is a strong source nearby. There is also a concern that, when full, these filters may release trapped pollutants back into the air (EPA, 1991).

A properly designed and built gas or vapour-phase filtration system is used less often in homes, compared to particle air filters. The operating lifetime of gas or vapour sorption filters is generally short; hence, the operating and maintenance costs associated with these filters is high (EPA, 1991).

¹⁴ Gaseous and vapour pollutants can come from combustion processes, such as cooking stoves, vehicle exhaust, tobacco smoke, building materials, furnishings, adhesives, paints, varnishes, cleaning products and pesticides) (EPA, 1991)

¹⁵ E.g., activated carbon or chemically treated active clays

IV.B.2 Pollutant destruction

It should be mentioned that there are portable or inline air cleaning devices that are intended or claimed to destroy indoor air pollutants (EPA, 1991). These devices include:

- **UVGI (Ultra violet germicidal) cleaners**

UVGI Cleaners use ultraviolet (UV) lamps. The UV radiation is the germicidal agent that is used to destroy biological pollutants, such as viruses, bacteria and mould, that may be found growing on HVAC surfaces including cooling coils, drain pans or ductwork.

UVGI Cleaners have little effectiveness against microbiological agents. According to EPA (1991), “effective destruction of some viruses, most moulds and bacterial spores usually require much higher UV exposure than is provided in a typical UVGI unit. Furthermore, dead mold spores can still produce allergic reactions, so UVGI cleaners may not be effective in reducing allergy and asthma symptoms.”

- **PCO (Photocatalytic oxidation) cleaners**

PCO Cleaners use a UV lamp and a catalyst that reacts with the light to convert gaseous pollutants to less harmful products.

With respect to PCO Cleaners, there is limited practical application because “currently available catalysts are ineffective in destroying gaseous pollutants from indoor air. Some PCO cleaners fail to destroy pollutants completely and instead produce new indoor pollutants that may cause irritation of the eyes, throat and nose” (EPA, 1991).

- **Ozone generators**

Ozone generators use UV light or an electrical discharge to intentionally produce ozone, which is a lung irritant. This technology has not been proven in removing most indoor air contaminants. Consumers should be cautioned on their use. There may be other safer and more effective devices available to resolve their indoor air quality concerns¹⁶.

IV.B.3 Personal protection control

Personal protection from indoor air contaminants can be achieved by using personal protective equipment, such as a respirator. However, this option is not viable in most commercial or residential IAQ situations that a public health inspector is likely to encounter.

¹⁶ Ref.: <http://www.epa.gov/iaq/pubs/ozonegen.html>.

IV.B.4 Practical maintenance and control strategies

The following summary of engineering principles and practices that can be employed to prevent or minimize occupant exposures to indoor air contaminants (and allergens) is presented in the following order (OSHA, 1999b; IOM, 1993):

1. Ventilation efficiency can be improved by:
 - Ensuring that the outdoor air supply dampers, if applicable, and room air vents are open
 - Removing or modifying partitions or obstructions that block fresh air flow
 - Rebalancing the system to prevent inflow or outflow of contaminated air because of pressure differentials between rooms
 - Preventing poor distribution of make-up air by proper placement of air inlets and exhausts, if applicable
 - Filters should be changed regularly
 - Using room fans to improve mixing and dilution of pollutants
2. Outside air intakes should not be near potential sources of contamination including garages, cooling towers, building exhausts, roadways, pigeon harborages or areas where smokers congregate.
3. Air treatment encompasses the removal of air contaminants or the control of room temperature and humidity level in the ambient environment. The treatment include:
 - Using filtration, electronic cleaners, or chemical treatment with activated charcoal or other sorbents. Note: the client should consult with a HVAC company.
 - Control ambient relative humidity and temperature by ensuring that the humidity control ranges between 20% and 50% and temperature ranges between 20.0°C and 24.4°C (68°F to 76°F).
4. To remove aeroallergens from the ventilation airstream include filters with at least a moderate atmospheric dust spot efficiency between 30% and 50% in the central forced air system. Care is needed to ensure that the fan capacity of the system is sufficient to overcome the additional air flow resistance (pressure drop) imposed by this higher efficiency filter and that the filter bracket is designed to accommodate the use of a higher efficiency HEPA or ULPA filter.
5. To prevent the forced-air ventilation system itself becoming a source of allergens and irritants, prevent the accumulation of water, dust and debris in the system. For commercial HVAC systems, stagnant water in the heat exchangers should be avoided. Ventilation system should be kept clean through regular maintenance.

IV.B.5 Other considerations

Other factors need to be considered with respect to the use of air cleaning devices (EPA, 1991):

- Installation – duct air cleaning devices have certain installation requirements that must be met, such as air flow rates, access for inspection, and maintenance and repairs.
- Purchase and maintenance costs, such as filter cleaning or replacement, parts, increased operational expenses, etc.
- IAQ issues – particle removal filtration devices will not control gases, vapours, or odours, such as tobacco smoke. Gas and vapour sorption filters have only an effect on a few airborne pollutants.
- Soiling of walls or other surfaces – ion generators are generally not designed to remove charged particles that they generate from the air. These particles may deposit on the walls and ceilings of rooms
- Noise – noise may be a problem with portable air cleaners with fans.

IV.B.6 Risk management approach

Risk assessors are responsible for the characterization of risks associated with indoor air contaminants. Risk managers must be able to decide what to do with those risks. So from a management perspective, decisions have to be made regarding the level, acceptability and distribution of risks in the society.

Risk management decisions take into consideration, scientific evidence, political judgment, economic and health effects and interests of different stakeholders (Zimmerman, 1990, cited in Williams, 2001). An effective risk assessment process will help in understanding the effectiveness of risk management options and in decision-making.

For a detailed discussion on risk assessment and the relationships between risk assessment, risk management and risk communication, the reader should refer to chapter II of the manual. In the broader context of organizational management and safety hazard analysis, the management of human health risks is very important (Zimmerman, 1990, cited in Williams, 2001). Also, from a public health perspective, our goal should be to minimize risk and protect the sensitive or vulnerable group.

There is no single approach guiding the risk management process. Various formal and informal processes are available to risk managers. In the formal approach presented here, the risk management framework consists of six different stages (*Presidential/Congressional Commission on Risk Assessment and Risk Management 1997*).

These processes, listed below and depicted in Figure IV.B-5, in many ways, describe the work of public health inspectors:

- Define the problem or context.
- Analyze risks.
- Examine options.
- Make a decision.
- Take action.
- Evaluate action.

For a detailed discussion on this framework, see *Presidential/Congressional Commission on Risk Assessment and Risk Management (1997), Framework for Environmental Health Risk Management, Final Report (Volume 1)*.

Figure IV.B-5 Risk management framework



Source: *Presidential/Congressional Commission on Risk Assessment and Risk Management, 1996, Framework for Environmental Health Risk Management. Final Report, Volume. 1, Washington, DC. (Website: http://www.riskworld.com/Nreports/1996/risk_rpt/images/hex-lrg.gif, accessed, June20 2002).*

IV.C. Mitigation

IV.C.1 Chemical factors

IV.C.1.1 Gases

- **Carbon monoxide**

There are a variety of measures that can be taken to control sources and exposures to indoor concentration of CO.

1. Residential houses

- ▶ Replace or modify an unvented space heater to exhaust combustion gases.
- ▶ Take special precautions, such as using the proper fuel and storage and regularly maintaining equipment. A yellow flame confirms poor adjustment and increased contaminant emissions from the equipment.
- ▶ Do not use unvented space heaters.
- ▶ Install and use exhaust fans over gas stoves and ranges. Keep the burners properly adjusted.
- ▶ Open flues when fireplaces are in use.
- ▶ Alberta Building Code requires combustion air intakes for furnaces, fireplaces and woodstoves. For fireplaces, a less desirable alternative for providing combustion air is to open a window.
- ▶ Keep woodstove emissions to a minimum. Use certified stoves, such as those certified by U.S. EPA, CSA, or other regulatory agencies.
- ▶ Have central air handling systems including furnaces, flues and chimneys inspected annually. Promptly repair cracks and damaged parts.
- ▶ Do not leave vehicles idling inside attached garages.

Steps to eliminate CO in the home (CMHC, 2000)

1. Every year, before the cold weather sets in, a qualified technician should inspect and clean fuel-burning appliances to ensure that they are in good condition.
2. A qualified technician should inspect chimneys and vents yearly for cracks, bird's nests, twigs, old mortar, corrosion or holes.
3. Fireplaces should be checked for closed or blocked flues.
4. Check with a qualified technician before enclosing heating and hot water equipment in a smaller room, to ensure there is adequate air for proper combustion
5. If a stove has a powerful overhead or downdraft exhaust fan, a qualified technician should check its operations to make sure that the exhaust fan is not pulling exhaust gases from other appliances, such as furnaces or hot water tanks, back down the chimney. Because of backdrafting concerns,

avoid locating clothes dryers in proximity to or in the same room as a furnace.

6. Propane or natural gas stove tops or ovens should not be used for home heating purposes.
7. Propane, natural gas or charcoal barbecue grills should not be used indoors or in an attached garage.
8. Use of an unvented kerosene space heater should be avoided indoors or in a garage.
9. The fossil fuel burning equipment for refrigeration, cooking, heating and lighting inside tents, trailers and motorhomes should be regularly maintained with the combustion exhaust vented outside. Use of electric and battery-powered equipment should be encouraged where possible.
10. Installation of at least one CO detector is a recommended safety practice.

Table IV.C-1 summarizes CO detector performance criteria and relationship with acute health effects (CMHC, 2000).

Table IV.C-1 Carbon monoxide detector performance criteria and associated acute health effects

CO (ppm)	Conditions
0-2	Normal conditions in and outside Canadian houses
11	Maximum tolerable indoor concentration over an eight-hour period ¹
25	Maximum allowable concentration for continuous exposure for healthy adults in any eight-hour period ¹
30	CO detectors must not sound alarm within 30 days ²
70	CO detectors must sound alarm within one to four hours ²
150	CO detectors must sound alarm within 10 to 50 minutes ²
200	Slight headache, fatigue, dizziness and nausea after two to three hours ³
400	CO detectors must sound alarm within 4 to 15 minutes ²
800	Dizziness, nausea and convulsions within 45 minutes, death within two to three hours
1600	Death within one hour ³
13,000	Danger of death after one to three minutes ³

1 - Exposure Guidelines for Residential Indoor Air Quality, Health Canada, 1989, 1995

2 – From the CSA Standard 6.19, *Residential Carbon Monoxide Detectors*

3 – Carbon Monoxide Poisoning, IOWA State University of Science and Technology, AEN-172

Source: Canadian Mortgage Housing Corporation (2000). "About your House", Carbon Monoxide CE 25, Canada Mortgage and Housing Corporation, website: <http://www.cmhc-schl.gc.ca>

2. Indoor motor events

Diesel or gasoline engines should not be operated in confined spaces; however, indoor motor events, such as tractor pulls and car shows, do mean gasoline- and diesel-powered vehicles are contaminating indoor air. Therefore, the following control measures should be enacted:

- ▶ Pollution control devices should be installed in tractors and other automobiles taking part in the event. Vehicles should be tuned to minimize contaminant levels in the exhaust.
- ▶ Warm up vehicles outside rather than in the garage.

- ▶ Ventilation rates should be increased to 100 per cent exhaust air and arena doors should be opened.
- ▶ Indoor motor sports such as tractor pulls often occur in small-sized venues which increase the probability of CO contamination and poisoning. Therefore, the ventilation system should be periodically checked and properly maintained.
- ▶ Sufficient time should be provided between events to enable the ventilation system to sufficiently lower indoor levels of exhaust contaminants. This can be achieved by proper event timing and management.

3. Ice arenas

Ice re-surfacing machines should be properly maintained and serviced at regular intervals to reduce exhaust contaminant levels to a minimum. This can be accomplished by adjusting the carburetor at least twice a year and by tuning the engine for 0.5 per cent to one per cent CO in the exhaust (Kwok, 1983.)

- ▶ Before use, the ice re-surfacing machines should be started and warmed up in a well-ventilated environment, preferably outside the ice rink (Kwok, 1983). Alternatively, attach an exhaust hose to the tail pipe. Although these measure will have no effect on nitrogen dioxide emissions.
- ▶ Ice re-surfacing machines can be converted from gasoline or diesel powered engines to a much cleaner fuel such as propane or preferably to electrical batteries (Brauer & Spengler, 1994). The propane fuel mixture should not be too rich as this may lead to the emission of excessive levels of CO (Kwok, 1983).
- ▶ The installation and proper maintenance of catalytic converters combined with an adequate warm-up time will allow the converters to work effectively (Kwok, 1983).

Ensure the presence of a three-way catalytic converter with a Lambda fuel management system to reduce nitrogen dioxide and CO emissions from ice re-surfacers fuelled with gasoline, propane or natural gas.

- ▶ “Pooling” of CO above the ice surface can be prevented by discharging the re-surfacing machine’s exhaust vertically instead of horizontally and by extending the exhaust tailpipe to at least one-foot above the top of the rink’s plexiglass safety barrier (Kwok, 1983).
- ▶ To facilitate better circulation and the breakup of the inversion layer, all rink barrier doors should be completely open during ice re-surfacing to allow for increased air flow over the re-surfaced ice (Kwok, 1983).
- ▶ The ice re-surfacing time should be kept to a minimum and the interval time between the ice cleaning should be as long a duration as possible (Kwok, 1983).
- ▶ The installation and operation of mechanical ventilation should be properly managed in these indoor facilities. During cold weather, some arena managers may close outdoor air intakes on ventilation systems for reasons of

economy, which may contribute to the accumulation of CO in the building. This type of practice should be avoided (Kwok, 1983).

- ◇ The recommended ventilation design criteria is 2,000 cfm of outdoor air plus 40 cfm of outdoor air per person.

4. Underground parkades and garages

The infiltration of CO from car exhausts in underground parkades into overlying suites of apartment complexes can be a public health concern. There are several control measures that health professionals can recommend to control CO contamination incidents.

- ▶ The pathway or route of CO migration from the parkade into overlying suites should be identified and sealed. These include utility penetrations through the structural deck that provide a direct pathway linking the parkade to aboveground suites.
- ▶ Installation of CO sensors to control mechanical exhaust ventilation in parkades (as required by the building code). The CO sensors should be properly maintained and calibrated to 50 ppm.
- ▶ In the absence of CO sensor controls, parkade exhaust fans should operate continuously.
- ▶ Parkade ventilation systems containing both exhaust and make up fans should ensure that the parkade is under negative pressure.
- ▶ Ensure the presence of weather stripping in good condition on access doors leading from the parkade to the tenant stairwells and corridors.
- ▶ Tenants should shut off the engines as soon as possible once they have parked their vehicle. Vehicles should not be idling while parked inside parkades (or attached garages).
- ▶ Ensure all pathways into the building are sealed including plumbing lines for fire suppression or sprinkler systems and or electrical conduits.

• Carbon dioxide

In residences and offices, CO₂ concentrations can be reduced and maintained at or below acceptable levels by adequate ventilation with outdoor air. The following are recommended control measures.

- All combustion appliances must be properly vented.
- An appropriate level air exchange rate should be maintained at all times with the goal of minimizing as much as possible the amount of return air being recirculated; that is, maximizing the percentage of outdoor air or makeup air.
 - ▶ The Alberta Building Code requires continuous ventilation in business or commercial settings.
 - ▶ The goal should be to maintain indoor CO₂ levels below ASRHAE recommended maximums. A general rule of thumb is that fresh air intake louvres should always be opened a minimum of 10 per cent.

- CO₂ monitoring can be used as an indicator of adequate fresh air supply. Monitored CO₂ levels can be compared to corresponding equilibrium concentrations. Alternatively, the CO₂ decay rate measured after the building is vacated can be used to calculate the fresh air supply rate. However, consideration must be given to the limitations of rooftop air handling units (AHUs), which may result in CO₂ levels rising above recommended maximums. In addition, commercial spaces heated with domestic forced air systems are a special concern because of their limitations. Domestic forced air furnaces are not a balanced system; they have no engineered ability to exhaust return air and instead rely on pressurize-driven exfiltration.

- **Ozone**

There are various control measures to control, reduce or eliminate ozone from indoor air.

- **Photocopiers**
 - ▶ Ozone emissions from the photocopiers can be controlled or reduced by routine maintenance and cleaning. Photocopier manufacturers should include specifications on the amounts of ozone produced by each model.
 - ▶ Photocopiers should be located in a well-ventilated and separate room. With extensive use, installation of local exhaust ventilation is recommended.
 - ▶ Some photocopiers have the option of being fitted with a hopcalite filters which can reduce ozone emissions.
- **Electronic air cleaners and negative ion generators**
 - ▶ Ensure proper installation. The use of positive coronas instead of negative coronas can significantly reduce the production of ozone from air cleaners.
 - ▶ Regular cleaning of electronic air cleaner collection plates is important
 - ▶ In the United States, electronic air cleaners and negative ion generators, which are sold as medical devices, are regulated by regulatory agencies such as the US EPA and the Food and Drug Administration (FDA). Based on FDA requirements, indoor levels of O₃ may not exceed 0.05 ppmv because of the operation of these devices.
 - ▶ In Canada, both the Food and Drugs Act (FDA) and the Pest Control Products Act (PCPA) cover ozone generators. To avoid being subject to regulations under these acts, ozone generators continued to be marketed as air cleaners or pollution control devices. Before July 1, 1998, The Medical Devices Regulations of the FDA act prohibited medical devices from generating airborne ozone that which humans may be exposed to. A limit of 0.05 ppm (v/v) was also set for other medical devices which generated ozone. In July 1, 1998, the new Medical Devices Regulation came into effect. Therefore, the old regulations and schedules ceased to exist.
 - ▶ Presently, there are no regulations on medical devices that produce ozone. To replace the old schedule VIII, the Therapeutic Products Program drafted

a policy on ozone generators. The New Medical Devices Regulations established general safety and effectiveness requirements for medical devices.

- ▶ Health Canada does not recognize health benefits from human exposure to ozone. Therefore, it precludes approval of such devices under Medical Devices Regulation. Ozone generators are prohibited devices in Canada (Health Canada, 2000)

- **Nitrogen dioxide**

The following control measures can be carried out to prevent or reduce exposure to NO₂ in indoor environments.

- Keep gas appliances properly adjusted through routine servicing and maintenance.
- Replace the pilot lights of gas ranges and ovens with electronic ignition devices.
The installation of a production-type wire insert for range-top burners reduces NO_x emissions by 35 per cent and NO₂ emissions by 26 per cent (Godish, 1989). A low NO_x dual-rod insert for oven burners can reduce NO_x emissions by 63 per cent and NO₂ by 25 per cent (Godish, 1989).
- A new gas range design, which incorporates perforated tile burners with glass ceramic plates located above, significantly lowered NO_x, NO₂ and CO emissions (Godish, 1989).
- Replace un-vented space heaters with vented heaters.
- Use the best grade of fuel in kerosene space heaters.
- Install and use an exhaust fan, vented to the outdoors, over gas stoves.
- Ensure fireplaces have open flues when in use and combustion air intakes. Install a combustion air intake if one isn't yet installed. In the interim, open a window to provide combustion air.
- Choose properly sized wood stoves that are certified to meet emission standards.
- Make certain that doors on all wood stoves fit tightly.
- Have a trained professional annually inspect, clean and tune-up central air heating system, including the furnace, flues and chimney.
- Repair any defects promptly.
- For ice arenas and ice re-surfacers, refer to carbon monoxide section.
- Avoid or prohibit cigarette smoking indoors.
- Minimize candle-burning indoors.
- Do not idle vehicles in attached garages; instead immediately turn off the vehicle engine on entry into a garage.

IV.C.1.2 Vapours (volatiles and semi-volatiles)

- Total VOCs (TVOCs)

Several control measures can be used to control or eliminate indoor TVOCs. As TVOCs are a common constituent of other products, please refer to other control measures sections provided in Appendix A *Chemical Factors*, for example Appendix C *Environmental tobacco smoke*, Appendix F *Consumer products* and Appendix H *Built environment, mechanical and physical factors*.

Selection of low emission construction materials and furnishings should be used to reduce TVOC emissions (Godish, 2000). Table IV.C-2 presents TVOC recommended emission limits for building materials and furnishings (Godish, 2000).

Table IV.C-2 Recommended and acceptable TVOC emission rate for building materials and furnishing

Material/product		USEPA	IRC/NRC2			
		Max EF ¹	EF @ 24 hr ¹		EF @ 96 hr ¹	
			Min	Max	Min	Max
Flooring	Particleboard	0.6	3.87	6.90	2.12	4.35
	Plywood		0.22	0.67	0.19	0.46
	Oriented strand board		0.27	0.98		1.76
	Solid wood		0.07	4.53	0.05	3.55
	Vinyl flooring		0.05	3.77	0.07	2.73
	Underpad		0.10	0.45		0.28
	Carpet		0.20	1.91	0.07	0.99
Floor coatings	Wood stain	0.6	18.2	124.4		52.3
	Polyurethane coating		88.1	154.5	3.88	359.3
	Floor wax		51.4	409.0	5.55	26.0
	Paint/primer		29.9	216.2	0.34	19.0
Wall/ceiling Covering	Gypsum board	0.4				
	Acoustic tile	2.5 mg/hr per WS				
Partitions		0.25mg/m3/hr				
Office furniture						
Office machines						
Workstation			0.5 mg/hr	0.5 mg/hr	0.5 mg/hr	0.5 mg/hr
Others	Adhesive		3.28	659.1	3.88	359.3
	Caulking sealant		448.0	10467.2	51.13	3842.6

¹ The units are mg/m²/hr unless otherwise specified

² The values are the minimum and maximum emission factors among those determined from testing three products in each category

Source: National Research Council Canada (2005). "Managing Volatile Organic Compounds and Indoor Air Quality in Office Buildings – An Engineering Approach". NRC website: <http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/rr/rr205/rr205.pdf>.

Canada Mortgage and Housing Corporation (CMHC) (2005) released a publication entitled, *Building Materials for the Environmentally Hypersensitive* providing recommendations on building materials for sensitive or vulnerable individuals. The reader is encouraged to refer to this publication for additional information.

- **Benzene (C₆H₆)**

The following source control methodologies can be followed to reduce or eliminate exposure to benzene:

- Eliminate smoking within the home.
- Provide maximum ventilation during use of paint and varnishes.
- Discard paint supplies and special fuels that will not be used immediately, or store in exhaust cabinets.
- Move away from the filling nozzle while refueling vehicles at gas stations.
- Ventilate exhaust from attached garages (on timers) or build detached garage.
- Maintain gas fired furnaces and ensure conformance to the Building Code.
- Minimize or curtail indoor wood burning.
- Situate new construction away from busy roadways, gas stations and other industrial sources.
- Ensure the best available pollution control equipment is installed on industrial sources.

- **Toluene**

The source control methodologies for benzene can be followed to reduce or eliminate exposure to toluene.

- **Formaldehyde (HCHO)**

The most effective way to control potential for HCHO exposure is to use HCHO-free products. Consumers are also advised to assess for the presence of other potentially hazardous compounds. The following methods can be effective in controlling or reducing HCHO emissions from potential indoor sources (Calgary Health Region, 1993).

- **Ventilation**

Increasing ventilation exchange by opening windows can be useful for reducing and relieving symptoms caused by low to moderate (0.05 ppm to 0.20 ppm) indoor HCHO levels; however, opening windows is not practical during the winter months (cited in Calgary Health Region, 1993).

- **Temperature and relative humidity control**

Temperature and relative humidity are important factors affecting the off-gassing rate of HCHO from building materials. An increase in temperature can encourage the release of HCHO and a decrease in temperature inhibits it. Research has shown that an approximate 5°C to 6°C increase in temperature can double the HCHO emission rate. Maintaining indoor temperatures between 18°C and 21°C during the winter and between 22°C and 24°C during the summer can reduce HCHO emissions.

Relative humidity should be maintained at low levels as increases in this variable will also encourage HCHO off-gassing. For example, an approximate 40% increase in indoor HCHO levels can result by increasing the relative humidity between 30% and 70% (cited in Calgary Health Region, 1993).

- **Bake-out**

The "baking" process uses a combination of increased temperature, increased relative humidity and increased ventilation to reduce indoor HCHO levels. This process involves emptying the building and increasing the indoor temperature, relative humidity levels and air change rate over a specified period of time, such as 24 hours to 72 hours. An indoor temperature of >30°C, relative humidity >70 per cent and an air change per hour between 1.5 and 4 will encourage HCHO off-gassing and removal and, potentially reduce the half-life of emissions from sources of HCHO.

The baking process is to occur concurrently with increased ventilation to ensure that off-gassed VOCs, such as HCHO, are not sorbed onto interior surfaces. Air exchange can be enhanced by turning on building exhaust fans, continual operation of furnace fans and, if possible, for commercial buildings ensuring that the HVAC systems operate at 100 per cent or the maximum exhaust setting.

The California State Architect for all new state office buildings has recommended the bake-out process. However, the effectiveness of the "baking" process remains unproven and bake-out cannot be used if exterior air is contaminated because of temperature inversion or the influence of a nearby industry (Calgary Health Region, 1993).

Bake-out is regarded as a general tool to control or reduce VOCs off-gassing from building materials. The effectiveness of baking-out depends on the following factors:

- ▶ Building temperature should be maintained between 30 °C and 35 °C (86 °F to 95°F).
- ▶ Bake-out duration should extend for least several days.
- ▶ An optimum ventilation rate should be maintained.

It is essential to optimize temperature, duration and ventilation to achieve maximum VOC reduction from a building. However, it should be noted that maintaining an optimal temperature for the desired length of time in a building is very difficult to achieve. In some cases, supplemental heating may be required. In addition, elevated temperature may affect or damage building materials, finishes, furnishings and equipment. There also may be difficulties associated with providing sufficient ventilation to flush VOCs out of the building. Various researchers have assessed the efficiency of the bake-out process and have concluded that it can reduce VOC levels between 30% and 75% (Godish, 2000).

- **Polycyclic aromatic hydrocarbons (PAHs)**

Control measures can include the following:

- Ensure correct installation, maintenance and operation of wood burning stoves, fireplaces, kerosene space heaters and gas appliances.

- Eliminate indoor tobacco smoking.
 - Individuals who use wood-burning stoves and fireplaces should be cautioned not to use wood products treated with preservatives, such as creosote.
 - Use exhaust fans vented to the outside when frying, sautéing, baking and broiling etc.
 - Minimize or reduce the consumption of barbecue foods to reduce overall PAH exposure.
 - Build new structures away from busy roadways and industrial sources.
 - Ensure the best available pollution control equipment is installed on industrial sources.
- **Chlorinated hydrocarbons**

Measures to control or limit exposure to chlorinated hydrocarbons (PERC):

- Know what you are buying.
 - Learn about cleaning processes for your garments and know what options are available.
 - Take your dry cleaning to professional cleaners who carefully follow safety requirements and properly maintain cleaning equipment.
 - Use dry cleaners who offer the wet-cleaning process as an option.
- **Chlorine disinfectant by-products (DBPs)**

Several engineering and management control measures can be adopted to reduce contamination of air in indoor swimming pools by DBPs:

- Maintain adequate air exchange levels in the enclosed pool buildings.
- As the production of halogenated organics is an inevitable result of common swimming pool treatment practices, different treatment processes may reduce the generation of chlorinated organics. Several European studies have shown that chlorinated organics may be substantially reduced by using complex treatment systems involving:
 - ▶ Chemical flocculation
 - ▶ Reduced rate sand filtration
 - ▶ Ozonation
 - ▶ Granular activated carbon filtration before chlorination
 - ▶ Use of high volumes of fresh replacement water to remove and dilute the organic precursors of the halogenated by-products

Note: These types of complex treatment systems are expensive and the high rate of fresh water replacement is not consistent with North American interests in energy and water conservation because of the high costs associated with heating and treating pool water).

- Controlling organic loading

To control organic loading, do the following:

- ▶ Ensure that pool occupancy limits are not exceeded, as the production of irritating halogenated organics is directly proportional to the number of pool users and resultant increased organic loading.
- ▶ Check the combined chlorine level in the pool water as a way to measure organic loading. When combined chlorine levels reach a certain value, the pool should be shock chlorinated. Total chlorine can be used as an indicator for combined chlorine:

$$\text{Total chlorine} = \text{free chlorine} + \text{combined chlorine}$$

If tests show that the combined chlorine level two times or greater than the free chlorine, the pool must be treated to lower the chlorine demand or organic loading. The swimming pool regulation requires that combined chlorine levels be kept below 1.0 mg/L at all times. Treatment of elevated organics, as shown by combined chlorine, is called shock chlorination.

- ▶ Shock chlorination involves increasing the chlorine residual to at least 10 times the combined chlorine level. The increase in chlorine level will burn off the organic compounds, leaving only free available chlorine.
- ▶ Superchlorination is not recommended for regular swimming pool maintenance. However, it may be a necessary treatment for algae control and infection control from fecal events. In this process, the chlorine level is increased up to 8-50 ppm (Calgary Health Region, 2000, in Swimming Pool Operator's Course Manual).

The reader should consult different municipal and provincial regulatory authorities for additional information on swimming pools.

- **Mercury vapours**

Most pesticide use of mercury was banned in 1976. In 1990, USEPA announced that use of mercury would be eliminated from interior latex paints. Paints that contain mercury carry a warning label stating the paint is for outdoor use only. In 1998, mercury based antimicrobial pesticides and mercury based exterior paints were phased out in Canada.

Although, the use of mercury in consumer products is severely restricted, the presence of mercury in the indoor and outdoor environments can have severe health consequences. Simple control measures can be carried out indoors to eliminate or reduce mercury exposure.

- Steps in disposing of products containing mercury:

- ▶ Evaluate any existing stock of paints and properly dispose of those paints that contain mercury (USEPA, 2002).
- ▶ Limit and reduce the use of mercury vapour lamps and other electrical products containing mercury, or alternatively ensure proper handling and disposal; that is, avoid breakage indoors.

- ▶ Mercury is used in the manufacture of various lamps and lighting fixtures, wiring devices, halide and high-pressure sodium lamps and switches. Mercury releases are associated with the manufacture, breakage and disposal of mercury lamps and light switches. Redesigning a low-dose mercury lamp will help to reduce leachable mercury.
- ▶ Consider fluorescent-lamp recycling options before disposing of the lamps at a landfill.
- ▶ In Alberta, used fluorescent lamps intended for disposal are currently not classified as a hazardous waste. However, the Fluorescent Lamp Stewardship Initiative, released by Alberta Environment in June, 2000, made the following recommendations:
 - ◇ Where recycling options are not available for large quantities of mercury, package fluorescent in absorbent materials such as calcium poly-sulfide or commercially available powdered sulfur.
 - ◇ If sulfur-based absorbent is used, the lamps should also be packed in a secondary container containing alkaline coating surrounding the core waste package.
 - ◇ Other mercury-containing wastes and materials, such as broken and obsolete instrumentation, such as thermometers and thermostats, should be pre-treated as previously described by packaging the items with poly-sulfide or an alkaline coating. After the items are pre-treated with absorbent materials, they can be disposed at any sanitary landfill after obtaining permission from the operator.
- ▶ Carefully handle mercury-containing devices to avoid breakage and spillage.
- ▶ Metallic mercury evaporates slowly. It should be stored in an airtight, closed container (ATSDR, 1999).
- ▶ To protect children against metallic mercury, educate them not to play with shiny, silver liquid droplets (ATSDR, 1999). Teachers and school staff should teach their students about the health consequences of metallic mercury (ATSDR, 1999).
- **Cleaning up an accidental release of mercury**

The following cleaning steps should be taken in the event of an accidental release of a small amount of mercury, such as a broken thermometer) (USEPA, 2011). Public health inspectors should consult indoor air quality experts before recommending those steps to the public.

- ▶ Put on rubber, nitrile, or latex gloves.
- ▶ If there are any broken pieces of glass or sharp objects, pick them up with care. Place all broken objects on a paper towel. Fold the paper towel and place in a zip-lock bag. Secure the bag and label it as directed by your local health or fire department.
- ▶ Locate visible mercury beads. Use a squeegee or piece of cardboard to gather mercury beads. Use slow sweeping motions to keep mercury from becoming uncontrollable. Take a flashlight, hold it at a low angle close to the floor in a

darkened room and look for additional glistening beads of mercury that may be sticking to the surface or in small cracked areas of the surface.

Note: Mercury can move surprising distances on hard-flat surfaces, so be sure to inspect the entire room.

- ▶ Use the eyedropper to collect or draw up the mercury beads. Slowly and carefully squeeze mercury onto a damp paper towel. Place the paper towel in a zip-lock bag and secure. Make sure to label the bag as directed by your local health or fire department.
- ▶ After removing larger beads, put shaving cream on top of small paint brush and gently dot the affected area to pick up smaller, hard-to-see beads. Alternatively, use duct tape to collect smaller hard-to-see beads. Place the paint brush or duct tape in a zip-lock bag and secure. Make sure to label the bag as directed by your local health or fire department.
 - ◇ *Optional step:* Use a commercially available powdered sulfur to absorb beads that are too small to see. The sulfur does three things: (1) makes the mercury easier to see since there may be a color change from yellow to brown and (2) binds the mercury so that it can be easily removed and (3) suppresses the vapor of any missing mercury. Powdered sulfur may be called mercury vapor absorbent in mercury spill kits. These kits can be purchased from laboratory, chemical supply and hazardous materials response supply manufacturers.

Note: Powdered sulfur may stain fabrics a dark color. When using powdered sulfur, do not breathe in the powder as it can be moderately toxic. Also, users should read and understand product information before use.

If you choose not to use the powdered sulfur option, you may want to hire a contractor who has monitoring equipment to screen for mercury vapors.
- ▶ Place all materials used in the cleanup including gloves in a trash bag. Place all mercury beads and objects into the trash bag. Secure trash bag and label it as directed by your local health or fire department.
- ▶ Contact your local municipal waste authority or your local fire department for proper disposal in accordance with legislation.
- ▶ For at least 24 hours after your successful cleanup, remember to keep the area well ventilated to the outside by opening windows or running fans in exterior windows. Continue to keep pets and children out of cleanup area. If sickness occurs, seek medical attention immediately.

IV.C.2 Particulates

IV.C.2.1 Airborne particulate matter

Several measures can be carried to control indoor particulate levels. They include:

- Replace filters on furnaces, air conditioners and air cleaners as specified by the manufacturer; and upgrade filters to improve performance.
- Ensure regular and effective house cleaning.
- Avoid installation of wall-to-wall carpets.
- Ensure that an annual inspection, cleaning and tune up of the chimneys and flues are done by a trained professional.
- Doors on all wood stoves should fit tightly and be correctly sized to function properly.
- All furnace combustion gases should be vented to the outside.
- Cease tobacco smoking indoors.
- Reduce or eliminate other indoor sources of particulates including wood- or coal-burning stoves, natural gas stoves (unless exhaust ventilated) and gas log fireplaces (USEPA, 2001).
- Avoid use of pressurized consumer products that aerosolize contents.
- Install timed exhaust ventilation in attached garages.
- Control emissions from hobbies and renovation activities.
- Build structures away from outdoor sources, such as gravel roadways and industrial sources.
- Remove shoes at home foyer.
- Install vacuflo systems that exhaust to the outside or use HEPA vacuums.

To reduce exposure to elevated ambient particulate matter, the following steps can be taken (USEPA, 2001):

- Stay indoors and keep windows and doors closed. In a tightly sealed building, this may provide short-term protection as indoor source may lead to an overall decline of indoor air quality. In addition, with time the indoor space will equilibrate with outdoor air. Filtration may provide some reductions, depending upon particulate capture efficiencies and air flow rate.
- Inspect and change filters often and upgrade them, if possible.

IV.C.2.2 Asbestos

The Government of Alberta's *Alberta Asbestos Abatement Manual* (2011) focuses on many facets of asbestos hazard assessment and mitigation. For further information, the reader is advised to refer to the manual, which is available Government of Alberta website: <http://employment.alberta.ca/documents/Asbestos-Abatement-Manual.pdf>.

The control strategies to resolve the presence of ACM in buildings should be developed on a site-specific basis. The first step is to conduct a building survey, especially for a building constructed before 1980. The survey must evaluate factors such as:

- Accessibility
- Type and nature of asbestos
- Condition of the materials (friability)
- Frequency of contact
- Damage status
- Function
- Cost of the proposed method for controlling asbestos exposure

Asbestos control measures can range from source removal, encapsulation and enclosure to implementation of an asbestos management plan. These basic approaches are described below.

- **Removal of asbestos-containing materials (ACMs)**

ACMs are removed from a building and buried in an approved landfill site. Removal of is mandatory during building demolition and, depending on circumstances, during renovation too. There are both advantages and disadvantage associated with removal. Removal eliminates both ACMs from a building and the need for a long-term surveillance program. However, it is an expensive method and can interrupt the day to day building activities. Asbestos workers and normal building occupants, have the highest potential for exposure during removal. Removal protocols can generally be classified as Low, Moderate or High Risk according to their potential for generating airborne asbestos fibres. A brief outline of these classifications is presented below (Table IV.C-3). All removal protocols follow the same four principles:

- Isolate the work area.
- Protect workers.
- Minimize the release of asbestos fibres.
- Ensure adequate clean-up and decontamination.

Table IV.C-3 Alberta asbestos removal protocols

Recommended removal work procedure	Type of asbestos product and activity
Low risk	Installing or removing non-friable ACMs manufactured products, in good condition, without cutting, breaking, sanding or vibrating the materials. This includes handling gaskets, floor tiles, asbestos cement exterior cladding and asbestos cement boards. Note: If the product is or becomes extensively damaged during the removal process, the use of moderate risk procedure is recommended
Moderate risk	Handling, disturbing, removing, hand cutting, hand drilling, etc., small amounts of friable asbestos products such as pipe insulation and any amount of low or non-friable product. Small amounts being less than 0.09 m ² (1 ft ²). Removal of 9.3 m ² (100 ft ²) or less of contiguous ceiling tile containing asbestos or sheet vinyl flooring/vinyl floor tiles having an asbestos backing. Note: if difficulty is encountered in removing sheet flooring because the flooring is badly damaged, then use of high-risk work procedures.
High risk	Handling, disturbing, removing large amounts of friable asbestos products such as pipe or furnace insulation or sprayed-on applications or where occupational exposures are likely to exceed the 8-hour OEL: ie. restricted area

Alberta Workplace Health and Safety should be contacted for assistance regarding asbestos concerns. Also, asbestos contractors and professionals can be contacted for further assistance.

Source: Government of Alberta (2011).

- **Encapsulation**

During this process, friable sprayed-on asbestos applications are coated with an approved bonding or encapsulating agent. Encapsulants penetrate into the spray applied material to produce a hard, protective coating. Encapsulants are usually applied using low-pressure airless spray equipment to reduce the potential of fibre release.

One of the major disadvantages of this process is that the source of asbestos-containing materials will always be present. Encapsulation is limited to those areas where sprayed-on asbestos is in good condition and not subject to further damage by contact. Continued long-term inspection and constant maintenance is a requirement of encapsulated surfaces.

- **Enclosure**

Enclosure is the installation of a physical barrier that physically isolates the asbestos from other areas of the building. Often, this can be accomplished using drywall construction for spray-applied products, or metal pipe cladding in the case of pipe insulation. A suspended ceiling does not constitute an acceptable or effective barrier. Enclosure is regarded as a rapid, economical and uncomplicated method of controlling exposure. However, because the asbestos remains in the building, a long-term asbestos management program is required to ensure the long term integrity of enclosed asbestos.

- **Implementation of asbestos management plan**

Generally, an asbestos management plan, or an operations and maintenance plan, is carried out for the long-term management of asbestos-containing materials in buildings. Generally, a long-term management plan is required whenever asbestos-containing materials are present in a building. The design of an effective management plan should be in writing and the following issues should be dealt with:

- Inventory of asbestos-containing materials in the building
- Inspection frequency and procedures
- Training requirements for maintenance staff and others who may come into contact with the materials or work in proximity to the materials
- Procedures to follow in the event of damage or other emergency situations
- Procedures to follow if the condition of the materials change or work routines are altered
- Notification procedures for occupants and others in the building
- Labeling of asbestos containing material
- Procedures for air monitoring and sampling
- Personal protection equipment for workers

In addition, all building tenants and occupants need to be informed about the presence of asbestos-containing materials and of precautionary measures against ACMs, such as no unauthorized ceiling access in the case of sprayed-on structural fireproofing.

Occupational health and safety legislation does not apply to privately owned residences. However, public health officials should recognize that asbestos is classified as a proven human carcinogen and that homeowners should minimize their exposures as much as possible by following the workplace procedures established by Alberta Occupational Health and Safety. If the homeowner hires a contractor to do any asbestos abatement work, the contractor must fully comply with workplace regulations and guidelines regarding asbestos. Similarly, provincial regulations apply if asbestos is located in any public or business facility including day cares, swimming pools, ice arenas, office towers and malls. For further information on abatement procedures, refer to the *Alberta Asbestos Abatement Manual*.

IV.C.2.3 Man-made mineral fibres (MMMFs)

MMMF exposure is mostly an occupational health concern; little information is available about environmental exposure in community settings. Education, prevention, material selection and source control are the most effective strategies in minimizing occupational exposure (International Labour Organization, 2000). Likewise, home owners and building occupants can apply similar principles for health protection. The control measures for man-made mineral fibres (MMMFs) include the prudent use of renovation or maintenance procedures, such as limited sanding, cutting and drilling of MMMF materials, that will reduce the release of fibrous glass, ceramic and mineral wool fibres into indoor air. In addition, exposed fibreglass insulation should not be present inside a ventilation system. Fibreglass insulation should be covered with a barrier, such as an aluminized fabric covering. Routine inspection and maintenance of ventilation systems should ensure that damaged coverings are repaired and that there is no exposed insulation subject to air erosion.

IV.C.2.4 Lead

To minimize the exposure of people and especially children, to airborne lead, it is recommended to observe the following steps (Health Canada, 1995).

- Keep areas where children play as dust-free and clean as possible. Where lead-painted surfaces are in good condition, lead exposure in the home can be controlled to some degree by frequent and thorough cleaning of surfaces suspected of being lead-contaminated.
- Leave lead-based paint undisturbed if it is in good condition; do not sand or burn off paint that may contain lead.
- Do not remove lead paint yourself.
- Do not bring lead dust into the home.
- If your work or hobby involves lead, change clothes and use doormats before entering your home. When engaging in activities in the indoor environment that produce lead (indoor hobbies such as stained glasswork and soldering, etc.) ensure that the area is well ventilated. Always wear a HEPA respirator when work involves lead. Alternatively, replace lead solder with no-lead solder.
- Eat a balanced diet, rich in calcium and iron.
- **Control measures for lead-based paint**

The following control measures are adapted and modified from *Indoor Air Quality Assessment. A Working Manual* (Calgary Health Region, 1993).

Small removal projects

For small-scale one-room paint removal projects or any project involving repair, enclosure, or demolition, the following safety precautions should be taken:

- Isolate the work area using plastic sheets or tarps to create an air-tight seal. Cover all recesses and cavities where dust may accumulate. Cover carpets with ripstop plastic sheets sealed along the perimeter edges using tape.
- Wear disposable overalls, footwear and head coverings. Alternatively, clothing can be washed providing that they are washed twice and air-dried. HEPA cartridge respirators should be worn at all times inside the work area. Remove contaminated clothing in the work area (except respirators) and wash hands, face and respirator (do not wet filters) immediately upon re-entry into a clean area. Keep susceptible population groups out of the work area, such as pregnant women, children—especially those six years of age and under—and people with high blood pressure.
- Do not use a heat gun or sander to strip surfaces coated with lead-based paint. Sanding sends a cloud of lead laden dust throughout the home and stripping with a heat gun vaporizes the paint, creating lead fumes. Alternative stripping methods include scraping by hand or the use of paint removers.
- If possible use a high-efficiency particulate air (HEPA) filter-equipped vacuum cleaner with the motor located outdoors or indoors to create negative pressure in

- the work area. If locating the HEPA filter-equipped vacuum cleaner indoors, ensure that the integrity of the filter and filter assembly have been tested (DOP test).
- Do not eat, drink, or smoke while removing the paint and practice good hygiene habits, such as thorough handwashing.
 - Follow other specified precautions when using paint removers. For example, do not use paint removers that have solvents that may explode or be an inhalation hazard. The use of nontoxic nonsolvent paint removers is recommended.
 - During removal, mist the air with a fine spray of water to reduce airborne lead-dust levels. Turn off and unplug electrical equipment and appliances electricals to reduce the risk of electrocution.
 - Clean the area thoroughly after completing the work including removing all dust and paint chips. Further cleaning should consist of the following:
 - ▶ Using a HEPA filter-equipped vacuum cleaner to clean all work area surfaces.
 - ▶ Washing all work area surfaces with a five per cent solution of trisodium phosphate (TSP).
 - ▶ Allowing surfaces to dry and vacuum them again.
 - Applying a sealer, paint and primer to all surfaces in the work area. Sealers used in the asbestos industry are also appropriate and can be purchased from local safety supply retailers.
 - ▶ Washing all work area surfaces with TSP. After the work area is dry, clean all surfaces and then HEPA vacuum the work area.
 - If you do not have a HEPA filter-equipped vacuum cleaner, using a wet vacuum cleaner is acceptable, but the surfaces being cleaned must be wet and the vacuuming must occur at the end of the two wash cycles rather than in the middle. For additional information on HEPA filters, refer to section B.2 of this chapter.. Because the wet vacuum cleaner will be contaminated with lead dust after use, decontamination is recommended.
 - As an option, collect dust samples from various areas to confirm the work area is ready for re-occupancy. Collect a sample by wiping a 900 cm² template (one square foot) with a commercially available wet-wipe or moistened towelette and place it in a re-sealable plastic bag. Wear disposable gloves when collecting the sample.
 - Remove all polyethylene sheeting; the area is now ready for re-occupancy. As a precaution, wash the area immediately with a mild solution of TSP, approximately once each week, for four weeks.
 - Call appropriate authorities, such as the local municipality or provincial environment department, before disposing off lead-containing waste products. Homeowners may dispose of lead-containing materials by placing them in double bagged regular garbage bags and labeling the bags appropriately. The

garbage collector should be made aware of the lead-containing waste products. However, disposal of lead waste by contractors should be done at approved landfill facilities.

- **Procedures for the enclosure, encapsulation and minor repair of localized damaged paint** (Calgary Health Region, 1994):
 - Turn off the ventilatory system.
 - Tape a polyethylene sheet below the repair area of sufficient dimensions to capture any debris. Seal all openings and cracks in the vicinity where dust may accumulate.
 - Ensure other occupants do not have access to the room where the repair work is being done.
 - Wear protective equipment, such as a HEPA respirator.
 - Lightly mist the area to be repaired with water.
 - Complete the repair work. During work, mist the air often with water so that airborne dust will settle onto the surface of the polyethylene.
 - Bag waste immediately and clean the work area and vicinity thoroughly. Wash with TSP twice. Dispose of the polyethylene drop sheet as contaminated waste.
 - Wash hands, face and respirator after all work is completed.

Large removal lead-removal projects

For large-scale removal projects involving whole houses or multiple rooms, the following safety precautions, in addition to those recommended for small-scale removal projects, should apply:

- Install a clean change room and a dirty room between the work area and non-contaminated area, with S-shaped curtain doorways between each room. The dirty room is used for removing contaminated clothing and washing hands and face before leaving the work area. Leave the respirator on.. The clean room is used for re-washing hands and face and for storing street clothing. Workers should take a shower at the end of each day's work.
- Create negative air flow in the work area, if required, by installing a negative-air fan unit equipped with a HEPA filter exhausting to the outside.
- The use of specialized contractors is recommended to complete large-scale projects.

Source: Office of Public and Indian Housing, Department of Housing and Urban Development, Lead-based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing, U.S. Department of Housing and Urban Development, Washington, D.C., September 1990.

The general mitigation procedures for lead are similar to the protocols developed for asbestos. The reader should refer to *Alberta Asbestos Abatement Manual* (Government of Alberta, 2011) for more information. The reader is also advised to refer to *Precautions with Lead-based Paints, A Safety Information Booklet* (Calgary Health Region, 1994) for additional information on lead-based paint, its control and abatement.

IV.C.3 Environmental Tobacco Smoke (ETS)

The biologic mechanisms review in the U.S. Surgeon General's Report (2006) suggests that any exposure to ETS will increase the risk for adverse health outcomes including a wide range of acute and chronic adverse health effects in infants, children and adults mentioned in Section 3.

“The only means of effectively eliminating health risks associated with indoor exposure is to ban smoking activity.”

—U.S. Surgeon General's Report (2006)

The Institute of Medicine (IOM) report *Secondhand-Smoke Exposure and Cardiovascular Effects: Making Sense of the Evidence* (2009) confirms that eliminating smoking in workplaces, restaurants, bars and other public places is an effective way to protect Americans from the health effects of second-hand smoke, particularly on the cardiovascular system. The IOM also concluded that the evidence is compelling that even brief second-hand smoke exposure could trigger a heart attack.

ETS has been classified as a Group A carcinogen under EPA's carcinogen assessment guidelines. International Agency for Research on Cancer (IARC) also classifies ETS as a Group 1 agent, carcinogenic to humans with a well-established link to lung cancer. There is no safe level of exposure to known human carcinogens.

Because there is no safe level of exposure to ETS, the only effective means to reduce cancer risk associated with ETS exposure is to eliminate indoor smoke activities. The following control measures are presented for discussion purpose but are not recommended or viable options in real practice.

- **Dedicated ETS areas**

The U.S. Surgeon General's Report (2006) concluded the following:

“ . . . eliminating smoking in indoor spaces fully protects nonsmokers from exposure to second-hand smoke. Separating smokers from nonsmokers, cleaning the air and ventilating buildings cannot eliminate exposures of nonsmokers to second-hand smoke.”

—U.S. Surgeon General's Report 2006

Supporting evidence adds:

- Conventional air cleaning systems can remove large particles, but not the smaller particles or the gases found in second-hand smoke.
- Current heating, ventilating and air conditioning systems alone do not control second-hand smoke exposure. In fact, these systems may distribute second-hand smoke throughout a building.
- Even separately enclosed, separately exhausted, negative-pressure smoking rooms do not keep second-hand smoke from spilling into adjacent areas.

ASHRAE, the U.S. standard-setting body on ventilation issues, does not completely prohibit smoking in all building classifications. It provides some requirements for

building containing ETS areas and ETS-free areas in Section 5.17.1 through 5.17.8. The requirements include pressurization, separation, air transfer flow rate, recirculation, exhaust system, signage, are classification, etc. (ASHRAE 62.1 -2010). However, meeting these requirements do not “purport to achieve acceptable indoor air quality in ETS areas” (quoted page 10, ASHRAE 62.1 -2010).

In addition, some exposure to ETS tars and other compounds is likely to occur during cleaning and maintenance of a dedicated smoking room and also during the maintenance of the exhaust only ventilation system. These exposures will occur via inhalation and dermal contact while cleaning. Consequently, an unacceptable exposure risk may still exist for some staff or workers who are involved in cleaning and maintenance activities. The construction and maintenance cost may be prohibitive for small businesses, which again introduces an element of economic inequity or unfairness in the application of a policy that allows separately ventilated smoking rooms. Such a policy discriminates against smaller businesses that may not have the same economic resources as large businesses.

The health risks associated with cleaning and maintenance activity can only be described qualitatively. During smoking, tars and other semivolatile compounds are deposited on surfaces in a room including the interior of ventilation ducts and on duct fans. At the end of the smoking activity, tars and other semivolatile compounds will, because of equilibrium phenomena, re-emit hazardous compounds into the air. In addition, cleaning and maintenance workers will be exposed to those hazardous compounds by dermal contact.

- **Two Scenarios**

The following two-scenarios illustrate the potential health risks to cleaning and maintenance staff from smoking tars deposited in an area partitioned smoking and nonsmoking restaurant and a dedicated smoking room. The example also illustrates why municipal bylaws aimed at allowing smoking only during certain hours of the day are not feasible. It also demonstrates the potential health risk to patrons, especially to children who commonly exhibit hand-to-mouth behaviour in a restaurant where smoking is permitted either in partitioned or temporally segregated areas.

- ▶ **Scenario one**

Two smokers smoking two cigarettes per hour, eight hours per day in a 30 m x 30 m room will result a deposit of approximately one kilogram of toxic tars every four years. ETS tars will be deposited on all surfaces inside the room where there is smoking: on windows, countertops, tables, walls, ceilings, clothing, food and inside ventilation ducts.

- ▶ **Scenario two**

If a 100 m² restaurant has occupancy of 70 persons (as per ASHRAE Standard 62-1999), an average occupancy factor of 50 per cent and a smoking prevalence of 1 in 3, there will be a daily average of about 12 smokers. Assuming the restaurant is open 360 days per year and that each cigarette emits 14 mg of tar, about 60,000 mg of tobacco tar will be liberated into the space, of which perhaps 25 per cent will be deposited on the room surfaces. Therefore, 15,000 mg of a semi-volatile mixture of organic material

which has evaporation times ranging from days to months, will be deposited and out gassed on room surfaces annually. Eventually, the building will become just like a toxic waste dump. Nonsmokers will be exposed to re-emitted tobacco tar. There is also the risk of dermal contact in these buildings (Repace J., personal communication).

- **Ventilation**

Alternative procedures such as the implementation of improved ventilation, electronic air filters, other air filtration technology as well as separating smokers and non-smokers can be put into place in buildings to control or reduce ETS exposure. However, these control measures will only reduce but not eliminate exposure to ETS.

Since smoking generates such diverse and toxic quantities of pollutants, natural or mechanical ventilation methods are not capable of removing these pollutants from the indoor environment, as fast as they build up or to the degree that would render them harmless (USEPA, 1995).

“Ventilation provides no solution to the problem of exposure to second-hand smoke.”

—Protection from second-hand tobacco smoke in Canada: Applying health science to occupational health and safety law (Collishaw & Meldrum, 2002)

Most commercial and residential buildings in Alberta and Canada are ventilated by furnaces or air-handling units. These systems are classified as “dilution ventilation” systems, operating on the principle of introducing outdoor air into indoor environments to dilute levels of indoor contaminants.

Dilution ventilation is an acceptable practice for handling relatively nontoxic indoor air. However, this ventilation system is not considered acceptable for handling toxic environments, such as chemical contaminants generated by industrial workplaces or ETS contaminated spaces.

. . . dilution ventilation, air cleaning or displacement ventilation technology (a new unproven ETS control technology) even under moderate smoking conditions cannot control ETS risk to de minimis levels for workers or patrons in hospitality venues without massively impractical increases in ventilation.

—Repace (2000)

General or dilution ventilation can only reduce the indoor concentration of ETS by diluting it with conditioned outdoor supply air. However, it cannot prevent ETS exposure. In addition, an HVAC system can redistribute ETS contaminated return air throughout a building to effectively contaminate the whole building and expose all occupants (Spengler, 1999). Repace (2000) reported:

IV.C.3.1 Air filtration

Air cleaning is not been an effective method for controlling ETS exposure. Devices such as smoke-eaters, electronic air cleaners, ozonators and mechanical or chemical filtration should be dismissed as ineffective for ETS control (American Lung Association and the American Thoracic Society, 1997, cited in Samet and Wang, 2001).

ETS is a complex mixture of about 4,000 compounds distributed among combustion gases, volatiles and particulates. Some of the major toxics include fine respirable particulates, nicotine, carbon monoxide, nitrogen oxides, acrolein, formaldehyde, acetaldehyde and cancer-causing chemicals such as arsenic, vinyl chloride, benzene, nitrosamines and polycyclic aromatic hydrocarbons (PAHs). Filtration of these diverse compounds is extremely complex and a filtration system capable of removing these contaminants does not commercially exist and may not be viable.

One researcher recommended starting with a 5 cm-deep filter with a 30% particulate capture efficiency, a 30 cm-deep 90% high-efficiency particulate filter, an activated carbon filter for volatiles and a final 10 cm-deep 30% particulate filter. However, this filter combination does not trap combustion gases or low molecular weight compounds such as formaldehyde and acrolein.

Even if a filter existed that was 100% effective, such a filter would not reduce contaminant levels in a restaurant to acceptable levels because general or dilution ventilation ensures that ETS contaminants have a half-life in the indoor space before they are captured by the return air system and brought into contact with filtration beds. Because of this delay in return air capture and filtration, restaurant occupants will inhale unacceptable levels of ETS contaminants.

IV.C.4 Radon

According to researchers at the U.S. National Cancer Institute, one of the most important steps for significantly reducing the risk of radon-induced cancer is to stop smoking (Minnesota Department of Health 1991). Since it is impossible to know which homes will have elevated levels without testing, the only way to determine whether your home has a high radon level is to test for it (Health Canada, 2008).

IV.C.4.1 Test for radon

Testing is easy and inexpensive. Most homes can be fixed for about the same cost as other common home repairs (Health Canada, 2008).

There are several types of devices that can be used to test a dwelling for radon. Short term radon test devices are typically used for a two to seven-day period of time, long-term radon test devices are used for three to 12 months. Since the radon concentration inside a home varies over time, measurements gathered over a longer period of time will give a much better indication of the annual average radon concentration. Health Canada recommends that homes be tested for a minimum of three months, ideally between October and April. For more information on how to test visit the Health Canada Web site www.healthcanada.gc.ca/radon

Long-term radon detectors commonly used are:

- Alpha track detection
- Electret ion chamber

There are two options for testing a house for radon: (1) purchase a do-it-yourself radon test kit, (2) hire a radon measurement professional.

Health Canada's document, *A Guide for Radon Measurements in Residential Dwellings (Homes)*, is available for concerned people who require guidance regarding types of measurement devices, device placement, measurement duration and the interpretation of measurement results in homes (available at http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/radiation/radon_homes-maisons/radon_homes-maisons-eng.pdf). A separate guide, *Guide for Radon Measurements in Public Buildings*, is also available for assessing radon in residential public buildings, such as hospitals, schools and long-term care facilities (available at http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/radiation/radon_building-edifices/radon_building-edifices-eng.pdf).

IV.C.4.2 Remediation of radon in existing homes

Remediation can be done through the following measures:

1. Seal major entry routes for radon such as sump holes, cracks and openings in walls and floors and around pipes and drains and disposed soil and rock in crawlspaces.
2. Increase the ventilation and exchange of air by opening a window, using an air exchanger or heat recovery ventilator (HRV).
3. Reduce negative air pressure in the building so that gas is not drawn up from underlying basement soil into the building. A well-functioning HVAC system can ensure positive pressure in the building. However, most home furnaces operate

intermittently in the summer and winter, to provide either demand cooling or heating and therefore cannot be relied upon to create sustained positive pressures.

4. Ventilate the soil beneath your basement floor slab.

The effectiveness of any above method will depend on unique characteristics of your home, the level of radon and the routes of radon entry.

IV.C.4.3 Control measures for new homes

When considering sites for new house construction, various factors should be considered including (Godish, 1989):

- **Soil permeability**

Increased permeability will facilitate the migration of radon within soil. Soil permeability is a site-specific variable determined by consulting "soil maps." For instance, clay soil will retard the movement of radon while sandy or gravelly soil will offer minimal restriction to the upward migration of radon gas.

- **Unstable soils**

Soils predisposed to frost heaving and or having high shrink-swell capacities may be unstable; therefore, causing the settling and cracking of subsurface structures, such as basements.

- **Site selection**

In areas where radon is a concern, homes should not be constructed on (a) glacially deposited materials such as eskers and kames because of increased soil permeability, or (b) the top of uranium and phosphate tailings as they have the potential for high radon concentrations.

Radon reduction measures, which can be used to reduce radon levels in newly constructed homes, include the following (Godish, 1989):

- If a specific housing site is identified as a high radon-emanating location, the site can be modified before construction by removing the high-radon soil and replacing it with low emanating fill.
- Apply an impermeable plastic barrier between the slab foundation and surrounding aggregate (a 6 ml polyethylene vapour barrier).
- Install a complete drainage tile system surrounding the basement perimeter of the building.
- Properly waterproof basement walls, capping of all sumps and sealing all service utility entries, such as electrical conduits, water pipes, etc.

Overall, when new homes are constructed in areas associated with high levels of radon, the homes should be:

- Designed to minimize pathways for soil gas to entry into buildings
- Constructed to maintain neutral pressure differentials between the indoors and outdoors

- Incorporated with mechanisms to remove radon after completion of the home in case prevention techniques prove to be inadequate (USEPA, 1987)

IV.C.4.4 Removal or radon from household water

Radon can be removed from water by using one of two methods (CDC, 2010):

- Aeration treatment

This treatment involves spraying water or mixing it with air, and then venting the air from the water before use. However, home aeration devices have not undergone broad testing or evaluation to determine their efficiency in removing radon from water sources.

- GAC treatment

This treatment involves filtering water through granular activated carbon. Radon attaches to the carbon and leaves the water free of radon. Disposing of the carbon may require special handling if it is used at a high radon level or if it has been used for a long time.

A GAC tank, which is similar in appearance to a water softener tank, has a radon collection efficiency up to 99 per cent (USEPA, 1987). Small carbon water filters, such as those normally attached to kitchen faucets or placed under the sink, are not large enough to lower radon levels in water.

As was mentioned previously, the various control measures outlined above are not presented in great detail, nor do they represent the only control options available. It is also important to note that no two structures are alike with regard to radon infiltration, building design, air exchange rates and atmospheric conditions.

Consequently, even homes located in close proximity to one another and similar in structure, will have unique conditions that can lead to quite different radon levels.

Therefore, site-specific control measures are recommended

IV.C.5 .Biological factors

IV.C.5.1 Mould

In general, control measures for indoor environments are directed at source control and prevention and universally involve moisture control. These practices include controlling humidity, ventilation and other factors related to building materials and building structures.

In all situations, the underlying moisture problem must be corrected to prevent recurring mould growth. Indoor moisture can result from numerous causes, such as façade and roof leaks, plumbing leaks, floods, condensation and high relative humidity. An appropriate building expert may be needed to identify and repair building problems. An immediate response and thorough cleaning, drying and removal of water-damaged materials will prevent or limit microbial growth.

Relative humidity should generally be maintained at levels below 65 per cent to inhibit mould growth. Short-term periods of higher humidity would not be expected to result in mould growth. However, condensation on cold surfaces could result in water accumulation at much lower relative humidity levels. Relative humidity should be kept low enough to prevent condensation on windows and other surfaces.

Emphasis should be placed on ensuring proper repairs of the building infrastructure so that water intrusion and moisture accumulation is stopped and does not recur.

Health Canada's *Residential Indoor Air Quality Guideline – Moulds* (2007) considers mould growth in residential buildings as a potential health hazard. Health risks depend on exposure and, for asthma symptoms, on allergic sensitization. However, the large number of mould species and strains growing in buildings and the wide-individual response to mould exposure precludes setting definite exposure limits. Therefore, Health Canada (2007) provides the following preventative and remedial measures to:

- Control humidity and diligently repair any water damage in residences to prevent mould growth.
- Clean thoroughly any visible or concealed mould growing in residential buildings.

These two recommendations apply regardless of the mould species found growing in the building. Further, in the absence of exposure limits, results from tests for the presence of fungi in air cannot be used to assess the health risks of building occupants.

Health Canada has published several other documents related to fungal contamination. The reader is advised to refer to *Fungal contamination in public buildings: A guide to recognition and management*. This publication primarily focuses on how to investigate and mitigate fungal contamination. The guide was developed to assist health professionals and IAQ experts to recognize and manage fungal contamination problems in public buildings. Health Canada (2004) has recommended that the guide be followed during indoor air investigation of all public buildings, except hospitals and buildings in industrial settings. The guide presents a step-by-step protocol for fungal contamination analysis and investigation.

- Phase I Assessing the magnitude of the health problem
- Phase II Identification of problems in the building environment
- Phase III Sampling and Identification of indoor fungal amplifiers
- Phase IV Risk communication
- Phase V Destructive sampling, if required
- Phase VI Remedial actions based on findings

The reader is advised to refer to the original publication for an extensive discussion on the various phases of investigation and remediation. The guide is available at http://www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/fungal.pdf.

Another publication by Health Canada, entitled, *Indoor Air Quality in Office Buildings: A Technical Guide* is also available. This publication primarily focuses on office buildings and provides recommendations including an investigation protocol. The report recommends several strategies for microbial remediation in buildings (Health Canada, 1995).

- Remove water sources that encourage fungal growth. Prevent the accumulation of standing water in and around HVAC system. Maintain a relative humidity at less than 60 per cent.
- Remove fungus-contaminated substrates, such as mouldy ceiling tiles and carpets. Wash all smooth surfaces with diluted five per cent bleach (250 mL/4L water).
- In HVAC systems, use direct-steam injection instead of recirculated water for humidification. If spray systems are used, a preventive maintenance program should also be put in place as these systems could become contaminated. Humidifiers should be drained and cleaned with chlorine bleach at intervals of two to four months. Rust and scale deposits should be cleaned and removed at least once or twice a year.
- Dirty contaminated insulation should be quickly removed.
- Personal portable humidifiers should not be allowed in offices.
- Use prefilters and extended face-type secondary filters with dust sport efficiency > 85 per cent. Replace prefilters 4 to 6 times a year and secondary filters once a year
- **Remediation of mould-affected areas**

(New York City Department of Health and Alberta Health Services)

New York Department of Health (NYDH, 2008) has five levels of remediation strategies determined by the extent of mould contamination, starting with small isolated areas less than 10 square feet or one square metre. The goal of remediation is the controlled removal and cleaning of mould-contaminated materials and surfaces to prevent mould aerosols from contaminating adjacent areas. Another goal of fungal remediation is to protect the health of workers performing the abatement work (NYDH, 2008). However, for very small mould-contaminated area, the remediation requirements can be less stringent. Alberta Health Services

Environmental Public Health (AHS EPH) has developed a protocol for the routine removal of mould contamination that is less than 1 ft² or 0.1 m² in size (AHS EPH, 2011).

- **Very small and localized areas**

(<1 ft² or 0.1 m²)

Building owners or regular maintenance staff can easily remediate these areas using standard cleaning techniques: scrubbing surfaces clean using a cleaning agent, such as e.g., soap and water solutions. The use of PPE is discretionary but recommended. At a minimum wash hands immediately after the work.

- **Small isolated areas**

(< 10 ft² or 1 m², examples: ceiling tiles, small areas on walls)

- ▶ The areas can be cleaned by building staff who have received training including proper cleaning methods and personal protection.
- ▶ Individuals associated with cleanup projects should be free from ailments such as asthma, allergy and immune disorders. Workers should wear gloves, eye protection and approved disposable respirators, such as a N95.
- ▶ The work area should be unoccupied.
- ▶ If work affects difficult-to-clean surfaces or items, such as carpeting and electronic equipment, cover the work-area floor, egress pathways and other materials and belongings with plastic sheeting and sealed the sheeting with tape.

Efforts should be made to reduce dust generation. Dust suppression methods particularly during any cutting or re-surfacing of materials are highly recommended. Methods to consider include: cleaning or gently misting surfaces with a diluted soap or detergent solution before removal; the use of High-Efficiency Particulate Air (HEPA) vacuum-shrouded tools; or using a vacuum equipped with a HEPA filter at the point of dust generation. Work practices that create excessive dust should be avoided.

- ▶ Mouldy materials that can be cleaned should be cleaned using a soap or detergent solution. Contaminated materials that can't be cleaned should be removed from the building in a sealed plastic bag. There are no special requirements for the disposal of mouldy materials.
- ▶ The work area and areas used by workers for egress should be cleaned up with a vacuum equipped with a High-Efficiency Particulate Air (HEPA) filter or wiped up with a soap or detergent solution on a damp cloth and or mop
- ▶ All areas should be left dry and visibly free from mould, dust and debris.

- **Medium-sized isolated areas**

(10 ft² to 100 ft² or 1 m² to 9 m²)

Perform all the preceding recommendations plus the following ones:

- ▶ Cover the floor, egress pathways and items left in the work area with plastic sheeting and seal with tape before remediation.
- ▶ Seal ventilation ducts and grills and other openings in the work area with plastic sheeting. The HVAC system servicing this area may need to be shut down to properly seal vents
- ▶ A polyethylene sheet containment barrier should be erected around the work area.
- ▶ After contaminated materials are removed, the areas should be HEPA vacuumed and cleaned with a detergent solution on damp cloth or mop.

○ **Large areas**

(> 100 ft² or 9 m² of contiguous mould. Example: 100 ft² or 9 m² of combined mould-contaminated surfaces on all walls in a single room)

Perform all the preceding recommendations plus the following ones:

- ▶ Hire personnel trained in the handling of mould-damaged materials equipped with the following protective equipment:
 - ◇ A minimum of half-face elastomeric respirators with P-100 filters used in accordance with the OSHA respiratory protection standard (29 CFR 1910.134)
 - ◇ Full-body coveralls with head and foot coverings
 - ◇ Gloves and eye protection
- ▶ To contain of the affected area, do the following:
 - ◇ The HVAC system servicing this area should be shut down during remediation.
 - ◇ Isolate the work area by using plastic sheeting sealed with duct tape. Furnishings should be removed from the area. Ventilation ducts and grills plus any other openings and remaining fixtures and furnishings should be covered with plastic sheeting sealed with duct tape.
 - ◇ Consider using an exhaust fan equipped with a HEPA filter to generate negative pressurization.
 - ◇ Consider using airlocks and a clean changing room. Egress pathways should also be covered if a clean changing room is not used.
 - ◇ Before leaving isolated areas, workers should remove disposable clothing to prevent the tracking of mould-containing dusts outside of the work area.

○ **Remediation of HVAC Systems**

Mould growth in heating, ventilation and air-conditioning (HVAC) systems can pose building-wide problems. Obtaining professional help should always be considered in resolving even small amounts of mould growth or moisture problems within an HVAC system. Recurring problems, regardless of size, may suggest a systemic problem and appropriate professional help should be sought. The use of disinfectant inside air handling and duct systems is not permitted in

Canada. Health Canada does not provide a DIN¹⁷ for disinfectant use inside HVAC systems. Please check and confirm.

▶ **Small isolated area of mould growth**

- ▶ (<10 ft², example: box filter or a small area on insulation)

Carry out all the preceding recommendations provided for small isolated area remediation plus the following ones:

- ◇ Shut down HVAC system.
- ◇ Erect containment and use wet suppression.
- ◇ Work area and immediate surroundings should be HEPA vacuumed and cleaned with a damp cloth or mop and a detergent solution.

Large areas of mould growth (>10 ft²)

All the recommendations provided above plus the following:

- ◇ Have work performed by expert professionals.
- ◇ Use plastic sheeting sealed with duct tape to isolate the work area from the other areas of the HVAC system.
- ◇ Consider using an exhaust fan equipped with a HEPA filter to generate negative pressurization should be considered.
- ◇ Consider using airlocks and a clean changing room. Perform air clearance before re-occupancy with HVAC operational.
- ◇ Cover egress pathways if a clean changing room is not used.

More information can be found from the following sources:

1. *Mould Guidelines for the Canadian Construction Industry* (Canadian Construction Association, 2004)¹⁷
2. *Guidelines on Assessment and Remediation of Fungi in Indoor Environments* (New York City Department of Health and Mental Hygiene, 2008)
www.nyc.gov/html/doh/html/epi/mouldrpt1.shtml
3. *Fungal Contamination in Public Buildings: Health Effects and Investigation Methods* (Health Canada, 2004) www.hc-sc.gc.ca
4. *Flood Cleanup: Avoiding Indoor Air Quality Problems Fact Sheet* (US EPA, 2003).
<http://www.epa.gov/iaq/pdfs/floods.pdf>
5. *A Brief Guide to Mould, Moisture and Your Home* (US EPA, 2010).
<http://www.epa.gov/mould/pdfs/mouldguide.pdf>
6. *Mould Prevention Strategies and Possible Health Effects in the Aftermath of Hurricanes and Major Floods* (Centers for Disease Control and Prevention, 2006)
<http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5508a1.htm>
7. *Best Practices for Mould at the Worksites* (Government of Alberta – Employment and Immigration, Occupational Health and Safety)
<http://employment.alberta.ca/documents/WHS/WHS-PUB-BH019.pdf>

¹⁷ www.cca-acc.com/mould

IV.C.5.2 Dust mites

CMHC (2008) recommends the following strategies to control dust mites (available at http://www.cmhc-schl.gc.ca/en/co/maho/yohoyohe/inaiqu/inaiqu_005.cfm):

- Reduce the relative humidity (RH) in your house to reduce dust mites and mould. Dust mites need RH above 55 per cent to grow. The most effective way to prevent the growth of dust mites is to reduce the RH of your house in the winter. The Canadian asthma consensus report (1999) recommends humidity levels below 50 per cent.
- Vacuum thoroughly and often since dust mites are a component of household dust. Use a vacuum cleaner with a HEPA filter or a central vacuum that exhausts to the outside.
- Wear an N95 respirator while vacuuming. Sensitive individuals and children should keep away from the immediate area. This will help reduce exposure to dust mites that become airborne with fine dust.
- Properly maintain furnace filters. This can reduce fine particles in your air distribution system that can be a home for dust mites (see CMHC's *About Your House fact sheet Your Furnace Filter*). To further reduce the amount of dust circulated by your air distribution system, regularly vacuum as far as you can reach into air registers and return ducts. If you find that the return air ducts are dirty, or if the ducts have not been cleaned since the house was built or you moved in, have your ducts cleaned. Ensure that the contractor does not spray chemicals, such as fungicides, disinfectants or essential oils into the ducts.
- Reduce the amount of particulates you bring into the house by taking off your shoes upon entry and by using washable doormats.
- Using a HEPA vacuum or dusting with damp cloth instead of dry one will help control dust (Canadian Partnership for Children's Health & Environment, 2005).
- Reduce the amount of upholstered furnishings and fabric coverings in your bedroom that can provide a home for dust mites.
- Wearing an N95 respirator while HEPA-vacuuming upholstered furnishings
- Avoid carpeting. Carpets are good dust collectors that can hold dust mites.
- Use the following strategies in bedrooms and other sleeping areas:
 - Change bedding often.
 - Wash bedding in warm water. Contrary to popular belief, hot water is not needed to kill dust mites. A warm water wash with pre-soaking is effective in controlling dust mites (Vyszynski-Moher, Arlian and Neal, 2002).
 - Use washable linens such as cotton with small enough pore size (for example, 200 thread count). Washing bedding often is more important than encasing a mattress with a cover that cannot be removed easily for cleaning.
 - Vacuum mattresses with a HEPA vacuum periodically.
 - Replace pillows at least once a year.

- Avoid the use of “acaricides,” which are pesticides that kill dust mites.
- After you get out of bed, don’t make your bed right away, but allow sheets, duvets and blankets to dry.

IV.C.5.3 Other insect allergens (cockroaches)

The following control measures are recommended to reduce exposure and eliminate cockroach allergens (Platt-Mills 2001, cited in Spengler et al. 2001, Barbara 2000) from indoors:

- Remove food sources.
- Bait trap stations or use boric acid where cockroach debris are found.
- Eliminate sites where cockroach can breed.
- Periodically inspect hard-to-reach places.
- Remove rotting leaves.
- Get rid of moist areas in and around a structure.
- Apply approved insecticides to basement walls, wood scraps and other locations.

Specific control measures vary by species, but the most successful and effective method for the control or elimination of an infestation is to establish an integrated pest management (IPM) program that includes identification, sanitation, exclusion, trapping/physical removal and chemical treatment. A detailed discussion of each of these steps is beyond the scope of this manual. (The reader should refer to the *Public Health Pest Control Manual* for additional information. The manual is available at <http://vector.ifas.ufl.edu/manual.htm>).

IV.C.5.4 Animal allergens

Allergens from both pets and wild animals need to be considered.

- **Dogs and cats**

The following general control measures or avoidance measures can be carried out to reduce exposure to dog and cat allergens.

- If possible, keep animals outside. Removal of a dog in one study improved asthma symptoms (cited in IOM, 2000).
- More frequent indoor vacuuming and wet-mopping may help reduce indoor levels of allergens. HEPA vacuums or vacuflows exhausted to the outdoors are recommended.
- Use effective air filtration.
- Wash animals regularly (twice a week is recommended) to reduce indoor allergen levels (IOM, 2000).

- **Pets and rodents**

- Strategies for minimizing the risk of hantavirus

The only confirmed carrier of the hantavirus in Alberta is the deer mouse, which has reddish-brown or grey fur, but always has white fur on the underside of the neck, belly, feet and tail. However, it is possible that other rodents may carry the virus as it is not always easy to determine what kind of mouse one is exposed to, particularly when the only evidence is droppings.

The virus does not appear to either affect the virus-carrying mice or pets. But dogs and cats which are exposed to the virus can pass the infection on to their owners. The main risk of infection comes from being exposed to accumulations of mouse droppings in enclosed areas, such as cleaning a garage or shed that mice have been living in during the winter. Hantavirus is passed to humans when they breathe in airborne particles released from the droppings, fresh urine, or nesting materials of infected rodents.

- ▶ All rodents should be treated as potential carriers.
- ▶ All rodent droppings should be treated as potentially harmful.
- ▶ The primary strategy for minimizing risk of being exposed to hantavirus is to ensure rodent control with the following strategies:
 - ◇ Keep mice out of homes and work areas and immediately trap any that get inside the house. Block openings that might allow rodents from entering.
 - ◇ Store human and animal food, water and garbage in containers with tightly fitted lids.
 - ◇ Keep yards clean and store woodpiles above the ground and away from the home.
 - ◇ When cleaning homes or other buildings, be aware of animal droppings and nesting materials. If you find any, clean them up safely. When you

begin cleaning, disturb the mouse droppings and nesting material as little as possible.

- ◇ Do not sweep or vacuum rodent droppings; this will release particles into the air where they can be inhaled.
- ◇ For at least 30 minutes before cleaning, ventilate enclosed areas by opening doors and windows. Stay out of the area while it airs out.
- ▶ Properly clean animal droppings
 - ◇ Wear rubber or plastic gloves to handle the droppings. Soak droppings with disinfectant (1.5 cups bleach to 1 gallon water or one part bleach, nine parts water) before mopping them up or picking them up with a paper towel. Make sure you get the droppings very wet. Let the area soak for 10 minutes. Place them in a sealed bag and bury it, or put it out for removal in garbage cans with tight-fitting lids.
 - ◇ Use a paper towel to wipe up the droppings. Dispose of the paper towel immediately.
 - ◇ Wash gloves in disinfectant and hot soapy water before removing them from your hands and then thoroughly wash your hands after removing gloves.
 - ◇ People who are likely to be exposed to high levels of contamination or are in areas with little ventilation should wear a (HEPA) filtered respirator or respirator-type mask with a filter rating of N100 or greater).
 - ◇ Do not sweep or use a vacuum cleaner to remove droppings in an enclosed space.

Hantavirus is not a new public health risk and there is no evidence that the virus is increasing or spreading. All that is new is our ability to recognize it and deal with it more effectively through early diagnosis and treatment.

Additional references:

1. *Alberta Health and Wellness Public Health Management Guidelines: Hantavirus*. Available at <http://www.health.alberta.ca/documents/ND-Hantavirus.pdf> (Accessed Feb 6, 2012).
2. *Alberta Health and Wellness Disease and Conditions: Hantavirus*. Available at <http://www.health.alberta.ca/health-info/hantavirus.html> (Accessed Feb. 6, 2012).
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IV.C.5.5 Bacteria

- **Legionella bacteria**

Several regulatory agencies, such as CDC and ASHRAE, have provided guidelines and recommendations to control or remediate Legionella bacteria contamination of indoor sources.

Legionella are ubiquitous in the environment. Therefore, a complete eradication of those organisms from indoor sources may not be possible (Barry, 2001, cited in Spengler et al., 2001). Periodic checking and maintenance of indoor sources (see Box III-B-6) is essential to minimize contamination (Barry, 2001; Spengler et al., 2001). Detection of a low level of Legionella bacteria ranging from 50 to 100 CFU/mL will require the implementation of an effective maintenance protocol to avoid a Legionella outbreak. CDC has developed several disinfection procedures for potable water systems and cooling towers that are contaminated with Legionella (CDC, 1994b).

- **Potable water systems**

Maintenance of potable water systems from Legionella contamination involves a one-time thermal disinfection process, which can be accomplished by:

- ▶ Raising the temperature of water to 65°C (150°F) in the hot water tank
- ▶ Flushing each water outlet for five minutes
- ▶ Eliminating dead lines

- **Cooling towers**

CDC has recommended a four-stage process of disinfection of cooling towers (Barry 2001, cited in Spengler et al. 2001):

- ▶ **Preparation**

Inspect the cooling tower by wearing PPE (personal protective equipment). Shut down the cooling system unit.

- ▶ **Chemical disinfection**

Use a chlorine-based disinfectant, such as sodium hypochlorite or calcium hypochlorite, to obtain free residual chlorine (FRC) of 50 ppm. Additional chlorine use is needed to maintain a chlorine concentration of 10 ppm for 24 hours. Adjust the pH to 7.5 or 8.0. Add detergents to remove built-up materials, such as scale, slime and sludge in the piping. Monitor free residual chlorine and pH levels often (15 minutes intervals in first two hours and at two-hr interval within next 24 hours disinfection cycle).

- ▶ **Mechanical cleaning**

After chemical disinfection, shut down the cooling tower and evaporative condenser. Inspect all water contact areas for sediments and sludge. If sediments and sludge are present, remove them with the help of a brush or a low-pressure water hose. Thoroughly clean all water contact areas including

basin, sump, fill, spray nozzles and fittings. Replace old components with new ones.

► **Restart of the cooling tower**

After completion of the mechanical cleaning, complete the following steps:

- ◇ Fill the system with water. Add chlorine to achieve FRC level of 10 mg/L.
- ◇ Let the water circulate for one hour.
- ◇ Open the blowdown valve to flush the system until the water is free of any turbidity. Then, drain the system.
- ◇ Open any air intake vents that were closed before cleaning
- ◇ Fill the system with water.
- ◇ Restart the cooling tower and evaporative condenser by setting up an effective water treatment program.

A detailed cleaning procedure protocol including mechanical cleaning and restart procedure can be obtained by referring to CDC’s publication entitled, *Guidelines for Prevention of Nonsocomial Pneumonia, Respiratory Care* 39: 1202-1205. The guideline document can also be obtained from CDC’s website (<http://www.cdc.gov>).

Comprehensive cleaning of cooling tower systems should be done at least once or twice a year. Before full start up, cleaning of the system is recommended in the spring season. Another cleaning can be done during summer and fall when outbreaks are more likely to occur. The following remedial actions are suggested based on detection of Legionella bacteria in water samples from different sources (Barry, 2001, cited in Spengler et al., 2001) (see Table IV.C-2).

Table IV.C-2 Recommended remedial actions for Legionella

Legionella (CFU/mL) of sample	Recommended remedial action	
	Cooling tower	Potable water sources
Detectable but < 1	1	2
1-9	2	3
10-99	3	4
100-999	4	5
> 1000	5	5

Source: Spengler et al. (2001), In Indoor Air Quality Handbook, Chapter 48, Legionella, McGraw Hill publications, 2001

An explanation of each of the five remedial action steps is presented in the following box:

Explanation for remedial action levels

Remedial action level 1

- Review routine maintenance program recommended by the manufacturer of the equipment to ensure that the recommended program is being followed.
- The presence of barely detectable numbers of *Legionellae* represents a low level of concern.

Remedial action level 2

- Implement action 1.
- Conduct the follow-up analysis after a few weeks for evidence of further *Legionella* amplification.
- Level 2 *Legionellae* represents little concern, but the number of organisms detected indicates that the system is a potential amplifier for *Legionellae*.

Remedial action level 3

- Implement action 2.
- Conduct review of premises for direct and indirect bioaerosol contact with occupants and health risk status of people who may come in contact with the bioaerosol.
- Depending on the results of the review of the premises, action related to cleaning or biocide treatment of the equipment may be indicated.
- Level 3 *Legionellae* represents a low but increased level of concentration.

Remedial action level 4

- Implement action 3
- Cleaning or biocide treatment of the equipment is indicated.
- Level 4 *Legionellae* represents a moderately high level of concern because this level are may cause an outbreak.
- It is uncommon for samples to contain numbers of *Legionellae* that are in this category.

Remedial action level 5

- Immediate cleaning or biocide treatment of the equipment is definitely indicated.
- Conduct post treatment analysis to ensure effectiveness of the corrective action.
- Level 5 *Legionellae* represents a high level of concern because of the potential of an outbreak.
- It is very uncommon for samples to contain numbers of *Legionellae* that fall in this category.

IV.C.6 Consumer products factors

IV.C.6.1 General measures for reducing exposure to household chemicals

Several precautionary measures can be taken to reduce chemical exposure to various household products (USEPA, 1995)

1. Carefully follow label instructions.

Hazardous products usually bear warning labels. These warning labels contain directions for product use and handling. All warning labels are meant to inform the user and reduce the risk associated with product use and storage. If a particular warning label recommends that the product should be used in a well-ventilated area or with local exhaust ventilation, then the direction should be followed.

2. Safely dispose of unused chemical containers and cleaning agent bottles.

Gases and vapours can leak from closed containers. Proper disposal of any unused or unneeded chemical containers will help reduce personal exposure to potentially toxic chemicals. Consumer products such as paints, stains and solvents, such as varsol, can leak and; therefore' should be kept in a well-ventilated area, such as exhaust-ventilated storage cabinets. These consumer products should also be out of reach of children. Care should be taken not to dispose of these containers in the regular garbage. Instead take the containers to eco-stations or depots set up during spring clean-up times. The local waste collection agency or fire department can also be contacted for disposal information.

3. Minimize exposure to dry cleaned clothing.

Perchloroethylene (PERC or tetrachloroethylene) is used in the dry cleaning process. PERC has been shown to cause cancer in laboratory animals. People bringing home dry-cleaned clothing directly from a dry cleaning facility can be exposed to elevated levels of PERC via the off-gassing process. Although some dry cleaners are more effective than others at extracting PERC during the drying phase of the dry-cleaning process, take steps to minimize exposure to PERC from dry-cleaned clothing. For example, if dry-cleaned garments have a strong odour, ask the dry cleaner to get rid of the odour by properly drying them. PERC has a relatively high odour threshold (1 ppm) in the air; therefore, dry-cleaned clothing should be kept outside on a porch or mudroom for some time to ensure complete off-gassing.

4. Avoid exposure to methylene chloride.

Consumer products such as adhesives and paint removers may contain methylene chloride. Methylene chloride has been shown to cause cancer in laboratory animals and is classified as a probable human carcinogen by EPA and IARC. Once absorbed, methylene chloride is converted to carbon monoxide in the body. Read warning and ingredient labels on these products and if you find methylene chloride, handle the product carefully. Avoid skin contact and use only in a well-ventilated area. If possible, select other products that do not contain methylene chloride.

IV.C.6.2 Personal care products

- Scent free awareness programs in Canada

Scented products are widely reported by individuals with asthma to trigger symptoms (Baldwin et al., 1995). Different Canadian provinces have initiated scent free awareness programs in workplaces. Nova Scotia, Alberta, British Columbia and Ontario have provided leadership roles in generating awareness among office workers regarding the use of fragrance products in the workplace.

IV.C.6.3 Cleaning products

Sprayed cleaning products increases the exposure and ventilation or dilution is an effective control measure. Aerosols and spray bombs are commercial products that are discharged under pressure from disposable containers and sprayed products can exist suspended as fine liquid or solid particles in the air (Health Canada, 1995). Because of the small size of aerosol-propelled particles and their ability to stay airborne for longer periods of time, they can migrate to other rooms in a house and be inhaled deeply into the lungs and then quickly absorbed into the blood. The use of aerosols in closed spaces such as bathrooms and workshops should be avoided (Felten, 1988). To help control exposure, an outside window or door should be kept open during cleaning activities. An exhaust fan should be used during cleaning activities.

Pressurized aerosol products or bombs have three main components:

1. Active ingredients
2. Propellant such as chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs)
3. Various additives (used for product improvement), for example, surfactants, synthetic resins, plasticizers and emulsifiers (Calgary Health Region, 1993)

The predominant component of aerosol bombs contaminating indoor air is the propellant, which constitutes 60% to 70% of the total content. A simple control measure is to use a hand-pump spray or other non-aerosol cleaning and grooming products. From a toxicological perspective, the active ingredients and various additives in aerosol products may be more important than the propellant as they may be corrosive and present acute or chronic health risks. The use of hand pump or manually applied products would lower exposures but does not guarantee of safety. Alternatives to pressurized or hand-pump aerosol products include cream, stick or roll-on products and the use of powder, paste or liquid cleaners (Faeltten, 1988, cited in Calgary Health Region, 1993).

IV.C.6.4 Hobbies and other activities

Several control measures can be put in place to reduce or eliminate exposure to toxic contaminants from arts and craft supplies and related hobbies and activities. Health Canada has recommended the following control measures in its publication *Art Teacher, Be Aware*. The reader should refer to *Chapter III Investigation of indoor air quality* and other publications for additional information. Public health inspectors can recommend the following control measures while conducting IAQ investigations in both residential and non-residential settings. Although these recommendations have been provided for school teachers and students, they can be used for other indoor settings.

- **Solvents**

Because of their toxicity, organic solvents should not be used by children from grades 1 through 6. Older students and teachers should take necessary precautions, such as using impermeable gloves or applying a barrier cream, while working with those solvents. Appropriate ventilation should be provided to the area where such solvents are used. Respiratory protection should be worn when handling concentrated solvents. (Refer to specific Material Safety Data Sheets).

- **Pigments**

Be aware that some paint pigments may contain heavy metals. Review Materials Safety Data Sheets or contact the supplier or manufacturer to ensure pigments are free of heavy metals, or that they are present at background concentrations, such as 0.06 per cent for lead. Pigments that contain heavy metals should be avoided in schools. Dried paint may release contaminated dusts into the air and building. Avoid using powdered pigments.

- **Adhesives**

To prevent exposure to organic vapours, the uses of synthetic adhesives should be avoided by small children. Alternative products such as water-based glues and flour pastes can be used. Water based glues may contain preservatives that may also harm small children. Small children should strictly avoid instant glues as they can be hazardous to skin.

- **Corrosives**

Corrosives, such as acids, should be handled carefully. Rubberized gloves, protective aprons and goggles should be worn at all times when handling corrosives. An eyewash station and fountain shower should be available in the vicinity of the area where corrosives are used. In case of eye contact, eye rinsing should be done for at least 15 minutes. Contact lenses should not be worn while working with corrosives. Proper instruction is essential to using any hazardous materials in a classroom setting, such as a chemistry lab.

- **Drawing**

Use of felt markers or correcting fluid should be avoided because of the release of organic vapours. Drawing ink may contain carbon black, which may harm some individuals. Small children, such as primary school students, should not use these products.

- **Painting**

For a detailed description on paints and associated contaminants, the reader should refer to “Chemical Factors” section and “Built environment” sections of *Chapter III Investigation of indoor air quality*.

- **Sculpting, modeling and carving**

Students and other individuals should not mix clay or plaster from powder. Dust from mixing plaster and related activities, such as chipping, grinding and sanding, should be controlled by local exhaust ventilation. Vacuuming or wet mopping should be used to collect dusts instead of dry sweeping. Hot wire-cutting, sawing and

sanding of plastics can produce toxic fumes and dusts. These activities should be avoided and are not recommended in schools.

- **Silk screening and printmaking**

Students that are involved in these activities should be aware of the types of inks being used. Water-based inks should generally be used. In the case of solvent-based inks, the installation and maintenance of proper ventilation is necessary. In addition, follow the recommendations provided in the “corrosives” section above.

- **Ceramics**

Follow the recommendations provided in the preceding “Sculpting, modeling and carving” section. Ceramics can generate some poisonous, such as CO and metal fumes. Refer to “Gases” subsection of *Chapter III Investigation of indoor air quality* for a discussion on control measures for CO and other gases.

- **Photo processing**

To minimize exposure, pre-mixed solutions should be used instead of raw chemical solutions. Prepare dry-powder solutions in controlled environments with fume hoods. Also, follow the manufacturer’s instructions and MSDS information. Students developing film should avoid skin and inhalation exposure by using sealed glove boxes. A glove box should be used for handling concentrated solutions and powdered products.

- **Copper enameling**

According to Health Canada, copper enameling should only be carried out by senior students (grade seven and above). The acids and alkalis used in this process should be handled carefully. Infrared goggles should be used to look into kilns. Proper ventilation should be provided in the kiln room and in additional areas as required. In addition, follow recommendations provided in the “corrosives” section above.

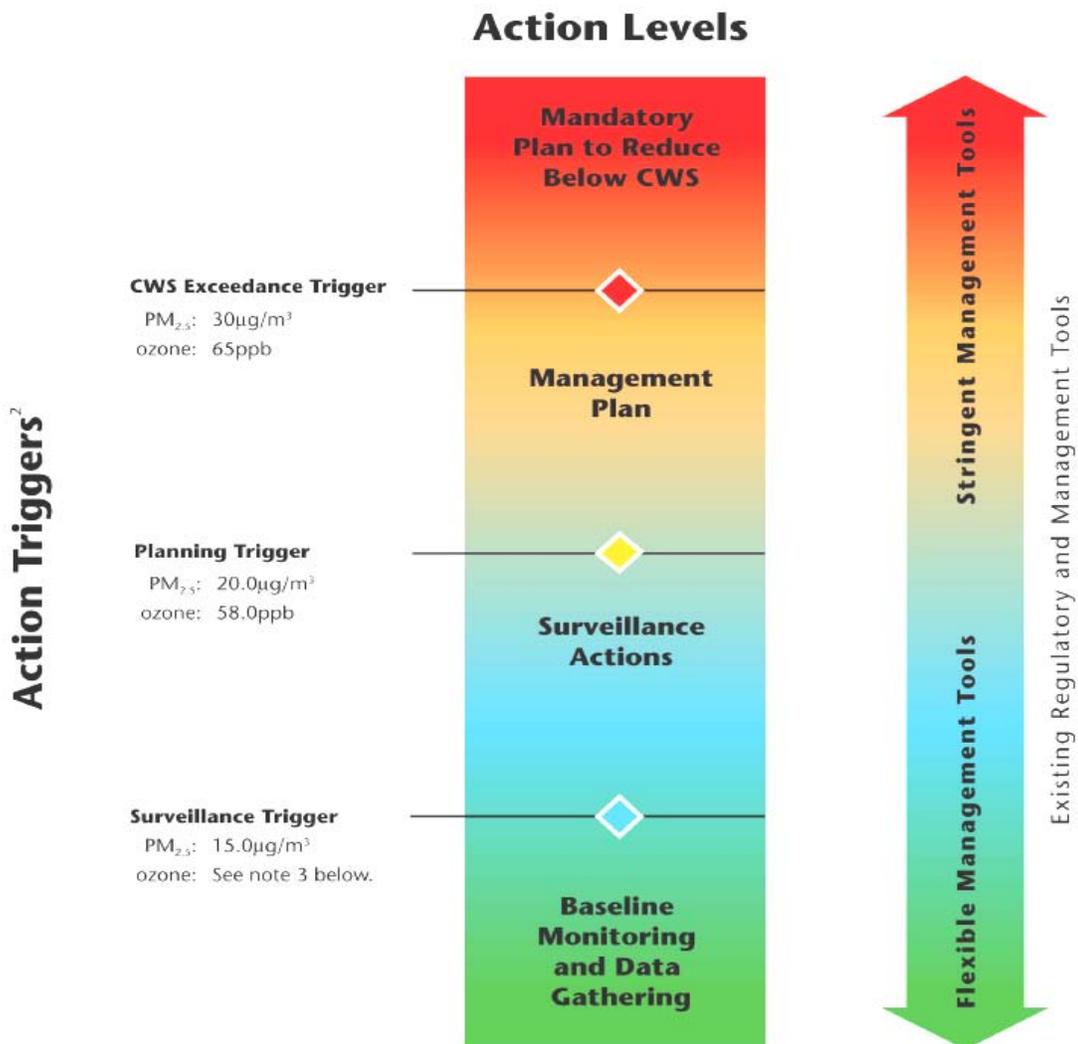
IV.C.7 Outdoor air factors

IV.C.7.1 Keeping clean areas clean framework and continuous improvement

Smog is an air quality issue in Alberta, across Canada and around the world. Fine particulate matter (PM_{2.5}) and Ozone (O₃) are two principal components of smog. In June, 2000, the Canadian Council of Ministers of the Environment established the Canada-wide Standards (CWS) for Fine Particulate Matter and Ozone.

The CASA (Clean Air Strategic Alliance) PM and Ozone Management Framework (see Figure IV.C-2) is Alberta's commitment to achieve CWS levels by the 2010 target date.

Figure IV.C-2 Fine particulate matter and ozone management framework



Sources: Clean Air Strategic Alliance. 2003. Particulate Matter and Ozone Management Framework. Available at: http://www.casabome.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=636&PortalId=0&TabId=78

Under the PM and Ozone Management Framework, Alberta Environment performs annual assessments of PM_{2.5} and ozone. These assessments follow the procedures set out by the CASA Framework and Canada-wide Standards. In these assessments, Alberta Environment assigned action levels, based on action triggers, to some areas of the province, which have now developed management plans.

The following box presents the metrics of PM_{2.5} and Ozone action triggers defined in the PM and Ozone Management Framework acknowledges that health effects can occur below the ozone and PM_{2.5} metrics. As a result, the action trigger concentrations are neither “pollute up to” levels, or “not to exceed” levels. The “Keep Clean Areas Clean” (KCAC) and “Continuous Improvement” concepts were developed to ensure that levels of these pollutants are kept as low as reasonably possible using best efforts and air quality management strategies strive for continuous improvement.

Action triggers		
Each of the CWS's action triggers for PM and O ₃ have specific metrics.		
PM_{2.5}	Exceedance:	30 µg/m ³ CWS and CWS metric
	Management:	20.0 µg/m ³ CWS metric
	Surveillance:	15.0 µg/m ³ CWS metric
	Baseline:	Below 15.0 µg/m ³ CWS metric
Ozone:	Exceedance:	130 µg/m ³ (65 ppb) CWS and CWS metric
	Management:	116 µg/m ³ (58.0 ppb) CWS metric
	Surveillance:	At the discretion of AENV based on considerations described immediately below
	Baseline:	At the discretion of AENV based on considerations described immediately below

For ozone, Alberta Environment and Water will determine on an annual basis which areas of the province are in baseline and which areas are in surveillance. This determination will take into account the following:

- Location of existing monitoring
- Ambient ozone data, prepared using a three-year CWS metric
- Available resources for baseline and surveillance activities
- Priorities for improving understanding of ozone sources, formation, concentrations and movement

Action triggers for PM_{2.5} are based on a 24-hour average and achievement is based on the 98th percentile ambient measurement annually, averaged over three consecutive years. Action trigger levels for ozone are based on an eight-hour average, an achievement is based on the fourth highest measurement annually, averaged over three consecutive years.

The purpose of the Alberta PM and Ozone Management Framework is to effectively manage ambient air quality in areas in Alberta and other Canadian provinces to ensure ambient air quality is managed to below the numeric Canada Wide Standard (CWS).

The management framework must be applied in the context of its key elements including guiding principles, existing initiatives and mechanisms that support management of PM and ozone and the goals and objectives for each action level.

The long-term goal of the framework is to minimize risks to human health and the environment, balancing the desire to achieve the best health and environmental protection possible in the near term and the feasibility of reducing the pollutant emissions that contribute to elevated concentrations of PM and ozone.

IV.C.8 Built environment, mechanical and physical factors

IV.C.8.1 Thermal comfort and physical factors

- **Humidity**

Because of Alberta's specific climatic conditions, portable or permanent humidification equipment is recommended for use in premises from October through April to help maintain a comfortable relative humidity (RH) level for the occupants. However, observing condensation on windows should be considered as evidence of excessive humidity. Relative humidity should be measured in occupied indoor environments to enable occupants to adjust humidity up or down relative to guideline levels and current conditions.

For high humidity levels, dehumidification equipment can be used to lower humidity levels.

- **Ventilation systems**

The following steps can be taken to resolve potential and existing biological contamination problems of the HVAC system (Yang, 1999; Health Canada, 1995):

- Maintain and clean the cooling coil and ensure the condensate collection pan drains to sewer.
- Minimize the conditions and amplifications of biological contaminants by maintaining impervious insulation coverings in the AHUs and the ductwork.
- Eliminate areas of dampness and moisture accumulation.
- Maintain and visually inspect the humidifier at regular intervals.
- Make sure that the outside air intake is placed away from any source of chemical and biological sources of contamination, such as accumulated debris, plumbing stack vents and washroom exhaust grilles, ponded water, street-level loading dock areas and cooling towers. Clean the air intakes regularly to remove litter and dirt.
- Clean the HVAC system when there are signs of microbial growth and heavy dust accumulation. Control dust deposits effectively.
- Set up a preventive maintenance program for all components of the HVAC system.
- Increase the supply of fresh air to the building, if required.
- In case of industrial operations or problematic emissions, extend the stack height well above (approximately 2 meters) the highest level of the roof. Also, consider removing rain caps to improve dispersion.

IV.C.8.2 Building materials concerns

- **Carpet**

The following control measures can be carried out to reduce or eliminate emissions from carpet materials (cited in Calgary Health Region, 1993).

- Building ventilation rates should comply with ASHRAE guidelines. During the carpet installation process and for the following 48 to 72 hours, the ventilation system should be operated at maximum fan speed and optimized to exhaust as much return air as possible.
- Where possible, use woven area rugs with a backing. Area rugs are generally made with wool or cotton without using adhesives and are regarded safer than wall-to-wall broadloom. However, area rugs are more expensive than broadloom.
- Try to purchase carpet that has already been aired for several weeks by having been unrolled in a well-ventilated area. In addition, during the installation process, keep windows and doors open to air out the premises. Also remember when buying wall-to-wall carpet, to have it installed during the summer months. For commercial buildings, ensure maximum operation of the ventilation system, with 100 per cent exhaust (no recirculation) if possible.
- Before purchasing a carpet, people who suffer from “chemical sensitivity” or asthma, should obtain a fresh sample of carpet from the carpet roll they intend to purchase. They should take it home and sleep near it for approximately one week. If there is a bothersome odour from the sample, the carpet should not be purchased.
- Avoid getting carpets wet for an extended period of time (maximum 3 days), as they can support bacterial and fungal growth.
- When carpet is first installed in a home, an individual, or family, may be plagued by a variety of upper respiratory symptoms. These symptoms can be expected to resolve themselves within three to six months because the VOCs in carpet decrease rapidly over time. Consequently, the best control measure for such a short time period is to provide increased air exchange rates by maintaining continuous ventilation by opening doors, windows and using the ventilation system.
- The “environmentally hypersensitive” (sensitive or vulnerable) individuals should avoid using carpets. Alternative materials, such as area rugs, hard wood flooring, ceramic tile or stone may be more appropriate. For area rugs, select natural fibres without any chemical treatment and horizontally woven carpet, which are less tightly woven and less likely to hold any dirt (CMHC, 2000).
- Use nail strips as an alternative to carpet glues (CMHC, 2000).
- Area rugs can be more easily cleaned than carpets (CMHC, 2000).

Source: A letter dated January 9, 1990, from Krista Keimel, CBC, “Market Place” to Pam Moore, Indoor Air Quality Consultant, Alberta health, filed in divisional records (cited in Calgary Health Region, 1993)

- **Carpeting recommendations from United States Environmental Protection Agency (USEPA) (1995)**

When purchasing or installing a new carpet, take following steps to ensure safe selection, handling and practices (USEPA, 1995).

- ▶ Ask for information on carpet emissions when talking to the carpet dealer.
- ▶ Ask the retailer to unroll and expose the carpet to the air in a ventilated area.
- ▶ Use low toxicity adhesives (if required).
- ▶ If possible, leave the area during and after installation of the carpet.
- ▶ Ask installer to follow Carpet and Rug Institute's installation guidelines.
- ▶ Ventilate the indoor space where the new carpet is being installed.
- ▶ Contact the carpet dealer if you feel there is an objectionable odour from the carpet.
- ▶ Always follow manufacturer's carpet maintenance instructions.

- **Hardwood flooring**

Test additional components such as subflooring material, adhesives and different parquet suppliers including different wood type, glue and finishing products to determine individual tolerance level before installation.

- Use low toxicity glues and adhesives, if required
- Conduct personal exposure testing.

- **Plywood**

CMHC recommends consumers select composite wood products made with more stable glues. In addition, surface treatment of wood with water-based acrylic sealers can help reduce formaldehyde emission rates. Water-based sealers are also effective in reducing terpene emissions from softwoods as well as formaldehyde emissions from composite wood products (CMHC, 2000). Preferred alternatives to composite wood products include solid wood, ceramics and stones.

- **Paints**

- Ensure that the lids and caps of all paint cans and solvent containers are tightly sealed. If possible, store them in a paint cabinet with exhaust ventilation to control VOCs (Calgary Health Region, 1993).
- Avoid spray painting, if possible.
- As some latex paints also contain solvents, read labels or obtain information regarding the solvent content and make use of products that with low VOC contents (Calgary Health Region, 1993).
- Ventilate thoroughly during painting and, if required, during the primary curing period. If necessary, use portable exhaust fans with flex ducting to carry exhaust to an outside location (Calgary Health Region, 1993).

- Many latex paints appear to be dry after several hours, but most paints may continue to release harmful vapours for several days after application. Therefore, ventilation should be sustained for at least 48 hours and preferably 72 hours (Montgomery County Department of Environmental Protection, 2002).
- Several VOCs from alkyd paints can be released through off-gassing. Vapour concentrations in a painted room can be reduced by setting box fans in a window blowing outward (Montgomery County Department of Environmental Protection, 2002). Ventilation will help painted surfaces dry faster (Montgomery County Department of Environmental Protection, 2002).
- Proper ventilation also prevents solvent vapours from settling into clothes, carpets, ceiling tiles, upholstery and other surfaces (Montgomery County Department of Environmental Protection, 2002).
- To reduce risks to a fetus, pregnant women should take following precautions:
 - ▶ Keep away from all areas undergoing painting. But if exposure is unavoidable, paint exposure should be kept to a minimum.
 - ▶ If exposure is unavoidable during painting, wear protective clothing including gloves and masks and effectively ventilate of the workplace to reduce exposure to paint vapours.
 - ▶ Home painting projects should be completed before becoming pregnant.
 - ▶ When removing paint, find out ahead of time if the paint is lead-free or not.
 - ▶ Avoid paints containing solvents, such as ethylene glycol ethers and biocides.
- **Recommendations from USEPA (2000):**
 - ▶ Schedule painting in the dry, warm months of the summer, fall or spring when windows can be left open for ventilation.
 - ▶ Keep windows wide open for about two to three days after painting so that building occupants can avoid unnecessary exposures to paint vapours.
 - ▶ Use window-mounted box fans to exhaust out vapours from indoor areas. If a fan is not available, make sure the areas have necessary cross ventilation. Use portable exhaust fans with flex ducting as required.
 - ▶ Some chemicals from paints have been reported to cause cancer or reproductive and developmental effects in laboratory animals. Because of these concerns, susceptible individuals, such as young children, pregnant women and individuals with breathing problems, should avoid exposure to paint vapors.
 - ▶ Pregnant women should avoid undertaking painting projects and should limit their time in freshly painted rooms to avoid any health risks for themselves and their unborn babies, especially when oil-based paints are being used.

For a detailed list of recommendations from USEPA on healthy painting practices, the reader should refer to the following website: <http://www.epa.gov/iaq/homes/hip-painting.html>.

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Appendices

Appendix A1

Chemical factors Gases

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A. Chemical factors

A.1 Gases

A.1.1 Introduction

Gas can be defined as a physical state of matter that has low density, is easily compressible and expands spontaneously when placed in a larger container. Gases are substances that are entirely gaseous at ordinary room temperature and pressure (Bailer et al., 1978). The following compounds, which are gases at room temperature and pressure, will be discussed in this chapter.

- Carbon monoxide (CO)
- Carbon dioxide (CO₂)
- Ozone (O₃)
- Nitrogen oxides (NO_x)

Gases are present both indoors and outdoors. Some of the gases are primarily produced as a byproduct of combustion processes, such as CO and NO_x (Godish, 2000). CO₂, along with CO, are oxides of carbon formed from the combustion of fossil fuels. For the purpose of this manual, CO₂ will be only discussed as an indicator of poor indoor ventilation.

Ozone (O₃) can be produced indoors directly from electrical equipment or in the ambient air as a result of photo-oxidation reactions with various natural and anthropogenic hydrocarbons in equilibrium with other combustion byproducts, such as NO_x. The chemical reaction between O₃ and unsaturated hydrocarbons at levels generally found indoors can produce aldehydes that in turn can affect human health (Godish, 2000).

A.1.1.1 Physical and chemical properties of gases

The physical and chemical properties of these gases (Table A.1-1) play an important role in their indoor fate and transport. Gases expand or contract with changes in temperature and pressure.

Table A.1-1 Physical and chemical properties of various gases

Properties	CO (WHO 1979)	CO ₂ (Weast 1985)	NO _x (NO ₂) Weast (1985)	O ₃ (Chemfinder 2002)
Molecular weight	28.01	44.01	46.01	47.9982
Colour	Colourless	Colourless	Reddish brown (yellow liquid)	Colourless
Physical state	Gas	Gas	Gas	Gas
Boiling point	-191.5 °C	- 78.5°C	21.2°C	
Odour	Odourless	Odourless	Pungent and irritating odour	Pungent characteristics odour, sharp disagreeable odour at 1 ppm
Solubility	In Water (at 0°C, 1 atm) = 3.54 ml /100 ml In Water (at 25°C at 1 atm) = 2.14 ml /100 ml In Water (at 37°C at 1 atm) = 1.83 ml /100 ml	Soluble in water, ethanol and acetone	Soluble in cold water, alkali, carbon disulphide and chloroform, decomposes in cold water	Almost insoluble (0.00003 g/100 ml at 20°C)

The health effects, regulatory criteria and guidelines, if available, and control measures associated with each of the gases are discussed in this section.

A.1.2 Carbon monoxide

CO is a colourless, odourless and tasteless gas formed as a byproduct from the incomplete combustion of carbon-based fuels. The indoor environment is particularly vulnerable to contamination from combustion-related byproducts from a variety of indoor and outdoor sources. The background concentration of carbon monoxide in the troposphere, which is the atmosphere closest to the earth's surface, is produced as an intermediate byproduct in the photo-oxidation of methane (CH₄) (WHO, 1979).

In high traffic areas, traffic tunnels and subways, carbon monoxide levels have been measured in concentrations ranging from 20 ppmv to 100 ppmv (Bounce, 1994). Ambient air levels of CO have been measured in the range of 0.04 ppm to 0.8 ppm (0.05 mg/m³ to 0.9 mg/m³) in rural areas, with urban areas reaching levels as high as 50 ppm (57 mg/m³); however, typical urban CO levels are generally in the range of 1 ppm to 10 ppm (1.1 mg/m³ to 11 mg/m³) (Health Canada, 2010). From 2002 to 2006, the annual average concentration of CO in Canada decreased by 31.5 per cent (Environment Canada, 2008). Indoor CO concentrations generally follow outdoor air concentrations. However, houses with tobacco smoking and unvented or poorly vented combustion appliances can have indoor levels higher than ambient. In Canada, CO levels as high as 115 mg/m³ (100 ppm) have been found in the kitchens of some houses immediately after cooking with an unvented gas stove (Health Canada, 2010).

A.1.2.1 Sources

There are various indoor sources of carbon monoxide:

- Gas appliances, such as stoves and cloth dryers, kerosene space-heaters, gas- and oil-fired heating systems and home water heaters
- Furnaces
- Exhaust from automobiles in attached garages
- Environmental Tobacco Smoke
- Fireplaces and wood stoves
- Candles and Incense sticks
- Carbon-fueled ice-re-surfacing machines and propane-fueled floor burnishers.

Outdoor combustion sources of CO, such as automobiles, power plants and factories, petroleum refineries, iron foundries, kraft pulp mills and sintering mills, can also contribute to the contamination of indoor air.

Indoor concentrations of CO are influenced by a combination of indoor and outdoor sources. Without any significant indoor sources, such as poorly ventilated and managed appliances, indoor concentrations of CO were found to be equal to outdoor concentrations (WHO, 1999). The highest indoor CO concentrations can be found in fully enclosed parkades without proper ventilation, service stations, automobiles, and residences and buildings located close to busy roadways. The lowest indoor CO concentration can be found in residences away from busy roadways, churches and health-care facilities (WHO, 1999).

Kerosene space-heaters produce CO because of the incomplete combustion of kerosene. Although portable kerosene heaters are very efficient in the burning of fuel to produce heat, low levels of carbon monoxide and nitrogen dioxide are emitted from them. There are three types of kerosene heaters: radiant, convective and two-stage. All of them operate at relatively high combustion temperatures. Radiant heaters produce two times more CO than convective heaters (Godish, 2000).

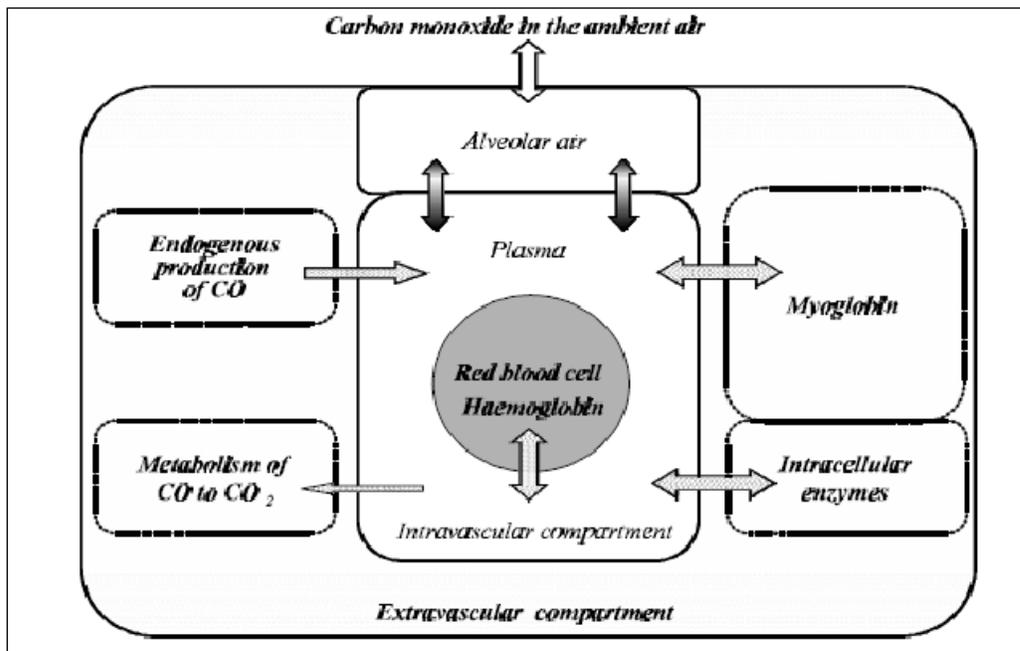
Attached garages are a potential source of intermittent indoor CO contamination. Carbon monoxide can enter a home through infiltration when an automobile enters or leaves the garage. Underground parkades in apartment complexes and commercial high rise buildings have the potential to contaminate buildings with exhaust gases, such as CO, because of poor ventilation or poor management of parkade ventilation systems.

There are specialized indoor facilities, such as ice arenas, where CO poisoning can be a serious public health issue. Use of carbon-fuelled ice re-surfacing machines in ice arenas can cause “Zamboni Syndrome.” The syndrome refers to CO and NO₂ exposure-related health effects, such as headache, nausea, drowsiness and impaired vision, in arena ice hockey players. The CO blood levels may rise dramatically in proportion to the airborne concentration of CO and the exertion level of the hockey player. A significant rise in COHb (carboxyhaemoglobin) concentration has the potential to increase the risk of heart attack in individuals with cardiovascular disease.

A.1.2.2 Mechanism of toxicity

Figure A.1-1 presents the transportation, distribution and metabolism of CO in the various body compartments.

Figure A.1-1 Transport, distribution and metabolism of Co in the body



Source: WHO 1999. Carbon Monoxide, Environmental Health Canada 213, International Programme on Chemical Safety, World Health Organization, website: http://who.int/pcs/ehc/summaries/ehc_213/html

There are other mechanisms in addition to the mechanism described in the figure by which CO exerts toxic effects. These other mechanisms include combining with myoglobin, which is involved with the transport of oxygen in muscle tissue and cytochrome enzyme systems, including cytochrome c oxidase and cytochrome P-450.

CO binds to the iron sequestered in haemoglobin, myoglobin, cytochrome oxidase and cytochrome P-450. At the molecular level, CO binds to the vacant binding site on Fe (II)-porphyrin group of hemoglobin to form carboxyhemoglobin (COHb). The formation of COHb reduces the effective oxygen uptake by hemoglobin. The binding affinity of carbon monoxide to hemoglobin is 200 to 300 times higher than oxygen with a resting half-life for the COHb of approximately three to four hours.

Hypoxia from the CO exposure may be the result of the interaction with myoglobin rather than hemoglobin. However, at low CO concentrations reversible binding with hemoglobin is believed to be more significant. Myoglobin is believed to provide a temporary oxygen reservoir for work and facilitates the diffusion of oxygen within muscle tissue.

The cardiac muscle is particularly rich in myoglobin and the myocardium is believed to be the most sensitive tissue in the human body to CO-induced hypoxia (see Figure A-1).

A.1.2.3 Health effects

Carbon monoxide can pose both acute and chronic health risks

- **Acute effects**

The symptoms associated with acute carbon monoxide poisoning depend on concentration and time relationships, and include both mild and severe health effects.

Symptoms of carbon monoxide poisoning

Mild acute effects

- Impaired vision
- Rapid breathing
- Excess salivation
- Vomiting
- Hallucinations
- Blue colouration of finger nails on the cuticle region
- Headaches
- Nausea
- Drowsiness

Severe acute effects

- Severe confusion
- At high concentrations (> 4000 ppm), convulsions, coma and death may occur (Alberta OH&S, 1998)

- **Chronic effects**

Although most cases of CO poisoning are a result of acute exposures, symptoms can also arise from long-term, low-level exposure. Symptoms of chronic CO poisoning include the following (WHO, 1999).

- Fatigue
- Headache
- Dizziness
- Cardiac symptoms and complications
- Sleep disturbances
- Apathy
- Nausea
- Central nervous system damage
- Memory disturbances²
-

A.1.2.3.1 Sensitive or vulnerable individuals

Sensitive or vulnerable individuals who are considered to be at increased risk from CO exposure include high-altitude residents (those who live above 1,500 meters), cigarette smokers, pregnant women, the developing fetus and newborns. Individuals with the following pathological conditions are considered vulnerable to CO toxicity.

- Peripheral vascular disease
- Hemolytic disease
- Anemia
- Cerebro-vascular disease
- Chronic obstructive lung disease
- Heart disease
- Severe hardening of arteries (arteriosclerosis)

The available evidence suggests that individuals with the following health impairments are at greatest risk from exposure to ambient levels of CO (USEPA, 1992) and Health and Welfare Canada, 1985):

- Stable exercise-induced angina
- Indications of ischemic heart disease
- Silent ischemia
- Cardiovascular disease
- Cerebrovascular disease
- Peripheral vascular disease
- Lung diseases and
- Anemia.

Table A.1-3 estimates the percent distribution of U.S. sub-populations who are potentially at risk from CO exposure, based on an estimated 1989 U.S. population of 235 million. A projected Canadian estimate has also been provided in the table for comparative purposes.

Table A.1-3: Summary of sub-populations sensitive or vulnerable to CO exposure¹

Group at risk to low level of CO exposure	Rationale	Population estimation	Percent of U.S. population ²	Projected Canadian population (from 30 million) ³
Coronary artery disease	Strongest evidence is for groups with symptomatic angina pectoris, although asymptomatic individuals have limited coronary flow reserve and are linked to be sensitive to CO induced decrease in O ₂ carrying capacity	-Prevalence of diagnosed ischemic heart disease (7 million) (in 1989)- Prevalence of undiagnosed (silent ischemic) estimated to be 3-4 million (in 1989)	~ 2.9%	~870,000
		-1.5 million heart attacks/year (in 1987)	~ 2.9%	~870,000
		-513,7000 heart attack fatalities / year	~ 1.4%	420,000
Peripheral vascular disease	This condition is associated with limited blood flow capacity and should be sensitive to CO exposure	0.75 million (in 1979)	~ 0.3%	~ 100,000
Cerebrovascular disease	This condition is associated with limited blood flow to the brain and may be sensitive to CO exposure	2.5 million persons (in 1983-1985)	~ 1%	~ 300,000
Anemia	CO ₂ carrying capacity of blood is already reduced; increasing likelihood of CO induced hypoxia effects at lower CO exposure levels than for non-anemic individuals	3.2 million (in 1987)	~ 1.3%	~ 390,000
Chronic obstructive lung disease	These subgroups have reduced reserve capacities for dealing with cardiovascular stresses and have reduced O ₂ supply in blood which may hasten onset of CO induced hypoxic effects	Bronchitis – 11.1 million	~ 4.6%	~ 1,380,000
		Emphysema – 2.0 million	~ 0.8%	~ 240,000
		Asthma – 8.6 million (1983-1985)	~ 3.5%	~ 1,050, 000
Fetuses and young infants	Several animal studies report deleterious effects in offspring (e.g., reduced birthweight, increased newborn mortality and lower behavioural activity levels)	3.6 million live births per year (1983)	~ 1.5%	~ 450,000

¹ All subgroups listed are not necessarily sensitive to CO exposure at normal ambient levels

² Percentages were calculated based on 1989 U.S. population base of 243.5 million

³ Canadian population numbers were calculated by taking USA percentage numbers and present Canadian population of 30 million

Source: USEPA, 1992, *Review of the National Ambient Air Quality Standards for CO. Assessment for Scientific and Technical Information, OAQPS Staff Paper, August 1992*

A.1.2.4 Exposure

Individuals are exposed to CO via inhalation in different indoor microenvironments, such as motor vehicles and indoor environments influenced by combustion sources including natural gas furnaces and stoves, charcoal or wood fires and tobacco smoking. The majority of public exposure to CO occurs in indoor environments (WHO, 1999).

Evaluations and assessments of human CO exposure shows that occupational exposure or exposure in homes with faulty combustion appliances, such as unvented space-heaters, can exceed 110 mg/m³ (100 ppm). The exposure to this CO concentration for a prolonged period can produce COHb levels of 10 per cent or more compared to the average urban non-smoker has baseline COHb levels of approximately one per cent. Such high exposure levels are much less common in outdoor air (WHO, 1999).

Outdoors, street level exposures to CO ranged between 9 ppm to 60 ppm, with an average of 18 ppm (eight-hour average concentrations). In remote areas away from city streets, the CO levels are typically below 9 ppm (WHO, 1979). Other studies have shown that automobile exhaust is a significant source of exposure to commuters. CO levels in the interior of automobiles can range between 10 mg/m³ and 29 mg/m³ (9 ppm to 25 ppm) with some commuters breathing in excess of 40 mg/m³ (35 ppm) (WHO, 1999).

The background COHb level in the blood, attributed to the endogenous CO formation, is 0.5% (Calgary Health Services, 1995). Baseline COHb levels in anaemic individuals ranges between 1.3% and 5.2% (Health and Welfare Canada, 1985). Smoking one pack of cigarettes per day can produce a daily COHb level of 5.9% (NIOSH, 1978) and the World Health Organization has reported that smokers typically have COHb levels ranging from 5% to 15%.

The concentration of COHb depends upon the duration of exposure, ambient temperature and the health and metabolic status of the exposed individual. COHb reduces the flow of oxygen supply to the body tissues by lowering the amount of oxygen in the blood. Table A.1-4 presents the percentage of blood COHb versus alveolar CO concentration in humans.

Table A.1-4 Percentage of carboxyhaemoglobin (COHb%) vs the equivalent alveolar CO¹

COHb %	Alveolar concentration (mg/m ³)	Alveolar concentration (ppm)
0.9	5.7	5
1.7	11.5	10
3.5	23.0	20
5.1	34.5	30
6.6	46.0	40
8.2	57.5	50
9.6	69.0	60
11.1	80.0	70
12.5	92.0	80
13.8	103.0	90
15.1	114.5	100
16.4	126.0	110
17.6	130.0	120
18.8	149.0	130
20.0	160.0	140
21.1	172.0	150
22.2	183.0	160
23.2	195.0	170
24.3	206.0	180
25.3	218.0	190
26.2	229.0	200

¹ Concentration (ppm or mg/m³) ¹(assumed 8-hour average)

Source: Alberta Occupational Health and Safety, Medical Monitoring for Workers Exposed to Carbon Monoxide, Alberta Human Resources and Employment, June 1992.

A.1.2.5 Guidelines

A.1.2.5.1 Health Canada

Residential indoor air quality guideline – carbon monoxide (2010)	
Guidelines	Averaging time
28.6 mg/m ³ (25 ppm)	1 hour
11.5 mg/m ³ (10 ppm)	8 hour

Source: Health Canada (2010) Residential Indoor Air Quality Guideline Carbon Monoxide. Website: http://www.bc-sc.gc.ca/emh-semt/pubs/air/carbon_mono/index-eng.php

These guidelines were derived based on the toxicokinetic model developed by Gosselin *et al.* (2006) and have been established to maintain COHb levels in blood below two per cent (Health Canada, 2010)

A.1.2.5.2 World Health Organization

WHO guidelines for indoor air quality: selected pollutants (2010)	
Guidelines	Exposure time
100 mg / m ³ (87 ppm)	For 15 minutes
35 mg/m ³ (52 ppm)	For 1 hour
10 mg/m ³ (25 ppm)	For 8 hours
7 mg/m ³ (10 ppm)	For 24 hours

Source: Carbon Monoxide, Environmental Health Criteria Series, WHO, IPCS, No. 213 (2nd edition) Summary; (http://www.who.int/pes/ehc/summaries/ehc_213.html)

The above guidelines were derived using the Coburn-Forster-Kane equation to maintain the COHb level of two per cent for a normal adult under resting conditions for the various intervals (WHO, 2010).

A.1.2.5.3 United States Environmental Protection Agency

United States Environmental Protection Agency (1992)	
Percentage of COHb	Explanation
2.9 – 3.0 %	Ambient air exposure standards should be established to prevent the formation of 3% or less COHb to prevent myocardial ischemia

“Cardiovascular effects, as measured by decreased time to onset of angina pain and by decreased time to onset of significance ECG ST-segment depression, are judged to be the health effects of greatest concern which clearly have been associated with CO exposure at levels observed in the ambient air” (USEPA 1992)

Source: USEPA 1992, Review of the National Ambient Air Quality Standards for CO. Assessment for Scientific and Technical Information. OAQPS Staff Paper. August 1992

A.1.2.5.4 North American Indoor Air Quality Guidelines for Ice Arenas

Jurisdiction	Carbon monoxide	Comments
State of Minnesota Air Quality Standard for Ice Arenas	≤34 ppm 1 hour average	Corrective action must be taken
	>125 ppm	Immediate arena evacuation
Public Health and Recreational Facilities Association of B.C. (Dr. Michael Brauer, U.B.C.)	≤11 ppm	Target zone (ensures adequate health protection of facility users, including children)
	>11-50 ppm	Action zone (some individuals may experience symptoms at these levels. Immediate action is required to reduce to Target Zone Levels)
	>50 ppm	Danger zone (immediate corrective action required , such as evacuation, ventilation)
Air Quality Guidelines for Arena Operations in Manitoba (2008)	<12.5 ppm	Levels within acceptable parameters; continue with standard operating procedures.
	12.5-25 ppm	Investigate and take corrective actions.
	>25 ppm	Stop all activities within the arena. Investigate and take corrective actions. If carbon monoxide and/or nitrogen dioxide levels continue to rise or remain at unsafe levels, remove all patrons to a well-ventilated area.

Note: Three-tiered PHRFA IAQ guideline is recommended because the guideline seeks to protect sensitive and vulnerable populations, active skaters, people with compromised lung function (e.g. asthmatics) and spectators.

A.1.2.6 Control measures

There are a variety of measures that can be taken to control sources and exposures to indoor concentration of CO.

- **Residential houses**
 - Replace or modify an unvented space-heater to exhaust combustion gases.
 - Take special precautions, such as using the proper fuel use and regularly maintaining equipment. A yellow flame shows poor adjustment and increased contaminant emissions from the equipment.
 - Do not use unvented space-heaters.
 - Install and use exhaust fans over gas cooking stoves and ranges. Keep the burners properly adjusted.
 - Open flues when fireplaces are in use.
 - The Alberta Building Code requires combustion air intakes for furnaces, fireplaces and woodstoves. For fireplaces, a less desirable alternative for providing combustion air is to open a window.
 - Keep woodstove emissions to a minimum. Use certified stoves, such as those certified by EPA or other regulatory agencies.
 - Have central air handling systems, including furnaces, flues and chimneys inspected annually. Promptly repair cracks and damaged parts.
 - Do not leave vehicles idling inside attached garages.

- **Steps to eliminate CO in the home (CMHC, 2011)**
 - ▶ Every year before the cold weather sets in, a qualified technician should inspect and clean fuel-burning appliances to ensure that they are in good condition.
 - ▶ A qualified technician should annually inspect chimneys and vents for cracks, blockages, such as bird's nests, twigs, old mortar, corrosion or holes.
 - ▶ Fireplaces should be checked for closed or blocked flues.
 - ▶ Check with a qualified technician before enclosing heating and hot water equipment in a smaller room to ensure there is adequate air for proper combustion.
 - ▶ If a stove has a powerful overhead or downdraft exhaust fan, a qualified technician should check its operations to make sure that the exhaust fan is not pulling exhaust gases from other appliances, such as furnaces or hot water tanks, back down the chimney. Because of backdrafting concerns, avoid locating clothes dryers in proximity to or in the same room as a furnace.
 - ▶ Propane or natural gas stove-tops or ovens should not be used for home-heating purposes.
 - ▶ Propane, natural gas or charcoal barbecue grills should not be used indoors or in an attached garage.
 - ▶ An unvented kerosene space-heater should not be used indoors or in a garage.
 - ▶ The fossil-fuel burning equipment for refrigeration, cooking, heating and lighting inside tents, trailers and motorhomes should be regularly maintained with the combustion exhaust vented outside. Use of electric and battery-powered equipment should be encouraged where possible.
 - ▶ Installation of at least one CO detector is a recommended safety practice.

Table A.1-5 summarizes CO detector performance criteria and relationship with acute health effects (CMHC, 2011).

Table A.1-5 Carbon monoxide detector performance criteria and associated acute health effects

CO (ppm)	Conditions
0-2	Normal conditions in and outside Canadian houses
11	Maximum tolerable indoor concentration over an eight-hour period ¹
25	Maximum allowable concentration for continuous exposure for healthy adults in any eight-hour period ¹
30	CO detectors must not sound alarm within 30 days ²
70	CO detectors must sound alarm within one to four hours ²
150	CO detectors must sound alarm within 10 to 50 minutes ²
200	Slight Headache, fatigue, dizziness and nausea after two to three hours ³
400	CO detectors must sound alarm within 4 to 15 minutes ²
800	Dizziness, nausea and convulsions within 45 minutes, death within two to three hours
1600	Death within one hour ³
13,000	Danger of death after one to three minutes ³

1 - "Exposure Guidelines for Residential Indoor Air Quality", Health Canada, 1989, 1995

2 - From the CSA Standard 6.19, "Residential Carbon Monoxide Detectors"

3 - "Carbon Monoxide Poisoning", IOWA State University of Science and Technology, AEN-172

Source: Canada Mortgage and Housing Corporation (CMHC). *About your House: Carbon Monoxide*, 2011. All rights reserved. Reproduced with the consent of CMHC. All other uses and reproductions of this material are expressly prohibited.

• **Indoor motor events**

Diesel or gasoline engines should not be operated in confined spaces; however, indoor motor events, such as a tractor pull and car shows, do involve the use of gasoline- and diesel-powered vehicles contaminating indoor air. The following control measures should be carried out.

- Pollution control devices should be installed in tractors and other automobiles taking part in the event. Vehicles should be tuned to minimize contaminant levels in the exhaust.
- Warm up vehicles outside.
- Ventilation rates should be increased to exhaust 100 per cent of the air. Also open the arena doors.
- Indoor motor sports, such as tractor pulls, often occur in small venues which increase the probability of CO contamination and poisoning. Therefore, ventilation systems should be periodically checked and properly maintained.
- Sufficient time should be provided between events to enable the ventilation system to sufficiently lower indoor levels of exhaust contaminants. This can be achieved by proper event timing and management.

• **Ice arenas**

Ice re-surfacing machines should be properly maintained and serviced at regular intervals to reduce exhaust contaminant levels to a minimum. This can be accomplished by adjusting the carburetor at least twice a year and by tuning the engine for 0.5% to 1% CO in the exhaust (Kwok, 1983).

- Before use, the ice re-surfacing machines should be started and warmed up in a well-ventilated environment, preferably outside the ice rink (Kwok 1983). Alternatively, attach an exhaust hose to the tail pipe although these measures will have no effect on nitrogen dioxide emissions.
- Ice re-surfacing machines can be converted from gasoline- or diesel-powered engines to a much cleaner fuel, such as propane or preferably electrical batteries (Brauer & Spengler, 1994). The propane fuel mixture should not be too rich as this may lead to the emission of excessive levels of CO (Kwok, 1983).
- The installation and proper maintenance of catalytic converters combined with an adequate amount of warm-up time will allow the converters to work effectively (Kwok, 1983).
 - ▶ Ensure the presence of a three-way catalytic converter with a Lambda fuel management system to reduce nitrogen dioxide and CO emissions from ice re-surfacers fuelled with gasoline, propane or natural gas.
- “Pooling” of CO above the ice surface can be prevented by discharging the re-surfacing machine’s exhaust vertically instead of horizontally, and by extending the exhaust tailpipe to at least one foot above the top of the rink’s plexiglass safety barrier (Kwok, 1983).
- To facilitate the better circulation and the breakup of the inversion layer, all rink barrier doors should be completely open during ice re-surfacing to allow for increased airflow over the re-surfaced ice (Kwok, 1983).
- The ice re-surfacing time should be kept to a minimum and the interval between the ice cleaning should be as long as possible (Kwok, 1983).
- The installation and operation of mechanical ventilation should be properly managed in these indoor facilities. During cold weather, some arena managers may close outdoor air intakes on ventilation systems for reasons of economy, which may contribute to the accumulation of CO in the building. This type of practice should be avoided (Kwok, 1983).
 - ▶ The recommended ventilation design criteria are 2,000 cfm of outdoor air + 40 cfm of outdoor air per person.

- **Underground parkades and garages**

The infiltration of CO from car exhausts in underground parkades into above-ground suites of apartment complexes can be a public health concern. There are several control measures that health professionals can recommend to control CO contamination incidents.

- The pathway or route of CO migration from the parkade into the suites should be identified and sealed. These include utility penetrations through the structural deck which provide a direct pathway linking the parkade to aboveground suites.
- Installation of CO sensors to control mechanical exhaust ventilation in parkades as required by the building code. The CO sensors should be properly maintained and calibrated to 50 ppm.
- In the absence of CO sensor controls, parkade exhaust fans should operate continuously.

- Parkade ventilation systems containing both exhaust and make-up fans should ensure that the parkade is under negative pressure.
- Ensure the weather stripping is in good condition on access doors leading from the parkade to the tenant stairwells and corridors.
- Tenants should shut off their car engines as soon as possible once they have parked their vehicle. Vehicles should not be idling while parked inside parkades or attached garages.

A.1.3 Carbon dioxide

Carbon dioxide is a colourless, odourless and non-flammable gaseous byproduct of the combustion of fossil fuels and biomass, and of aerobic respiration. An average adult's breath on exhalation contains about 35,000 ppm to 50,000 ppm of CO₂ (Washington State University Cooperative Extension Energy Program, <http://www.es.wapa.gov/pubs/briefs/co2/co2.html>, August 2002). In indoor air quality, CO₂ serves as a general indicator for assessing the indoor air quality (Scheff *et al.*, 2000). Specifically, CO₂ is used as a marker for ventilation efficiency, indicating whether sufficient outdoor air or supply air is being delivered to occupied spaces. Conceptually, the delivery of adequate amounts of outdoor air to indoor spaces serves to dilute and flush-out indoor air contaminants generated by occupants, building materials and activities (Battermann & Peng, 1995).

As CO₂ is a natural byproduct of the human metabolic process, it is not considered an "indoor contaminant" in the normal sense of the phrase. However, extremely high concentrations of CO₂ can have severe health consequences.

A.1.3.1 Sources

Natural indoor sources of CO₂ include respiratory exhalation by humans and pets. Nonbiogenic sources include non-vented gas appliances such as gas stoves, cloth dryers, space and kerosene heaters (Godish, 2000).

The indoor concentration of CO₂ can be related to the occupant density and other factors, such as the effectiveness of the ventilation system, the presence of environmental tobacco smoke and other combustion sources. Indoor CO₂ levels are generally higher than outdoor levels. In occupied residential premises, the indoor carbon dioxide concentration can range between 300 ppm to 2,000 ppm. Higher levels of CO₂ are generally found in poorly vented or heated dwellings where occupants tend to spend the majority of their time (Alberta Energy, 1988).

Outdoor CO₂ levels tend to vary widely depending on time and temperature. However, the average outdoor air concentration contains about 365 ppm to 380 ppm CO₂ (CSIRO, 2000). Elevated ambient levels of CO₂ can be found in high-density traffic areas, industrial sites and in proximity to various other combustion sources (Godish, 2000).

A.1.3.2 Indoor CO₂ concentrations, ventilation rates and sick building syndrome

Researchers have established a positive association between indoor CO₂ concentrations and incidence of Sick Building Syndrome (SBS) (Godish, 2000).

The rate at which fresh outdoor air is supplied to a building via ventilation is specified by the building code. The reader should refer to the *Section H Built environment, mechanical and physical factors* later in this chapter for additional information on the outdoor air requirements of different buildings. Supply rates are based on the requirement to control odour and carbon dioxide levels in buildings. The accumulation of CO₂ above acceptable levels confirms inadequate ventilation. An increase in the ventilation rate or improvements in ventilation effectiveness and indoor air contaminant

control can potentially decrease the prevalence of SBS health symptoms including sore throat, nose sinus, chest tightness and wheezing between 70% to 85% (Apte *et al.*, 2000). Increased ventilation rates have been associated with reductions in building-related symptoms and increased occupant satisfaction with overall indoor air quality (Godish, 2000).

A.1.3.3 Health effects

- **Acute effects**

The general symptoms and health effects associated with high concentrations of CO₂ are fatigue, headaches, sleepiness, dizziness, shortness of breath and a general feeling of stuffiness. Other general symptoms, such as increased perceptions of warmth and unpleasant odours, have been observed in human subjects exposed to CO₂ ranging from 900 mg/m³ to 5800 mg/m³ (500 ppm to 3200 ppm) (Health Canada, 1995). Health symptoms, such as dizziness, headache, confusion and dyspnea, occurred at 5% CO₂ while concentrations of 8 % to 10% CO₂ caused severe headache, sweating and impaired vision (HSDB, 2000). In some office indoor air quality studies, workers complained of fatigue and inability to concentrate when the CO₂ concentration exceeded 800 ppmv (Kreiss & Hodgson, 1984).

Toxicologically, inhaling increased concentrations of CO₂ increases the acidity of the blood which in turn increases the breathing rate. Carbon dioxide displaces oxygen in the pulmonary alveolar space, causing simple asphyxiation at concentrations greater than 110, 000 ppm (Gregus & Klassen, 2001).

Manifestation of neurotoxic symptoms, such as headaches, dizziness, visual distortion and cardiovascular effects in humans, were reported during exposure to excessively high concentrations of CO₂ at 90,000 mg/m³ (50,000 ppm) (Health Canada, 1995).

- **Chronic effects**

At moderate CO₂ levels (1,000 ppm to 5,000 ppm), no long-term health effects have been documented (Alberta Energy, 1988). After chronic exposure for several weeks to a concentration of 7,000 ppm CO₂, the acid-base balance in the blood was altered and this can lead to bone demineralization in response to chronic CO₂ exposure (Health and Welfare Canada, 1995).

A.1.3.3.1 CO₂ Guidelines for indoor air

Ventilation guidelines have been developed and recommended by the American Society for Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). They are incorporated in the National and provincial building codes, such as the Alberta Building Code. ASHRAE guidelines specify minimum ventilation rates, which provide occupants with a comfortable environment without any discomfort or human odour. Changes in the guidelines for mechanically ventilated buildings have occurred in the past. As of 2010, the ventilation guideline for schools is 10 cfm/person (5 lps/person) while office environments and residential dwellings is 5 cfm/person (2.5 lps/peson) (ASHRAE 62.1-2010).

The following table presents steady state concentrations of indoor CO₂, which should not be exceeded indoors, for ventilation rates of 5 cfm and 10 cfm of outdoor air. The values presented in the table below were calculated using the following equation.

$C_s - C_o = N/V_o$ <p style="text-align: right; margin-right: 20px;">eq. (1)</p> <p>C_s = CO₂ concentrations in space C_o = CO₂ concentrations in outdoor air = 368 ppm + (1.5 ppm/yr * 12 yrs) = 86 ppm N = CO₂ generation rate per person = 0.31 litres/min V_o = Outdoor air flow rate per person</p>

As reported in the *Technical Summary Report of Inter Governmental Panel on Climate Change (IPCC)*, the average concentration of CO₂ in the ambient air in the year 2005 was 379 ppm. The reader should bear that there is an average increase of 1.5 ppm of CO₂ each year. This rate has fluctuated between 0.9 ppm/year and 2.8 ppm/year over the period 1990 to 1999 (IPCC 2001, 2007).

A.1.3.3.1.1 American Society of Heating, Refrigerating and Air Conditioning Engineers

	Outdoor air requirement (cfm/person)	Outdoor air requirement (litre/second/person) V_o	Steady state concentration of CO ₂ relative to outdoor air (calculated using the equation provided above) $C_s - C_o$	Steady state CO ₂ + ambient bkgnd concentration of 386 ppm $C_s + C_o$
School	10	5	2,067 ppm	2,453 ppm (~ 2,500 ppm)
Offices and residences	5	2.5	1,033 ppm	1,419 ppm (~ 1,500 ppm)

Source: © ASHRAE (*Ventilation for Acceptable Indoor Air Quality*), (Standard 62.1-2010), (2010).

A.1.3.3.1.2 Health Canada

Exposure guidelines residential indoor air quality	
≤ 6,300 mg/m ³ (≤ 3,500 ppm)	Acceptable long-term exposure range (ALTER) for CO ₂ in residential indoor air

Source: *Exposure Guidelines for Residential Indoor Air Quality, A report of The Federal Provincial Advisory Committee on Environmental and Occupational Health, Health Canada 1987 (Revised and updated)*

Based on the health considerations, the acceptable long-term exposure range (ALTER) for carbon dioxide in residential indoor air is less than or equal to 6,300 mg/m³ (≤ 3,500 ppm).

A.1.3.4 Control measures

In residences and offices, CO₂ concentrations can be reduced and maintained at or below acceptable levels by adequate ventilation with outdoor air. The following are recommended control measures:

- All combustion appliances must be properly vented.

An appropriate level of air exchange rate should be maintained at all times with the goal of minimizing as much as possible the amount of return air being recirculated, such as maximizing the percentage of outdoor air or makeup air.

 - The building code requires continuous ventilation in business or commercial settings.
 - The goal should be to maintain indoor CO₂ levels below the ASRHAE recommended maximums. A general rule of thumb is that fresh air intake louvres should always be open to a minimum of 10 per cent.
- CO₂ monitoring can be used to check for adequate fresh air supply. Monitored CO₂ levels can be compared to corresponding equilibrium concentrations. Alternatively, the CO₂ decay rate measured after the building is vacated can be used to calculate the fresh air supply rate. However, consideration must be given to the limitations of rooftop air handling units (AHUs), which may result in CO₂ levels rising above recommended maximums. In addition, commercial spaces heated with domestic forced air systems are a special concern because of their limitations. Domestic forced air furnaces are not balanced systems; they have no engineered ability to exhaust return air and instead rely on pressurize-driven exfiltration.

A.1.4 Ozone

Ozone is a highly reactive, odorous, bluish gas and a very strong oxidizing agent. It is photochemically formed by the reaction of natural and anthropogenic pollutants. It is also produced as a result of high-energy electrical discharges produced by lightning storms outdoors and electrical equipment indoors. Ozone is an unstable form of molecular oxygen that has three atoms. In the stratosphere, ozone acts as a protective shield against the sun's harmful ultraviolet rays. In the troposphere, ozone is damaging to humans, animals, plants and building materials (Calgary Health Region, 1993).

Outdoors, ozone is formed primarily through the interaction of hydrocarbons, nitrogen oxides and sunlight. Indoors, it reacts with many indoor organic pollutants by oxidizing them to produce potential toxic byproducts. Evidence suggests that chemical reactions between ozone and indoor unsaturated hydrocarbons, such as d-limonene, α -pinene, α -terpene, styrene and isoprene, can produce aldehydes that can affect indoor air quality and human health (Godish, 2000, Spengler, 2001). The box on the next page describes the various reactions involving ozone, nitrogen oxides and hydrocarbons.

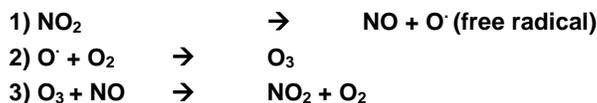
Various indoor ozone sources, such as ozone generators, electronic air cleaners, photocopiers and laser printers, are generally responsible for the higher indoor ozone concentrations. However, outdoor ozone appears to be the major source of indoor ozone, entering buildings through infiltration and air handling systems. Because of its high reactivity with indoor contaminants, concentrations of ozone in indoor settings are typically lower than those found outdoors. The exception is during summer months when windows are open and indoor ozone readily equalizes with outdoor levels. Concentrations of ozone can be elevated indoors when there are indoor sources

Indoor sources of ozone include electronic air cleaners and other high voltage electrical equipment (Godish, 2000). Ozone can be generated in the home by the arcing of electric motors and by improperly installed or maintained electronic air cleaners (Health Canada, 1995). Some air cleaners otherwise known as ozone generators use an electrical charge to generate ozone. Ion generators can also indirectly produce ozone.

Photocopiers and laser printers emit ozone during use. Ozone is formed in photocopy machines during the high electricity discharge process involving the corona wires. Corona wires apply a charge to the paper to attach the ink to the paper.

Reaction sequences

The presence of NO₂ plays an important role in the O₃ production process. NO₂ is the only gas in the boundary layer which shows absorption of solar radiation. NO emitted into the atmosphere will react with monoatomic oxygen to form NO₂



The result of the above reaction:



The above resultant reaction is in a pseudo equilibrium. The reaction is photochemically driven to the right direction and thermally to the left direction. It results in a small steady state concentration, dependent on the ambient temperature and amount of sunlight.

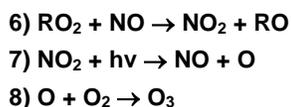


k = rate constant for equation 3

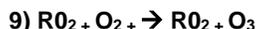
j = photolysis rate of NO₂

In reaction 3, one O₃ molecule is needed to regenerate a molecule of NO₂. The rate of this reaction is not sufficient to produce ozone on the level typically present in a photochemical ring smog. A reaction that converts NO to NO₂ without consuming O₃ would allow elevated levels of tropospheric O₃ to accumulate. The presence of VOC in the atmosphere also provides such a path. The small concentration of O₃ from equation 4 absorbs UV-B (~ 300nm) radiation. As a result of this, -OH radicals are produced from atmospheric water. In the presence of atmospheric VOCs, -OH radicals catalyze the oxidation of a variety of VOCs in a sequence that produced more O₃. For example:

Peroxy radicals (RO₂) produced in the oxidation of VOCs react with NO to form NO₂, which shifts the photostationary state of equation (equation 4) in favour of O₃ production. The following reactions are provided for a better understanding of this complex process.



The net result of the above reactions:



Newer models of photocopiers use a different system and produce lower amounts of ozone. However, the average amount of ozone emitted in the photocopy process is about 40 µg per copy. At peak production rates, the concentrations of ozone can exceed 131 µg per copy. Ozone can reach dangerous levels in small and poorly ventilated photocopy rooms.

Laser printers employ a printing mechanism similar to photocopiers, involving a corona-wire discharge. Concentrations between 100 µg/m³ and 4000 µg/m³ with an average of 438 µg/m³ O₃ were recorded from laser printers (Hetes et al., 1995). Other home electronic products, such as televisions, may also generate very minute quantities of ozone.

A.1.4.1 Dynamics between outdoor O₃ and indoor O₃ concentrations

In 2009, the average concentration of ground-level ozone in the outdoor ambient air was 36.9 parts per billion (ppb) in Canada (Environment Canada, 2011) and indoor concentrations are typically less because of reactions that consume ozone. Indoor concentrations can fluctuate greatly, depending on outdoor air concentrations and the presence of indoor sources. Indoor ozone concentrations can vary between 10% and 80% of outdoor levels. Indoor ozone concentrations have been reported between 0.12 ppm and 0.80 ppm where there is an indoor ozone source, such as zone-generating air cleaners. (North Carolina Department of Health and Human Services, 2001)

Ultimately, the indoor air concentration of ozone depends on the outdoor ozone concentration, air exchange rates, indoor emission rates, surface removal rates and reaction between ozone and other chemicals in the air. Other variables kept constant, indoor air concentrations generally track outdoor levels, fluctuating from hour-to-hour, day-to-day and season-to-season. Under normal conditions, the indoor half-life of ozone is between seven and 10 minutes (Weschler 2000).

A.1.4.2 Indoor air chemistry of ozone

Chemical reactions between ozone (O₃) and unsaturated hydrocarbons, such as styrene and isoprene, at concentrations usually found indoors generate oxidized byproducts, such as aldehydes, which can affect indoor air quality (Godish, 2000).

The reactions between ozone (O₃) and other gaseous contaminants, such as, NO_x, are thermodynamically favourable and can be fast or slow depending on various factors, such as air-exchange rates and concentrations of hydrocarbon contaminants. Some reactions between O₃ and hydrocarbons are very slow, which are usually nullified by the natural air exchange rate in the building. Other reactions can be fast, such as reactions involving hydrocarbons with unsaturated carbon-carbon bonds. Although those hydrocarbons may comprise 10 per cent of the indoor pollutant, their reactions with ozone can be significant in terms of the formation of various contaminant byproducts (Godish, 2000). Toxicologically, ozone can also act synergistically with other indoor contaminants.

A.1.4.3 Health effects

Indoor ozone and the byproducts derived from the O₃ reactions can pose a risk to human health. The predominant physiological effect of short-term ozone exposure is being unable to inhale to total lung capacity. Controlled human exposure studies have demonstrated that short-term exposure causes lung function decrements, such as reductions in forced expiratory volume, and the following respiratory symptoms (USEPA, 2011, 2012):

- Cough
- Pain, burning or discomfort in the chest when taking a deep breath
- Chest tightness, wheezing or shortness of breath
- Airway irritation
- Wheezing and breathing difficulties during exercise or outdoor activities

- Inflammation, which is much like a sunburn on the skin
- Aggravation of asthma and increased susceptibility to respiratory illnesses like pneumonia and bronchitis

These effects are reversible, with improvement and recovery varying from a few hours to days after an elevated ozone exposure (USEPA, 2012). However, studies show that short-term exposure to ozone is also associated with increased daily mortality and permanent lung damage with repeated exposures (USEPA, 2012)

A.1.4.4 Exposure

Exposure to ozone can occur both indoors and outdoors. Inhalation and dermal contact are two routes of indoor ozone exposure, with the inhalation pathway considered to be more significant. The dynamic between outdoor and indoor ozone and personal exposure is very complex.

A.1.4.5 Guidelines

A.1.4.5.1 Health Canada - Residential

Residential indoor air quality guideline – ozone (2010)	
40 µg/m ³ (20 ppb)	8 hour

Source: Health Canada (2010) Residential Indoor Air Quality Guideline Ozone. Website: <http://www.hc-sc.gc.ca/ewb-semt/pubs/air/ozone/index-eng.php>

A.1.4.5.2 World Health Organization

WHO air quality guidelines for ozone (2005)	
100 µg/m ³	8 hour mean

Source: WHO (2005) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. WHO Press, World Health Organization. Geneva, Switzerland

A.1.4.6 Control Measures

There are various control measures to control, reduce or eliminate ozone from indoor air.

- Photocopiers
 - Ozone emissions from the photocopiers can be controlled or reduced by routine maintenance and cleaning. Photocopier manufacturers should include specifications on the amount of ozone produced by each model.
 - Photocopiers should be located in a well-ventilated and separate room. In some circumstances, such as extensive use and commercial use, local exhaust ventilation is recommended.
 - Some photocopiers have the option of being fitted with a “hopcalite filters,” which can reduce ozone emissions.
- Electronic air cleaners and negative ion generators
 - Ensure proper installation. The use of positive coronas instead of negative coronas can significantly reduce the production of ozone from air cleaners.

- Regular cleaning of electronic air cleaner collection plates is important.
- In the United States, electronic air cleaners and negative ion generators, which are sold as medical devices, are regulated by regulatory agencies such as the USEPA and the Food and Drug Administration (FDA). Based on FDA requirements, indoor levels of ozone may not exceed 0.05 ppmv because of the operation of these devices.
- In Canada, both the Food and Drugs Act (FDA) and the Pest Control Products Act (PCPA) cover ozone generators. To avoid being subject to regulations under these acts, ozone generators continued to be marketed as “air cleaners” or “pollution control devices”. Before July 1, 1998, The Medical Devices Regulations of the FDA act prohibited medical devices to generate airborne ozone to which humans may be exposed. A limit of 0.05 ppm (v/v) was also set for other medical devices which generated ozone. In July 1, 1998, the new Medical Devices Regulation came into effect. Therefore, the old regulations and schedules ceased to exist.
- Presently, there are no regulations on medical devices that produce ozone. To replace the old schedule VIII, the Therapeutic Products Programme drafted a policy on ozone generators. The New Medical Devices Regulations established general safety and effectiveness requirements for medical devices.
- Health Canada does not recognize health benefits from human exposure to ozone. Therefore, it precludes approval of ozone-producing devices under the Medical Devices Regulation. Ozone generators are prohibited devices in Canada (Health Canada 2010).

A.1.5 Nitrogen oxides (NO_x)

Nitrogen, the most abundant gas in the atmosphere, forms oxides in the presence of high temperature and oxygen. NO (nitric oxide) is a relatively non-toxic gas produced by the high-temperature reaction between N₂ and O₂ during combustion processes. It rapidly oxidizes to NO₂ (nitrogen dioxide), which has a greater toxic potential than NO (Godish, 2000). From an indoor air perspective, discussion of nitrogen oxides in this section will be limited to NO₂ or nitrogen dioxide.

A.1.5.1 Sources

Nitrogen dioxide is a colourless, odourless and irritating gas affecting the mucous membrane of the eyes, nose and throat and causing breathing difficulties, such as shortness of breath (Godish, 2000). The important indoor sources of NO₂ include (Calgary Health Region 1993):

- Gas ranges
- Kerosene space-heaters
- Tobacco smoke
- Candles
- Wood-burning stoves
- Pilot lights
- Vehicle exhaust from garages
- Indoor ice re-surfacing machines

A.1.5.2 Indoor and outdoor NO₂

Nitrogen dioxide (NO₂) is the only oxide of nitrogen in indoor air that has the toxicological potential to affect occupants (Health Canada, 1995). Exposure to nitrogen dioxide at typical indoor concentrations has been observed to significantly affect human health. The average level of nitrogen dioxide in homes without combustion appliances is about half that of outdoors. In homes with gas stoves, kerosene heaters, or unvented gas space-heaters, indoor levels of NO₂ often exceed outdoor levels (USEPA, 1999).

Indoor NO₂ levels have been reported in the range of 18 ppbv to 35 ppbv in homes with gas cooking stoves. The use of gas cooking ranges varies in different regions of the United States and Canada. The use of unvented gas ovens as a source of heat during cold winter months can be a significant source of several gaseous contaminants including NO₂ (Godish, 2000).

Another important source of nitrogen dioxide is environmental tobacco smoke (ETS). One of the major chemical changes that occur in ETS is associated with the conversion of non-toxic NO to toxic NO₂. Burning candles can also be a source of NO_x emissions (Godish, 2000).

Ice-hockey rinks can be considered as one of the major sources of NO₂ and other combustion-generated contaminants. These contaminants are produced from the combustion of carbon based fuels, such as propane, diesel or gasoline, by ice re-surfacing machines, such as Zambonis, which are used in between 70% and 75% of the Canadian and European ice rinks (Godish, 2000). Studies reported airborne concentrations of more than one ppmv NO₂ in ice rinks (Godish, 2000). In an extensive study of 332 rinks in nine countries, the average NO₂ concentration in the breathing zone of humans on the ice surface was 221 ppbv while in the spectators' area the concentration reached 228

ppbv (Godish, 2000). The highest concentrations recorded were from the ice surface at 2.68 ppm and the spectator's area at 3.18 ppm. The highest NO₂ levels were in arenas of smaller size and that had low ventilation rates.

The indoor and outdoor ratios for NO₂ in residences where there are no indoor sources are generally less than or near unity (Godish, 1989). In premises where gas stoves or ranges are used for cooking, or where combustion appliances remain unvented, such as kerosene space-heaters, indoor NO₂ levels will often exceed outdoor NO₂ levels. Some airborne contaminants and building surfaces, such as cement blocks, wallboard and wool carpet, can react with NO₂ to remove or "scavenge" the gas from indoor air (Dish, 1989).

A.1.5.3 Mechanism of toxicity

The principal site of NO₂ toxicity is the lower respiratory tract. The relatively low water solubility of NO₂ results in minimal mucous membrane irritation of the upper respiratory airways. Prolonged exposure to low concentrations of NO₂, or high concentrations for a short period, could affect a number of physiological systems in animals and humans (WHO, 1997).

Nitrogen dioxide is a strong oxidant. In the human body, unsaturated lipids are readily oxidized with peroxides as the dominant product. The oxidant properties of nitrogen dioxide induce the peroxide detoxification pathways, involving several enzyme systems in the body (WHO, 1997). Membrane proteins are also oxidized by NO₂. The oxidation of membrane lipids or proteins disrupts cell permeability. The lungs of people exposed to nitrogen dioxide have relatively more proteins within the lumen which is an inflammatory response to the effect of NO₂ on membrane proteins (WHO, 1997).

A.1.5.4 Health effects

- **Acute effects**

NO₂ acts mainly as an irritant affecting the mucosa of the eyes, nose, throat and respiratory tract causing eye, nose and throat irritation with short-term exposure. It may also cause impaired lung function and increased respiratory infections in young children. Extremely high-dose exposure to NO₂ as in a building fire may result in pulmonary edema and diffuse lung injury. Continuous exposure to high NO₂ levels can contribute to the development of acute bronchitis. (USEPA, 2010)

- **Chronic effects**

Continued exposure to high NO₂ levels can contribute to the development of acute or chronic bronchitis. Low level NO₂ exposure may cause increased bronchial reactivity in some asthmatics, decreased lung function in patients with chronic obstructive pulmonary disease and increased risk of respiratory infections, especially in young children. (USEPA, 2010)

A.1.5.4.1 Sensitive or vulnerable individuals

The following groups of individuals show hypersensitivity to NO₂.

- Asthmatic individuals (Calgary Health Region, 1993)
- Patients with chronic obstructive pulmonary disease (COPD)
- Children

Compared to healthy people, children and individuals with respiratory illnesses including asthma are more susceptible to the effects of NO₂. Children can be more susceptible to colds and flu when exposed to low levels of NO₂. Bronchial reactivity is found to be increased in some asthmatic individuals when exposed to NO₂. Lung function decreased in patients with chronic obstructive pulmonary disease during long term exposure to low level NO₂. Breathing high levels of NO₂ can cause irritation of the respiratory tract and shortness of breath in humans.

A.1.5.5 Exposure

The primary route of exposure to NO₂ is through inhalation. A causal relationship has been reported between increased risk of pulmonary symptoms in children under seven years of age and living in homes with a gas stove (because of elevated NO₂). The presence of a gas stove is a significant risk factor for respiratory illnesses among those children (Godish, 2000).

In a North American study, children under the age of seven were exposed to 16 ppbv NO₂ from kerosene heaters. They were reported to have more than a two-fold higher risk of lower respiratory symptoms than children residing in homes with non-kerosene heaters (Godish, 2000).

A.1.5.6 Guidelines

A.1.5.6.1 Health Canada

Exposure guidelines for residential indoor air quality	
480 µg/m ³ (0.25 ppb)	Acceptable short-term exposure range (ASTER) for CO ₂ in residential indoor air
100 µg/m ³ (0.05 ppb)	Acceptable long-term exposure range (ALTER) for CO ₂ in residential indoor air

Source: Exposure Guidelines for Residential Indoor Air Quality, A report of The Federal Provincial Advisory Committee on Environmental and Occupational Health, Health Canada 1987 (Revised and updated)World Health Organization

A.1.5.6.2 World Health Organization

WHO air quality guidelines for nitrogen dioxide (2005)	
200 µg/m ³	1 hour mean
40 µg/m ³	Annual mean

Source: WHO (2005) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. WHO Press, World Health Organization. Geneva, Switzerland

A.1.5.6.3 North American indoor air quality guidelines for ice arenas

Jurisdiction	Nitrogen dioxide	Comments
State of Minnesota Air Quality Standard for Ice Arenas	≤0.5 ppm 1 hour average	Corrective action must be taken
	>2 ppm	Immediate Arena Evacuation
Public Health and Recreational Facilities Association of B.C. (Dr. Michael Brauer, U.B.C.)	≤0.25 ppm	Target Zone (ensures adequate health protection of facility users and children)
	>0.5-1.5 ppm	Action Zone (some individuals may experience symptoms at these levels. Immediate action is required to reduce to Target Zone Levels)
	>1.5 ppm	Danger Zone (immediate corrective action required, such as evacuation, ventilation)
Air Quality Guidelines for Arena Operations in Manitoba (2008)	< 0.25 ppm	Levels within acceptable parameters; continue with standard operating procedures.
	0.25-3 ppm	Investigate and take corrective actions.
	>3 ppm	Stop all activities within the arena. Investigate and take corrective actions. If carbon monoxide and/or nitrogen dioxide levels continue to rise or remain at unsafe levels, remove all patrons to a well-ventilated area.

Note Adoption of the three tiered indoor air quality guideline of the Public Health and Recreational Facilities Association is recommended. The goal of the guideline is to protect the sensitive and vulnerable population, those that are actively skating and those that have compromised lung function (e.g. asthmatics). The guidelines are also protective of spectators.

A.1.5.7 Control measures

The following control measures can be carried out to prevent or reduce exposure to NO₂ in indoor environments.

- Keep gas appliances properly adjusted, serviced and maintained.
- Replace the pilot lights of gas ranges and ovens with electronic ignition devices.
- The installation of a production-type wire insert for range top burners reduces NO_x emissions by 35% and NO₂ emissions by 26% (Godish, 1989). A low NO_x dual rod insert for oven burners can reduce NO_x emissions by 63% and NO₂ by 25% (Godish, 1989).
- A new gas range design, which incorporates perforated tile burners with glass ceramic plates located above, significantly lowered NO_x, NO₂ and CO emissions (Godish, 1989).
- Replace unvented space-heaters with vented heaters.
- Use the best grade of fuel in kerosene space-heaters.
- Install and use an exhaust fan, vented to the outdoors over gas stoves.
- Ensure fireplaces have open flues when in use and combustion air intakes. Install a combustion air intake. If there isn't an intake, in the interim open a window to provide combustion air.
- Choose properly sized wood stoves that are certified to meet emission standards.
- Make certain that doors on all wood stoves fit tightly.

- Have a trained professional inspect, clean and tune-up the central air heating systems including the furnaces, flues and chimneys annually.
- Repair any defects promptly.
- For ice arenas and ice re-surfacers, refer to this chapter carbon monoxide section.
- Avoid or prohibit cigarette smoking indoors.
- Minimize candle burning indoors.
- Do not idle vehicles in attached garages; instead, immediately turn off the vehicle engine after parking in a garage.

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Appendix A2

Chemical factors

Vapours (volatiles and semi-volatiles)

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A. Chemical factors

A.2 Vapours (volatiles and semi-volatiles)

A.2.1 Introduction

The term “volatile” describes chemical compounds that easily evaporate or volatilize at room temperature. Volatile organic compound (VOC) is a collective term assigned to a diverse group of carbon-based gases and vapours, with vapour pressures greater than 1 mm Hg, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate (WHO, 1999). There are different international classifications of volatile organic compounds. Boiling point is an indicator of the ability of VOCs to become airborne at atmospheric pressure (WHO, 1989). Table A.2-1 presents the WHO classification for VOCs based on boiling point.

Table A.2-1 Classification of indoor organic pollutants (WHO 1989)

Category	Description	Boiling point range (°C)
1	Very volatile (gaseous) organic compounds (VVOCs)	< 0 to 5 – 100
2	Volatile organic compounds (VOCs)	50 – 100 to 240 – 260
3	Semi-volatile organic compounds (SVOCs)	240 – 260 to 380 – 400
4	Organic compounds associated with particulate matter or particulate organic matter (POMs)	> 380

Volatility can also be ranked according to vapour pressure and Henry’s Constant (Table A.2-2).

Table A.2-2 Volatility ranking scheme

Volatility	Vapor pressure (mm Hg)	Henry’s constant (atm-m ³ /mole)
Non-volatile	< 10 ⁻⁵	H < 10 ⁻⁷
Slightly volatile	10 ⁻⁵ < VP < 10 ⁻³	10 ⁻⁷ < H < 10 ⁻⁵
Moderately volatile	10 ⁻³ < VP < 10 ⁻⁰	10 ⁻⁵ < H < 10 ⁻³
Highly volatile	VP > 10 ⁻⁰	H > 10 ⁻³

Source: Welsh et. al., 1993

TableA.2-3 Classifications of VOCs volatility

Volatility ranking	Abbreviation	Vapor pressure (at 25°C)		Boiling point (°C)	Comments
		Kpa	mm Hg		
Non-volatile	NVOCs	<10 ⁻⁸	<8x10 ⁻⁸	<350	Primarily in condensed state
Semi-volatile	SVOCs	10 ⁻² -10 ⁻⁸	0.08-8x10 ⁻⁸	180-350	Existing in gaseous and condensed state
Volatile	VOCs	>10 ⁻²	>0.08	30-180	Evaporate quickly at room temp., primarily found in gaseous state
Very Volatile	VVOCs	>15	<112	<30	

Nagda and Rector (2001) provide the following classifications for volatility (cited in Spengler et. al., 2001)

Based on their unique physical and chemical properties, VOCs can be broadly classified under the following categories:

- Halogenated hydrocarbons
- Aldehydes
- Ketones
- Aliphatic hydrocarbons
- Alcohols
- Ethers and esters

A.1.1.1 Semi-volatile organic compound (SVOCs)

Semi-volatile organic compounds (SVOCs) are the subset of organic compounds having a boiling point ranging from 240°C to 400°C with vapour pressures ranging from 10⁻¹ to 10⁻⁷ mm Hg (Godish, 2000; Bidleman, 1988, cited in Van Loy et. al., 1997). Semi-volatile organic compounds tend to be in the condensed phase (possibly adsorbed to particles) both indoors and outdoors. SVOCs have lower odour and irritation thresholds than VOCs (Brinke, 1995, cited in Van Loy et. al., 1997).

Examples of SVOCs found in the indoor environment include nicotine (from ETS), PAHs and PCBs. Other SVOCs can include pesticides and herbicides, such as DDT, 2,4-D and 2,4-5-T) and plasticizers, such as phthalates. There is limited information on the characteristics and factors controlling SVOCs concentrations in indoor air (Van Loy et. al., 1997).

A.2.1.1 Sources

VOCs are commonly found in various indoor sources, such as tobacco smoke, furniture, cleaning products, paints, wood stains, adhesives, dyes, solvents, caulks, pesticides, clothing, food, flooring materials, plastics, building materials, office equipment and petroleum product derivatives.

Many VOCs have been found in higher concentrations indoors than outdoors (Brown *et. al.*, 1994, Samet, 2001, Tucker, 2001, Wallace, 2001, Spengler *et. al.*, 2001). Evidence of a possible linkage between the presence of indoor VOCs and Sick Building Syndrome (SBS) has been reported by several researchers (Kostiainen, 1995; Brinke, 1995; Morrow, 1992; Molhave, 1982). The United States Environmental Protection Agency (USEPA) has identified 300 VOCs in homes (Cooke, 1991). The Canadian Mortgage Housing Corporation has identified more than 900 organic chemicals from synthetic and natural sources in indoor environments.

Examples of VOCs commonly found in indoors include benzene, chloroform, trichloroethylene and tetrachloroethylene (otherwise known as perchloroethylene). Humans also release contaminants from their body that are known as “bioeffluents” (VOCs and other gases, such as CO₂, contributing to indoor VOCs concentrations. A list of bioeffluents is provided below (Godish, 2000, Fenske & Paulson, 1999). Phenol and toluene are considered as secondary bioeffluents as they are generated from other primary indoor sources rather than endogenously.

- Acetone
- Acetaldehyde
- Acetic acid
- Alkyl alcohol
- Amyl alcohol
- Butyric Acid
- Diethyl ketone
- Ethylacetate
- Ethyl alcohol
- Methyl alcohol
- Phenol
- Toluene

Table A.2-4 lists VOCs emitted from building materials and various consumer products. VOCs emitted by building materials are identified as a major indoor air quality problem affecting the health, comfort, lifestyle and productivity of human beings (Huang & Haghghat, 2001).

Table A.2-4 VOCs from building materials and consumer products

Building materials / consumer products	Major VOCs
Adhesives, spot cleaners, alkyd paints, paint removers, particleboard, furniture waxes	Benzene
Floor/wall coverings, fibreboard, caulking compounds, particleboard	2-Butanone
Edge sealings, molding tapes, jointing compounds, cement flagstones, linoleum floor coverings, floor lacquers, industrial cleaners, paint removers	n-Butyl alcohol
Solvent for paint, used in manufacture of phenol	Chlorobenzene
Solvent for lacquers and resins, paint and varnish removers	Cyclohexane
Plasticizer	Dibutylphthalate
Floor/wall coverings, insulation foam, chipboard, caulking compounds, jointing compounds, fibreboard, adhesives, floor lacquers, grease cleaners	Ethyl benzene
Major Sources: MDF, plywood, particleboard, ceiling panels, fibreboard, chipboard. Minor Sources: Upholstery fabrics, latex-based fabrics, fibreglass, fibreglass insulation in air ducts, urea formaldehyde foam insulation, wallpaper, caulking compounds, jointing compounds, floor and furniture varnishes, adhesives, floor lacquers, gypsum board.	Formaldehyde
Edge sealings, molding tapes, jointing compounds, cement flagstone, linoleum floor coverings, floor lacquers	Isobutyl alcohol
Paints, adhesives, chipboard, detergents, furniture polish	d-Limonene
Paint removers, aerosol paints, industrial solvents	Methylene chloride
Wallpaper, caulking compounds, floor coverings, chipboard, adhesives, cement flagstone, jointing compounds, floor varnishes, floor waxes	Nonane
Manufacturing byproduct in carpets with BR latex backing	4-Phenylcyclohexene
Insulation foam, jointing compounds, fibreboard, carpets with SBR latex backing	Styrene
Furniture polishes	α -Terpinene
Widely used in the textile industry for dry cleaning, processing, and finishing of fabrics; used in metal degreasers, spot removers, adhesives, wood cleaners, and lubricants.	Tetrachloroethylene
Solvent-based adhesives, water-based adhesives, edge sealings, molding tapes, wallpaper, jointing compounds, floor coverings, vinyl coated wallpaper, caulking compounds, paints, chipboard, vinyl floor coverings	Toluene
Solvent for paints and varnishes	Trichloroethylene
Floor/wall coverings, floor waxes, linoleum floor coverings, caulking compounds, vinyl coated wallpaper, jointing compounds, cement flagstone, floor varnishes, chipboard	Trimethylbenzene family of compounds 1,2,3 Trimethylbenzene 1,2,4 Trimethylbenzene 1,3,5 Trimethyl benzene
Adhesives, jointing compounds, wallpaper, caulking compounds, floor coverings, floor lacquers, grease cleaners, varnishes	Xylenes

Source: California Department of Health Services 1996. *Reducing Occupant Exposure to Volatile Organic Compounds (VOCs) from Office Building Construction Materials: Non-binding Guidelines, Appendix B: VOCs That May Be Emitted from Building Materials and Cleaning Products*. Online document: 1999, website: <http://www.cal-iaq.org/VOC/VOC>.

A.2.1.2 Sorption and desorption characteristics of VOCs

The sorption-desorption characteristics of VOCs play an important role in their indoor distribution (Tichenor *et. al.*, 1991; Colombo *et. al.*, 1993; Kajaer *et. al.*, 1996). Indoor materials act as buffers for VOCs, acting to reduce peak concentrations but extending their presence in indoor air and various indoor surfaces act as sinks, adsorbing emitted VOCs. Most buildings and houses are characterized by a large surface area to volume ratio. As a result, surface interactions can significantly affect the behaviour of sorbable contaminants.

After airborne VOC levels fall below equilibrium concentrations, the sorbed VOCs are re-emitted, prolonging their presence in indoor air. Sinks; that is, surfaces that remove pollutants from indoor air) have a significant role in determining contaminant concentrations in indoor air. Sinks can be reversible and irreversible. A sink may appear to be irreversible when the contaminant concentration is high and then becomes reversible when the contaminant concentration is low. A reversible sink re-emits indoor contaminants whereas, an irreversible sink does not.

VOC sorption (adsorption and desorption) by building materials can be very complex. Sorption depends on various factors, such as material properties, the type and concentration of VOCs, and environmental parameters, such as temperature, relative humidity and air velocity (Tichenor *et. al.*, 1991; van der Wall, 1994; Kirchner *et. al.*, 1996; Kjaer and Tirkkonen 1996; Kephelopoulos *et. al.*, 1996, cited in Zhang, 2002).

The molecular characteristics of a particular VOC and the properties of the adsorbent material are important in determining the adsorption and re-emission dynamics and the VOC concentration in the air. Various materials and products found in a home, such as carpets, painted walls, wallpapers and PVC materials are known to be VOC sources and can act as adsorbents and remitters of and for those same and other VOCs. VOCs may also enter a building from the outdoors or can be generated indoors by activities, such as cooking and tobacco smoking (Meininghaus *et. al.*, 2000).

Several experimental chamber studies have demonstrated VOC sorption characteristics under specified laboratory conditions. Those studies may not represent a real world scenario because of the dynamic nature of the VOCs in an indoor environment; however, researchers have derived the following conclusions regarding the sorption and desorption characteristics of VOCs (Sparks, 1991, 1995, 2000):

- Sinks are indoor materials that remove VOC contaminants from the indoor air. VOCs that are trapped in the sink can be re-emitted later. The effect of sinks on individual exposure depends on the activity patterns of the individual. Sinks can slightly reduce the peak exposure of individuals who spend 24 hours per day in a building, but they will not have an effect on their cumulative exposure.
- An irreversible sink can act as an air cleaner, reducing personal exposure for as long as the sink is active. On the other hand, the effects of reversible sinks are more complex because they can have a major effect on the concentration and time history of contaminants. The re-emission rates of contaminants are generally inversely proportional to the volatility of a compound.

Different building materials can have different emission rates and decay constants. Sparks (2000) estimated initial emission rates (R_0) and decay constants (k) in an indoor

air quality source and sink model. Table A.2-5 lists emission rates and decay constants for various indoor VOC sources. The smaller the decay constant, the longer the off-gassing period is for that VOC. For example, if $k = 0.1$, then 10% the VOC emissions off-gassed from that material will occur in the first hour.

Table A.2-5 Emission rates and decay constants of various building materials

Indoor source	Contaminant	R0 (initial emission rates)	K 1/h (first order decay constants)
Linoleum (sheet flooring)	VOC	1.8 mg/m ² -h	0.0001
Painted walls	VOC	0.27 mg/m ² -h	8 x 10 ⁻³
Lacquered parquet floor	VOC	0.247 mg/m ² -h	2.2x10 ⁻⁵
Polyurethane varnish	VOC	20,000 mg/m ² -h	0.25
Wood stain	VOC	17,000 mg/m ² -hr	0.4
Wood floor wax	VOC	20,000 mg/m ² -h	6
Liquid nail adhesives	VOC	26,800 mg/m ² -h	0.43
New carpet	4 PC	150 ug/m ² -h	0.0036
Linoleum(sheet flooring)	Formaldehyde	5 ug/m ² -h	1x 10 ⁻⁸
Painted gypsum board	Formaldehyde	20 ug/m ² -h	8 x 10 ⁻⁵
Painted gypsum ceiling	Formaldehyde	9 ug/m ² -h	1.8 x 10 ⁻⁴
Lacquered paraquet floor	Formaldehyde	12 ug/m ² -h	2.2 x 10 ⁻⁵

However, the decay constant only captures the adsorption behaviour of VOCs. Understanding the more complex phenomena of adsorption and desorption requires further empirical elaboration. Experimental data in a test house (USEPA) and small chamber studies show that for a variety of VOCs, the adsorption (k_a) and desorption (k_d) rate constants can vary from 0.1 to 3.2 and from 0.0001 to 0.1, respectively (see Table A.2-6).

Table A.2-6 Absorption rate constants and desorption rate constants for different indoor materials

Indoor materials	Pollutant	Adsorption rate constants (k_a) (m/h)	Desorption rate constants (k_d) (1/h)
Carpet	TVOC	0.1	0.008
Painted wallboard	TVOC	0.1	0.1
Ceiling Tiles	TVOC	0.1	0.1
All Surfaces	P-dichlorobenzene	0.35	0.01
All Surfaces	Ethylene glycol	3.2	0.0001
All Surfaces	Propylene glycol	3.2	0.0

Source: cited in Sparks (2000), Risk Version 1.7

The emission rates and decay constants (Table A.2-6) are used as inputs in complex IAQ calculations and computer modeling programs. A detailed description of different IAQ models is beyond the scope of this manual. The reader should refer to other publications for a better understanding of the principles and applications of IAQ models

A.2.1.3 Health effects of VOCs

Clinical signs of VOC exposure range from irritation of the eyes, mucous membranes and the respiratory system to headache, nausea, drowsiness, fatigue, general malaise and severe distress in asthmatics (Becher *et. al.*, 1996; Kostianen, 1995). Several VOCs have been classified as proven, probable or suspected human carcinogens.

Table A.2-7 Carcinogenic classifications of common VOCs

Common VOCs	Carcinogenic classification and health effects
Formaldehyde	IARC Group 1 known human carcinogen. USEPA B1 probable human carcinogen Considered to be “toxic” as defined in Section 64 of CEPA 1999 and is weakly carcinogenic
Chloroform	USEPA Group B2 probable human carcinogen IARC Group 2B possibly carcinogenic to humans Considered to be “toxic” as defined in Section 64 of CEPA 1999
Benzene	USEPA Group A known human carcinogen IARC Group 1 known to be carcinogenic to humans Considered to be “toxic” as defined in Section 64 of CEPA 1999 and carcinogenicity is potentially the most sensitive endpoint
Toluene	USEPA Group D not classifiable as to human carcinogenicity IARC Group 3 not classifiable as to its carcinogenicity to humans Health Canada probably not carcinogenic
Tetrachloroethylene (perchloroethylene)	USEPA does not currently have a classification IARC Group 2A Probably carcinogenic to humans Health Canada possibly carcinogenic to humans

Source: USEPA, IARC websites

The following VOCS are discussed in greater detail in the following pages:

- TVOCs (total VOCs)
- Benzene
- Toluene
- Formaldehyde

Formaldehyde is classified as a very volatile compound (boiling point -20°C). It is specifically discussed below because of its common presence in the indoor air.

- Chlorinated hydrocarbons

The following SVOCs are discussed in more detail below.

- Polycyclic aromatic hydrocarbons (PAHs)
- Polychlorinated biphenyls (PCBs)

A.2.2 Total VOCs (TVOCs)

Total volatile organic compounds (TVOCs) are defined by the World Health Organization (WHO) as a set of volatile organic agents including toluene, xylene, pinene and ethanol with a melting point below room temperature and a boiling point in the range of 50°C to 260°C (Jokl, 1998). If a mixture of VOCs is measured, then the total concentration can be expressed as TVOCs. There are no regulatory standards or universal rule on which compounds are to be included in the definition of TVOCs (Pyy *et. al.*, 1997). Identification and analysis of individual VOCs are time-consuming and expensive. Therefore, the concept of TVOC was devised to measure total VOCs present in an air sample without distinguishing different VOCs (Health Canada, 1995).

A.2.1.1 Sources

Sources of volatile organic compounds can differ widely in different indoor settings. Tirkkonen *et. al.* (1993) measured TVOC emission rates from the building and furnishing materials presented in Table A.2-8.

Table A.2-8 TVOC emissions from different building and furnishing materials

Material	History	TVOC (mg/m ² -hour)
Building materials		
Gypsum board	New from store	0.003
Mineral wool	New from store	0.106
Glass wool	New from store	0.131
Cellulose wool	New from store	0.777
Expanded polystyrene	New from store	0.177
Wall coverings and Paints		
Alkyd paint	Two weeks old	1.861
Solvent-free latex paint	Two weeks old	0.04
Solvent-free acrylate latex paint	Two weeks old	0.302
Water-resistant latex-based painting system	Two weeks old	3.833
Wallpaper	New from store	0.023
Textile floor cover	New from store	0.024

Source: Tirkkonen, T., Mattinen, M-L., Saarela, K., *Volatile organic compound (VOC) emission from some building and furnishing materials. Proceedings of Indoor Air '93, Vol. 2: 477-482, 1993*

Other sources of TVOC include:

- Interiors of automobiles
- Carpets and vinyl sheet floors
- Plywood, particle board and paper products
- Inks and printers
- Cleaning and personal care products, such as deodorizers, polishes, shampoo, deodorants and hair spray
- Fabrics and fabric softeners
- Environmental Tobacco Smoke (ETS)

A.2.2.1 Health effects of VOCs

TVOCs have been shown to cause Sick Building Syndrome (SBS) symptoms because (Godish, 2000):

- TVOC have the potential to cause sensory irritation and CNS-related abnormalities and symptoms.
- TVOC concentrations are generally higher indoors than outdoors.
- Many TVOC have the potential to cause health effects through additive and synergistic effects.

Based on those above characteristics of TVOC, indoor air quality experts have devised a theory known as the “TVOC theory”. It suggests that the incidence of sensory irritation and neuro-toxic type symptoms attributed to TVOC are because of the combined effects of exposure to various VOCs. The following box presents human symptoms of low level TVOC exposure.

Symptoms of TVOC exposure	
• Fatigue	• Euphoria
• Headache, drowsiness and dizziness	• Chest tightness
• Weakness	• Unsteadiness
• Joint pains	• Blurred vision
• Peripheral numbness or tingling	• Skin and eye irritation

A.2.2.2 Sensitive or vulnerable individuals

Sensitive or vulnerable individuals and population subgroups can be severely affected by exposure to low TVOC concentrations produced from building materials, furniture and finishing materials and various consumer products including cosmetics, soaps, perfumes, tobacco, plastics and dyes (Health Canada, 1995).

Individuals and population subgroups suffering from chronic diseases and allergies may show a higher sensitivity to VOCs than normal healthy individuals, even at chronic low level exposures. Other sensitive or vulnerable individuals such as pregnant women and young babies may also show higher sensitivity than normal healthy individuals. However, the data on sensitive or vulnerable individuals with respect to VOCs exposure is very limited and further research is warranted at this time (IEH, 1999, posted at <http://www.le.ac.uk/ieh>, website accessed July 24, 2002).

A.2.2.3 Exposure and health effects

Several exposure studies have been conducted with respect to TVOC. A mixture of 22 VOCs was used in an acute exposure study in which volunteers were exposed to TVOC ranging from 5 to 25 mg/m³ (toluene equivalent) for 2.75 hours (Godish, 2000). Volunteers, who were exposed to these concentration ranges, complained of high irritation and exhibited reduced performance in neurobehavioral tests compared to those

exposed to clean air. Several other exposure related studies on TVOC by USEPA revealed other health effects such as headache and general discomfort.

Molhave (2001) summarized the health effects results from several controlled human exposure experiments. The goal was to establish a dose–response relationship. Human subjects were exposed to a VOC mixture that ranged from 0.087 mg/m³ to 25 mg/m³. Table A.2-9 lists the various health symptoms reported in the tests.

Table A.2-9 Symptoms following VOC exposures

Symptom (health effects)	Range of thresholds shown (mg/m ³)	Number of reported cases
Perceived air quality	1.7-5	12
Odor intensity	1.0-1.7	12
Irritation of eyes or nose	1.7-8.0	12
Additional ventilation needed	1.7-3.0	5
Feeling of cough	1.7-25	3
Irritation of throat	5-25	12
General well being	8-10	4
Feeling of skin humidity	10-25	3
Headache	≥ 20	5
Concentration difficulties	12=20	5
Feeling of sleepiness	≥ 25	3

Source: Molhave (2001), *Sensory irritation by VOCs: 12 exposure experiments, chapter 25, Indoor Air Quality Handbook, McGraw Hill publications (2001).*

A.2.2.4 Guidelines

A.2.2.4.1 TVOC concentration and comfort range in residential environment

Based on the dose–response studies conducted by Molhave, the following table summarizes the relationship between TVOC exposure and health effects (Table A.2-10). The TVOC dose-relationship in the table provides a useful tool for indoor air quality investigators, but should be used judiciously with an understanding of site-specific VOC sources and contaminants of concern.

Table A.2-10 Molhave’s TVOC dose–response model relationship

TVOC concentration (mg/m ³)	Response	Exposure range
< 0.20	No effects	Comfort range
0.20 – 3.0	Irritation / discomfort possible	Multifactorial exposure range
3.0 – 25.0	Irritation and discomfort; headache possible	Discomfort range
> 25.0	Neurotoxic effects	Toxic Range

With reference to the above table, Dr. Molhave states that for normal and average people, the threshold for headache and other weak neurotoxic effects by exposure of less than a few hours duration are expected to be between 3 mg/m³ and 25 mg/m³. However, more sensitive individuals may experience these health effects at concentrations lower than those specified above.

A.2.2.4.2 TVOC range in office buildings

- **Health Canada**

At present there are no Canadian standards for TVOC. However, Health Canada has presented the following quantitative TVOCs guidelines for office buildings (Table A.2-11).

Table A.2-11 Health Canada recommended TVOC levels in office buildings

Jurisdiction	TVOC criteria	
Tentative North American criteria	Target level for TVOC	1 mg/m ³
	Action level for TVOC	5 mg/m ³
European Community	Target (see the section below for more information)	0.3 mg/m ³ with no one VOC exceeding 10% of the TVOC concentration
Molhave criteria	See Table A.2-10	

Source: Indoor Air Quality in Office Buildings: A Technical Guide, Health Canada, Minister of Supply and Services Canada, 1995

Health Canada states that sensitive individuals can be severely affected by a variety of VOCs at very low concentrations. They can react to organic compounds that are released by building materials, carpets, and various consumer products including cosmetics, soaps, perfumes, tobacco, plastics and dyes. These reactions can occur after exposure to a single sensitizing dose or a sequence of doses. After a sensitizing dose, a much lower dose can provoke health symptoms. Because of the limited knowledge of toxicological and sensory effects of VOC mixtures, reduction of overall exposure to TVOC is highly desirable.

- **European Community target guidelines**

The European Collaborative Action (ECA) report no. 11, *Guidelines for Ventilation Requirements in Buildings* (CEC, 1992) lists TVOC concentration ranges as measured with a flame ionization detector calibrated to toluene. These recommendations are based on Molhave's toxicological studies on mucous membrane irritation (Molhave, 1990).

- Comfort range: < 200 ug/m³ (< 0.2 mg/m³)
- Multifactorial exposure range: 200 to 3,000 ug/m³ (0.2 to 3 mg/m³)
- Discomfort range: 3,000 to 25,000 ug/m³ (3 to 25 mg/m³)
- Toxic range: > 25,000 ug/m³ (> 25 mg/m³)

A second criteria is based on the research of Seifert (1990) who has established TVOC guidelines based on the ten most prevalent compounds in each of seven chemical classes. The concentrations in each of these classes should be below the maximums listed below.

- Alkanes: 100 ug/m³ (0.1 mg/m³)
- Aromatic hydrocarbons: 50 ug/m³ (0.05 mg/m³)
- Terpenes: 30 ug/m³ (0.03 mg/m³)

- Halocarbons: 30 ug/m³ (0.03 mg/m³)
- Esters: 20 ug/m³ (0.02 mg/m³)
- Aldehydes and ketones (excluding formaldehyde): 20 ug/m³ (0.02 mg/m³)
- Other: 50 ug/m³ (0.05 mg/m³)

The TVOC concentration is calculated by adding the totals from each class. Therefore a target TVOC concentration of 300 ug/m³ (0.3 mg/m³) is established. No individual compound concentration should exceed 50% the guideline for its class or 10% of the TVOC target guideline concentration. However, according to Seifert (1990), the proposed target level for TVOC is not based on toxicological considerations but on the best scientific judgment at that time.

European Community	Target guideline for TVOC
Target Level for TVOC	300 ug/m ³ (0.3 mg/m ³) with no individual compound concentration exceeding 50% of the guideline for its class or 10% of the TVOC target guideline

Sources: Indoor Air Quality in Office Buildings: A Technical Guide, Health Canada, Minister of Supply and Services Canada, 1995 California Department of Health Services (2001), Reducing Occupant Exposure to Volatile Organic Compounds (VOCs) from Office Building Construction Materials: Non-binding Guidelines.

A.2.2.4.3 National Institute of Health Sciences, Global Information Network of Chemicals

Advisable TVOC value for Indoor air quality	
TVOC	400 ug/m ³

Source: Committee on Sick House Syndrome: Indoor Air Pollution, Progress Report No. 2, Summary on the discussions of the 4th and 5th meetings, National Institute of Health Sciences, Global Information Network of Chemicals, Japan.

The value of 400 ug/m³ is regarded as an ALARA (as low as reasonably achievable) level and was not determined on the basis of toxicological effects. Rather, it was determined by investigating residential indoor air quality in Japan (NIHS, 2000).

The TVOC advisable value has to do with the condition that quite an amount of time has passed since the habitation started. It is probable that, not long after the habitation, the measured TVOC will exceed the advisable value. It is also noted that all the chemicals comprising the TVOC do not have cause for concerns about adverse health effects and that the TVOC may include chemicals derived from the sources normally used in residential environment. Therefore, if the measured TVOC turned out to exceed the advisable value, the interpretation should be made taking into consideration the background factors such as the timing of the conduct of sampling and analysis, chemicals included in the TVOC analysis and the indoor chemical sources”

—In Progress Report No.1, 26 June 2000).

A.2.2.5 Control measures

Several control measures can be carried out to control or eliminate indoor TVOCs. As TVOCs are a common constituent of other products, please refer to other control measures provided in this appendix and also see *Appendix C Environmental tobacco*

smoke, Appendix F Consumer products and Appendix H Built environment, mechanical and physical factors.

Selection of low-emission construction materials and furnishings should be used to reduce TVOC emissions (Godish, 2000). Table A.2-12 presents TVOC-recommended emission limits for building materials and furnishings (Godish, 2000).

Table A.2-12 Recommended and acceptable TVOC emission rate for building materials and furnishings

Material/product		USEPA	IRC/NRC ²			
		Max EF ¹	EF @ 24 hr ¹		EF @ 96 hr ¹	
			Min	Max	Min	Max
Flooring	Particleboard	0.6	3.87	6.90	2.12	4.35
	Plywood		0.22	0.67	0.19	0.46
	Oriented strand board		0.27	0.98		1.76
	Solid wood		0.07	4.53	0.05	3.55
	Vinyl flooring		0.05	3.77	0.07	2.73
	Underpad		0.10	0.45		0.28
	Carpet		0.20	1.91	0.07	0.99
Floor coatings	Wood stain	0.6	18.2	124.4		52.3
	Polyurethane coating		88.1	154.5	3.88	359.3
	Floor wax		51.4	409.0	5.55	26.0
	Paint/primer		29.9	216.2	0.34	19.0
Wall/ceiling covering	Gypsum board	0.4				
	Acoustic tile	2.5 mg/hr per WS				
Partitions		0.25mg/m ³ /hr				
Office furniture						
Office machines						
Workstation			0.5 mg/hr	0.5 mg/hr	0.5 mg/hr	0.5 mg/hr
Others	Adhesive		3.28	659.1	3.88	359.3
	Caulking sealant		448.0	10467.2	51.13	3842.6

¹ The units are mg/m²/hr unless otherwise specified

² The values are the minimum and maximum emission factors among those determined from testing three products in each category

Canada Mortgage and Housing Corporation (CMHC) released a publication in 2005 entitled, "Building Materials for the Environmentally Hypersensitive" providing recommendations on building materials for sensitive or vulnerable individuals. The reader is encouraged to refer to this publication for additional information.

Source: National Research Council Canada (2005). "Managing Volatile Organic Compounds and Indoor Air Quality in Office Buildings – An Engineering Approach". NRC website: <http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/rr/rr205/rr205.pdf>

A.2.3 Benzene (C₆H₆)

Benzene is both a naturally occurring and anthropogenic volatile organic compound produced by volcanoes, forest fires, and fossil-fuel combustion. Consequently, it is found in varying concentrations in the ambient air.

Benzene is a major industrial chemical byproduct produced from coal and oil processing and by the incomplete combustion of organic materials including gasoline (CEPA, 1993). Benzene is also an important component of gasoline fuel. In its purest form, it is a clear and colourless liquid. Benzene quickly evaporates into the air and can be smelled at 1.5 to 4.7 ppm in the air and at 0.5 ppm to 4.5 ppm in water (ATSDR, 1997). Table A.2-13 presents relevant physical and chemical properties of benzene.

Table A.2-13 Physical and chemical properties of benzene

Physical and chemical properties		Reference (from ATSDR 1997)
Molecular weight	78.11	Merck 1989
Colour	Clear, colourless liquid	Merck 1989
Physical state	Rhombic prisms	HSDB 1996
Melting point	5.5 °C	Merck 1989
Boiling point	80.1 °C	Merck 1989
Density at 15°C g/cm ³)		
Odour	Aromatic	NFPA 1994
Odour threshold:		
• Water	2.0 mg/L	
• Air	4.9 mg/m ³	HSDB 1996
• Taste threshold	0.5 – 4.5 mg/L	
Solubility:		
• In water at 25oC	Wet/wet: 0.188%	Merck 1989
• In organic solvents	Alcohol, chloroform, ether, carbon disulfide, acetone, oils, carbon tetrachloride and glacial acetic acid	Merck 1989
Vapour pressure at 20°C	75 mm Hg	NFPA 1994

Source: *Toxicological Profile for Benzene (ATSDR 1997)*

A.2.3.1 Sources

Benzene is ubiquitous in the atmosphere occurring in both rural and urban outdoor air as well as in indoor air (ATSDR, 1997). There are various indoor and outdoor sources of benzene, which have the potential to affect indoor air quality. Some of the major sources of benzene in air in the indoor environment are:

- Environmental tobacco smoke (ETS)
- Infiltration of benzene vapours from attached garages
- Residential wood burning stoves
- Infiltration of vapours from the outdoor combustion of gasoline and diesel fuels
- Other sources include glues, cleaning solvents, paints and cosmetic products.

Gasoline contained a small percentage of benzene before the 1950s when tetraethyl lead was the most widely used anti-knock engine additive. With the global phaseout of leaded gasoline, benzene is the gasoline additive of choice in some nations to increase the octane rating and reduce engine knocking. The concern over the harmful health effects and the possibility of benzene entering the groundwater is being seen in the creation of more stringent regulation of benzene content in fuels, with limits typically around 1 per cent.

A.2.3.2 Sensitive or vulnerable individuals

Individual susceptibility is one of the most important variables in the development of chronic benzene toxicity (ATSDR, 1997). Unusually susceptible individuals may exhibit an increased response to benzene exposure because of their genetic makeup, age, health, nutritional status and exposure to synergistic toxic substances, such as environmental tobacco smoke. These factors may influence the detoxification and excretion process in sensitive or vulnerable individuals. Genetic factors play an important role in benzene susceptibility.

The hematotoxic effect of benzene can be exacerbated by ethanol (ethyl alcohol); therefore, alcohol consumers can be considered as highly susceptible to benzene exposure (Nakajima *et. al.*, 1985). Increased central nervous system (CNS) disturbances including depression may be observed in those individuals after concurrent exposure to benzene and ethanol (ATSDR, 1997).

A.2.3.3 Metabolism of benzene

The metabolism of benzene plays an important role in its toxicity. Approximately 50 per cent of inhaled benzene is absorbed through the lungs and a small amount through the dermal pathway. Absorbed benzene is distributed throughout the body and has the potential to accumulate in the adipose tissue (ATSDR, 1997).

Benzene is metabolized in the liver, and to some extent in the bone marrow, to elicit myelotoxicity or toxic effects in the bone marrow. Liver metabolism is mediated by cytochrome P-450 monooxygenase to form benzene oxide (a reactive intermediate). In this process other toxic metabolites such as phenols, quinones and semi-quinones are also produced. Both benzene and its metabolic byproducts play an important role in eliciting myelotoxicity (Snyder & Hedli, 1996; Witz *et. al.*, 1996).

A.2.3.4 Mechanism of toxicity

A variety of potential mechanisms explaining benzene toxicity and leukemogenesis have been proposed (ATSDR, 1997). Benzene and its metabolites can bind to DNA, RNA and protein structures and inhibit enzymes of the hematopoietic system. Benzene metabolites may differentially attack cell populations in the bone marrow and in turn affect hematopoiesis. Benzene causes chromosomal abnormalities in blood cells, which is an indication of genetic damage. Benzene is carcinogenic in animals and leukemogenic in humans (Cronkite *et. al.*, 1984, 1985, 1989; Farris *et. al.*, 1993; IARC, 1982a; NTP, 1986, 1994, cited in ATSDR, 1997).

A.2.3.5 Health effects

Most of the acute and chronic health effect studies on benzene are derived from occupational studies (ATSDR, 1997).

- **Acute effects**

Several old studies have reported mortality and CNS depression from both acute inhalation and ingestion of high concentrations of benzene (Cronin, 1924; Greenburg, 1926; Tauber, 1970, cited in ATSDR, 1997).

The acute inhalation exposure of occupational workers to benzene (60 ppm) for two days resulted in hematological effects such as leukopenia, anemia, and thrombocytopenia, (Midzenski *et. al.*, 1992, cited in ATSDR 1997). Acute inhalation of benzene resulted in the following acute effects in humans:

- Respiratory effects

Mucous membrane irritation and dyspnea were noted in 80% and 67% of workers, respectively, at an exposure concentration of 60 ppm for up to three weeks (Midzenski *et. al.*, 1992, cited in ATSDR 1997).

- Cardiovascular effects

Fatal cardiovascular effects, such as ventricular fibrillation, was suggested to be the cause of death after exposure to benzene vapours (Avis & Hutton, 1993). The exposure concentration was not reported in this study.

- Gastrointestinal effects

Gastrointestinal effects or congestive gastritis were noted in human beings after inhalation (Winek & Collum, 1978) and ingestion exposure (toxic gastritis and pyloric stenosis) to benzene (Greenburg, 1926).

- Neurological effects

Neurological effects, such as vascular congestion of the brain (Avis & Hutton, 1993), were reported following acute inhalation of benzene by human beings (Midzenski *et. al.*, 1992, cited in ATSDR 1997; Tondel *et. al.*, 1995).

- **Chronic effects**

The most noted systemic effect from intermediate and chronic benzene exposure is hematotoxicity (ATSDR, 1997).

Chronic inhalation exposure to low-level benzene is associated with peripheral nervous system effects such as changes in motor conduction velocity in pancytopenic individuals (Baslo & Aksoy, 1982); that is, individuals with a pronounced reduction of white blood cells, platelets and red cells in the blood that generally occurs because of chemotherapy or disease. Those individuals were occupationally exposed to benzene-containing adhesives.

Chronic inhalation exposure has also been associated with distal neuropathy (neural dysfunction/pathology of the bodies extremities) (Baslo & Aksoy, 1982) and difficulty in sleeping and memory loss in humans (Kahn & Muzyka, 1973). Chronic effects such as prolonged nasal irritation and sore throat were also reported in

workers at exposures ranging from 33 ppm to 59 ppm benzene for one year (Yin *et al.*, 1987b).

- Carcinogenicity of benzene

According to Section 64 of CEPA 1999, benzene is considered to be toxic and carcinogenicity is potentially the most sensitive endpoint. The International Agency for Research on Cancer (IARC) a part of the WHO classifies benzene as a known human carcinogen stating:

- ▶ Sufficient evidence that benzene causes acute myeloid leukemia (AML)
- ▶ Limited evidence for acute lymphocytic leukemia (ALL), chronic lymphocytic leukemia (CLL), multiple myeloma and non-Hodgkin lymphoma

The U.S. National Toxicology Program (NTP) and the USEPA's electronic database—the Integrated Risk Information System (IRIS)—have classified benzene as known to be a human carcinogen.

Studies have also shown that the children of smokers die of leukemia two-and-a-half times more often than the children of non-smokers (Sandler *et al.*, 1985; Stjernfeldt *et al.*, 1986). Pregnant women who smoke during their pregnancy will be exposing their fetus to higher levels of benzene than non-smokers.

A.2.3.6 Exposure

Benzene is absorbed through all routes of exposure, demonstrating that the metabolism and distribution does not appear to depend significantly on route of exposure; however the level of exposure through air is higher than all other routes (ATSDR, 2007; OEHHA, 2000). Higher benzene exposures in the general population typically occur during different day-to-day activities such as filling gas tanks, travelling or living near high traffic roadways and around gas stations, and through inhalation of tobacco smoke by active and passive smoking (Adlkofer *et al.*, 1990; Chan *et al.*, 1993, 1994; Dor *et al.*, 1995). Consideration of both indoor and outdoor environments is relevant to benzene exposure assessment.

A major source of benzene in indoor air is environmental tobacco smoke (ETS). The inhaled smoke contains 12 µg to 48 µg benzene per cigarette (CEPA, 1993). The emitted smoke from cigarettes contains benzene at a concentration that can be ten times greater than the inhaled smoke (U.S. Department of Health and Human Services, 1986). Wallace (1989) reported an average additional increase of 3 µg/m³ benzene in the indoor air because of the presence of tobacco smoke in a study of 200 homes in the United States. Smoking has been identified as the single most important source of benzene exposure for the 40 million smokers in the United States (Wallace, 1989a, 1989b), and for adult and child non-smokers who lives with smokers.

From the available benzene exposure studies (both indoor and outdoor), a benzene exposure budget has been prepared (Wallace, 2001, in Spengler *et al.*, 2001). Smoking accounted for approximately half of the total population exposure risk. The other half was attributed to other sources of exposure such as unidentified personal factors, ambient air, passive smoking, occupational activities and filling gas tanks. Table A.2-14 lists the major sources of benzene exposure and total exposure risk estimate (Spengler *et al.*, 2001).

Table A.2-14 Major sources of benzene exposure and risk

Activity	Intake (µg/day)	Population at risk	Total exposure risk
Smoking	1,800	53	50
Unknown personal	150	240	20
Ambient	120	240	20
Passive smoking	50	190	5
Occupational	10,000	0.25	1
Filling petrol (gas tank)	10	100	<1

Source: Wallace (2001). "Assessing Human Exposure to Volatile Organic Compounds," Chapter 33. *Indoor Air Quality Handbook*, edited by Spengler et. Al. (2001) McGraw Hill Publications, 2001.

The total exposure risk estimate presented in Table A.2-14 was determined by taking into consideration various benzene exposure scenarios from different sources, such as ambient exposure, sitting in a vehicle, gas-tank filling, active smoking, passive smoking, attached garages, household products and materials, exposure from industries and wood smoke. After comparing all the sources, it was determined that smoking alone constituted approximately half of the U.S. population's total benzene exposure and the remaining half was distributed between personal activities (approximately 30 per cent) and the outdoor sources (approximately 20 per cent). The unidentified personal activity factors may include indoor exposure from the variety of unspecified products and materials in a home that are known to contain and release benzene into indoor air.

A.2.3.7 Guidelines

- **Health Canada**

Health Canada toxicological reference values (TRVS)	
3.3E-3 (mg/m3)-1	Inhalation unit risk from TC05a

a - Inhalation unit risk derived as: $URI_{inh} = 0.05/TC05$; TC05 from Health Canada (1996);

Source: *Federal Contaminated Site Risk Assessment in Canada, Part II: Health Canada Toxicological Reference Values (TRVs)*. (2004) Health Canada Website: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/contamsite/part-partie_ii/part-partie_ii-eng.pdf

- **World Health Organization**

WHO guidelines for indoor air quality: selected pollutants (2010)	
1.7 µg/m ³	1 in 100,000 risk

WHO (2010). *WHO guidelines for indoor air quality: selected pollutants*. World Health Organization. Website:

http://www.euro.who.int/data/assets/pdf_file/0009/128169/e94535.pdf

A.2.3.8 Control measures

The following source control methodologies can be followed to reduce or eliminate exposure to benzene.

- Eliminate smoking within the home.
- Provide maximum ventilation when using paints and varnishes.
- Discard leftover paint supplies and special fuels rather than store them, or store them in exhaust cabinets.
- Stand away from the filling nozzle while refueling vehicles at gas stations.
- Use timers to periodically ventilate exhaust from attached garages or a build detached garage.
- Properly maintain gas-fired furnaces and ensure they meet building code requirements.
- Minimize or curtail indoor wood-burning.
- Build new structures away from busy roadways, gas stations and other industrial sources.
- Ensure the best available pollution control equipment is installed on industrial sources.

A.2.4 Toluene (C₇H₈)

Toluene is a clear, colorless liquid that has a distinctive smell and the molecular formula C₇H₈. It is both naturally occurring in crude oil and in the tolu tree, and anthropogenically occurring in the processing of crude oil into fuel, the refining of coal into coke and the manufacturing of styrene. It is also a good solvent as well as a gasoline additive, along with benzene and xylene. A person can begin to smell toluene in the air at a concentration of eight parts of toluene per million parts of air (ppm), and taste toluene in water at a concentration of between 0.04 and 1 ppm (ATSDR, 2000).

Studies show that toluene is readily absorbed from the lungs of the respiratory tracts and, to a lesser extent, through the skin (ATSDR, 2000). Once absorbed toluene has been found in the adipose tissue, brain and bone marrow in high concentrations and toluene and its metabolites have been found in liver and kidney in moderately high concentrations (ATSDR, 2000).

Table A.2-15 Physical and chemical properties of toluene

Physical and chemical properties		Reference (From ATSDR 2000)
Molecular weight	92.14	Weast 1989
Colour	Colourless	NFPA 1994
Physical state	Liquid	NFPA 1994
Melting point	-95oC	Weast 1989
Boiling point	110.6oC	Weast 1989
Density at 20°C	0.8669 g/mL	Weast 1989
Odour	92.14	NFPA 1994
Odour threshold:		
• Water	0.04–1 ppm	EPA 1987a
• Air	8 ppm	HSDB 1998
Solubility:		
• In water at 25°C	534.8 mg/L	Howard 1990
• In organic solvents	Miscible	Budavari <i>et al.</i> 1989
Vapour pressure at 25oC	28.4 mm Hg	Howard 1990

Source: *Toxicological Profile for Toluene (ATSDR 2000)*

Levels of toluene measured in rural, urban and indoor air averaged 1.3 µg/m³, 10.8 µg/m³ and 31.5 µg/m³ (micrograms per cubic meter), respectively (USEPA, 2007). The median concentrations of toluene measured in Canadian residences range from 5.5 to 24.7 µg/m³ (0.0055 to 0.0247 mg/m³) and average concentrations from 11.5 to 34.4 µg/m³ (0.0115 to 0.0344 mg/m³) (Zhu *et al.*, 2005; Héroux *et al.*, 2008; Health Canada, 2010b; Health Canada, 2010c). Peak concentrations can reach values one to two orders of magnitude higher (Health Canada, 2011).

A.2.1.1 Sources

Toluene is used in making paints, paint thinners, fingernail polish, lacquers, adhesives, rubber and in some printing and leather tanning processes and as an additive in gas (ATSDR, 2000). Other products include auto polish and cleaners, floor polish, hard surface cleaners, inks, paint cleaners, paint and varnish removers, coatings, particleboard,

leather dressings, lubricating oils, fingernail enamels and removers, shoe polish and cleaners, solvent-thinned products including exterior stains, primers and interior stains, colouring pens and markers, wood office furniture, vinyl flooring. Vehicle exhaust may also contain toluene (Environment Australia, 2001). As a person works with these materials or spill them, the toluene evaporates and becomes mixed with the air people breathe.

Other possible emitters of toluene are tobacco smoke as well as natural sources including volcanoes, forest fires and crude oil. Automobile emissions are the principal source of toluene to the ambient air. Toluene may also be released into the ambient air during the production, use and disposal of industrial and consumer products that contain toluene (USEPA, 2007).

A.2.4.1 Health effects

The concern from exposure to toluene is adverse effects on the nervous system.

- **Acute effects**

Short-term exposure to high levels of toluene results in light-headedness and euphoria first, progressing to dizziness, sleepiness, unconsciousness and, in some cases, death. However, if exposure is halted before death, the symptoms disappear (Environment Australia, 2001). Reversible neurological symptoms are associated with acute exposures.

The following health effects with acute exposure to toluene have been reported (ATSDR, 2000; USEPA, 2007):

- CNS dysfunction, which is often reversible, and narcosis have been often observed as a result of acute exposure to low or moderate levels by inhalation. Symptoms include fatigue, sleepiness, headaches and nausea. CNS depression and death have occurred at higher levels of exposure.

Cardiac arrhythmia has also been reported in humans acutely exposed to toluene.

- **Chronic effects**

Studies of occupationally exposed workers suggests that chronic exposure to toluene at lower exposure levels from ~50 ppm to 200 ppm produces subtle changes in neurological functions including cognitive and neuromuscular performance, hearing and color discrimination (ATSDR, 2000). Long-term exposures to low levels of toluene affect the kidneys and exposures to high levels by intentional abuse have been linked to permanent brain damage, problems with speech, vision and hearing, loss of muscle control, loss of memory and balance and reduced scores on psychological tests (Environment Australia, 2001). Degenerative changes in white matter regions of the brain have been correlated with the severity of persistent neurological impairment in individuals who abused solvents and have repeatedly inhaled toluene at high exposure levels from 4,000 ppm to 12,000 ppm (ATSDR, 2000).

The following health effects with chronic exposure to toluene have been reported (ATSDR, 2000; USEPA, 1999, 2007):

- CNS depression is reported to occur in chronic abusers of toluene; symptoms include drowsiness, ataxia, tremors, cerebral atrophy, nystagmus or involuntary eye movements, and impaired speech, hearing and vision.
- Neurobehavioral effects have been observed in occupationally exposed workers.
- Chronic inhalation exposure irritates the upper respiratory tract, the throat and eyes, and also causes dizziness, headaches, and difficulty sleeping.
- Inflammation and degeneration of the nasal and respiratory areas.
- Mild effects on the kidneys and liver have been reported in solvent abusers; however, there are confounding factors including probable exposure to multiple solvents.

- **Reproductive and developmental effects**

The following reproductive and developmental effects have been reported with exposure to toluene (ATSDR, 2000; USEPA, 1999, 2007):

- The children of women who while pregnant were exposed to or were abusing toluene or other mixed solvents were reported to have CNS dysfunction, attention deficits, minor craniofacial, limb and developmental anomalies.
- Growth retardation and dysmorphism were reported in infants; however, these studies were confounded by exposure to multiple chemicals.
- Children born to toluene abusers have exhibited temporary renal tubular acidosis.
- Spontaneous abortions have been observed in pregnant women who had no occupational exposure to toluene, but the fathers did. These observations cannot be clearly linked to toluene because of the small number of cases evaluated and the large number of confounding variables.
- An increased incidence of spontaneous abortions was also reported among occupationally exposed women.

Case reports of mothers who abused toluene during pregnancy reported birth defects in their children and suggest that exposure to high levels of toluene may be toxic to the developing fetus; however, animal studies show that toluene can retard fetal growth and skeletal development and adversely influence behavior of offspring but does not cause fetal malformations (ATSDR, 2000).

- **Cancer risk**

The following reproductive and developmental effects have been reported with exposure to toluene (ATSDR, 2000; USEPA, 1999, 2007):

- Two epidemiological studies did not detect a statistically significant increased risk of cancer because of inhalation exposure to toluene; however, these studies were limited because of study population size and lack of historical monitoring data.
- EPA has classified toluene as a Group D, not classifiable as to human carcinogenicity.

A.2.4.2 Exposure

Exposure to toluene may take place from many sources, including drinking water, food, air and consumer products, breathing the chemical in the workplace or deliberate glue-sniffing or solvent abuse. Automobile exhaust also puts toluene into the air. People who work with gasoline, kerosene, heating oil, paints and lacquers are at the greatest risk of exposure (ATSDR, 2000).

Because toluene is a common solvent and is found in many consumer products, you can be exposed to toluene at home, at work, indoors and outdoors. Using gasoline, nail polish, cosmetics, rubber cement, paints, paintbrush cleaners, stain removers, fabric dyes, inks, adhesives, carburetor cleaners and lacquer thinners provides an opportunity for exposure to occur. Smokers are exposed to small amounts of toluene in cigarette smoke and add it to the air increasing the exposure potential for non-smokers (ATSDR, 2000).

The highest concentrations of toluene usually occur in indoor air as a result of using common household products, such as paints, paint thinners, adhesives, synthetic fragrances and nail polish, and cigarette smoke. The deliberate inhalation of solvent-based products, such as glue and paint, by solvent abusers may result in high levels of exposure to toluene as well as to other chemicals (USEPA, 2007).

The toluene level in the air outside your home is usually less than 1 ppm in cities and suburbs that are not close to industry and is expected to be the same in the indoor environment (ATSDR, 2000). Unless you smoke cigarettes or work with toluene-containing products, you are probably exposed to only minute amounts of toluene each day. Smoker who smoke a pack of cigarettes per day add 1,000 µg to their exposure. People who work in places where toluene-containing products are used with an air concentration of 50 ppm increase their exposure by 1,000 mg each day of work (ATSDR, 2000).

A.2.4.3 Guidelines

- **Health Canada**

The recommended short- and long-term maximum exposure limits for toluene are presented in the table below. Exposure to indoor air concentrations above these limits may result in potential health effects.

Residential indoor air quality guideline – toluene (2011)	
Guidelines	Averaging time
15 mg/m ³ (4 ppm)	Short-term (8 hour)
2.3 mg/m ³ (0.6 ppm)	Long-term (24 hour)

Source: Health Canada. (2011) "Residential Indoor Air Quality Guideline – Toluene". Website: <http://www.bc-sc.gc.ca/enh-semt/pubs/air/toluene/index-eng.php>

The short-term exposure limit was derived based on a no observed adverse effect level (NOAEL) of 151 mg/m³ from the study by Andersen et al. (1983) of healthy adult volunteers exposed for seven hours to toluene, and screened for neurologically-related symptoms, such as headaches, dizziness and intoxication. Applied to this NOAEL was an uncertainty factor of 10 (3.16 for pharmacokinetics and 3.16 for pharmacodynamics) to account for the potential differences in sensitivity among individuals.

A long-term exposure limit was derived from an NOAEL of 98 mg/m³ from the studies by Seeber et al. (2004; 2005) of printing shop workers, exposed for more than 20 years to toluene, and screened for neurobehavioural endpoints, such as attention span, psychomotor function and memory. This value was then adjusted to account for the difference in the duration of exposure for people in a workplace compared to people in a residence from eight hours/day, five days/week to 24 hours per day, seven days a week. Applied to this value was an uncertainty factor of 10 (3.16 for pharmacokinetics and 3.16 for pharmacodynamics) to account for the potential differences in sensitivity among individuals.

• **World Health Organization**

WHO guidelines for indoor air quality: selected pollutants (2010)	
Guidelines	Exposure time
0.26 mg / m ³ (87 ppm)	1 week

Source: WHO (2000). *Air Quality Guidelines for Europe, 2nd Edition*. World Health Organization website: http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf

This value is established from the LOAEL for effects on the central nervous system from occupational studies (332 mg/m³ or 88 ppm) and adjusting for continuous exposure (dividing by a factor of 4.2) and dividing by an uncertainty factor of 300 (10 for inter-individual variation, 10 for use of a LOAEL rather than a NOAEL, and an additional factor of three given the potential effects on the developing central nervous system). This guideline value should be applied as a weekly average. This guideline value should also be protective for reproductive effects (spontaneous abortions).

A.2.4.4 Control measures

Reduce or eliminate exposure to benzene through the following source control methodologies:

- Eliminate smoking within the home.
- Provide maximum ventilation when using of paints and varnishes.
- Discard leftover paint supplies and special fuels rather than store them or or store them in exhaust cabinets.
- Move away from the filling nozzle while refueling vehicles at gas stations.
- Use timers to ventilate periodically exhaust from attached garages or build detached garage.
- Properly maintain gas-fired furnaces and ensure they meet building code requirements.
- Minimize or curtail indoor wood-burning.
- Build new structures away from busy roadways, gas stations and other industrial sources.
- Ensure the best available pollution control equipment is installed on industrial sources.

A.2.5 Formaldehyde

Formaldehyde (HCHO) is a unique carbonyl compound with the carbonyl group directly attached to two hydrogen atoms. Due to this unique structural form, formaldehyde has a high degree of chemical and photochemical reactivity and thermal stability relative to the other carbonyl compounds (Godish, 2000). It is a colourless gas with a strong pungent odour. HCHO is a gas at room temperature with a boiling point of -21°C (ASTER, 1996).

Table A.2-16 Physical and chemical properties of formaldehyde

Physical and chemical properties		Reference (from ATSDR 1999)
Molecular weight	30.03	Lide and Frederikse 1996
Colour	Colourless	Budavari et. al. 1989
Physical state	Gas	Budavari et. al. 1989
Melting point	-92 °C	Budavari et. al. 1989
Boiling Point	-21°C	ASTER 1996
Odour	Pungent, suffocating odour	Budavari et. al. 1989, NFPA 1994
Odour threshold:		
• In water	50 ppm	HSDB 1999
• In air	0.5 – 1.0 ppm	Klassen 2000
Taste threshold	50 ppm	HSDB 1999
Solubility		
• Freshwater at 20°C	Very soluble, (up to 55%)	Budavari et. al. 1989
• Saltwater at 25°C	No data	Lide and Frederikse 1996, Budavari et. al. 1989
• Organic solvents	Ether, Alcohol, Acetone, Benzene	
Vapour pressure at 25°C	3,883 mm Hg	HSDB 1999, Howard 1989

A.2.1.1 Sources

Formaldehyde is commercially available as formalin. Formalin is an aqueous solution of 37% to 50% formaldehyde and 6% to 15% methanol (ATSDR, 1999). Formaldehyde is used in various chemical manufacturing processes. Urea formaldehyde resins are used as wood adhesives in the manufacture of pressure treated wood products, such as particleboard, medium density fiberboard, hardwood plywood, as well as textile treatments and urea formaldehyde foam insulation (UFFI). Phenol formaldehyde is used as an exterior grade adhesive for softwood plywood, oriented-strand board (OSB) and rigid plastic materials (Godish, 2000).

Formaldehyde is also used in rubber and latex manufacturing, photo-processing chemicals, laboratory fixatives, disinfectants and preservatives and is produced as a combustion byproduct. It can be detected in motor vehicle emissions, combustion appliances, wood fires and tobacco smoke (Godish, 2000). The following box lists the major indoor sources of formaldehyde (Dunn, 1987; Little *et. al.*, 1994, cited in Godish, 2000).

Common PAHS and their chemical structure

- Acenaphthene
- Acenaphthylene
- Anthracene
- Benz[a]anthracene
- Benzo[a]pyrene
- Benzo[e]pyrene
- Benzo[b]fluoranthene
- Benzo[g,h,i]perylene
- Benzo[j]fluoranthene
- Benzo[k]fluoranthene
- Chrysene
- Dibenz[a,h]anthracene
- Fluoranthene
- Fluorene
- Indeno[1,2,3-c,d]pyrene
- Naphthalene
- Phenanthrene
- Pyrene

A.2.5.1 Comparison of indoor and outdoor air concentrations

Formaldehyde is present both in the indoor and outdoor environment. Ambient formaldehyde concentrations in urban and suburban locations in the United States are typically < 10 ppbv. However, peak levels of 50 ppbv or more have been measured along the south coast of California (Godish, 2000).

There are a number of Canadian studies measuring ambient levels of HCHO. Between 1989 and 1998, 3,842 air samples were collected from eight urban locations in six cities across Canada, such as Quebec, Ottawa, Windsor, Winnipeg and Vancouver. The 24-hour average concentration of HCHO ranged from 0.05 µg/m³ or less to a maximum of 27.5 µg/m³. An average maximum concentration of 12.03 µg/m³ was reported for two suburban sites (Saint John and Montreal). An average maximum concentration of 9.88 µg/m³ was reported for four rural sites including: one site in Nova Scotia, two in Quebec and one in Ontario. HCHO in rural ambient air was attributed to urban and industrial influences (Environment Canada, 1999a, cited in CEPA, 2001).

A very limited number of studies are available on indoor concentrations of HCHO in houses constructed after the 1990s. HCHO levels in newly constructed conventional homes are less than 0.06 ppmv. Residential buildings in Canada and the United States are unlikely to exceed 0.10 ppmv HCHO with concentrations typically < 0.05 ppmv. In new manufactured or mobile homes, the concentration is usually reported to be <0.20 ppmv. Concentrations of HCHO in office buildings are not likely to exceed 0.05 ppmv with average concentrations ranging from 0.02 ppmv to 0.04 ppmv (Godish, 2000).

Data on ambient air concentrations for formaldehyde reported that formaldehyde concentrations in the outdoor air in remote areas were typically below 0.001 mg/m³ while concentrations in urban areas were typically lower than 0.02 mg/m³ (IARC, 1995). The presence of formaldehyde in remote areas is thought to be because of its formation from the photooxidation of hydrocarbons transported to these remote areas (EC, 2001). In indoor air, formaldehyde concentrations typically range from 0.02 mg/m³ to 0.06 mg/m³, in homes constructed with particle board or other formaldehyde-releasing materials (IARC, 1995). In recent years, indoor air formaldehyde concentrations have decreased because of a change in the construction materials used in homes (IARC, 1995).

A.2.5.2 Sensitive or vulnerable individuals

Two different population groups have shown sensitivity or vulnerability to HCHO via inhalation and dermal exposure: asthmatics and populations with dermal sensitization and general allergic sensitivity (ATSDR 1999).

- **Asthmatics**

The effect of formaldehyde on asthmatics may depend on previous, repeated exposure to HCHO. California Environmental Protection Agency cited several studies where some asthmatics exposed to HCHO vapours at concentrations from 1.5 ppm to 20.6 ppm for a brief duration exhibited delayed asthmatic reactions, whereas others showed immediate reactions (Burge *et al.*, 1985). Those that responded immediately were likely responding directly to the irritant effects of HCHO. In another experiment, asthmatics were exposed to HCHO and no significant changes in airway resistance were observed (Sheppard *et al.*, 1984, cited in California EPA, 2001).

Nordman *et al.* (1985) reported immediate bronchial reaction in eight asthmatic individuals from a group of 230 individuals when they were exposed to 2.04 ppm of formaldehyde for 30 minutes. Other individuals demonstrated both an immediate decrease in expiratory flow rate (up to 50%) and a delayed expiratory flow rate reactions (21% to 47% decrease).

- **Populations with dermal sensitization and general allergic sensitivity**

The second sensitive or vulnerable group consists of those with dermal sensitization or general allergic sensitivity. Liquid HCHO is known to act as a dermal sensitizer (Hilton *et al.*, 1996, cited in ATSDR, 1999). Dermal allergies have also been reported in doctors and nurses (Rudzki *et al.*, 1989, cited in ATSDR, 1999) and fiberglass workers (majority of fiberglass materials are coated with a phenol-HCHO resin) (Kilburn *et al.*, 1985a).

The role of HCHO in causing both irritant and allergic contact dermatitis as a result of contact with liquid or solid formaldehyde-releasing products has been well established. Whether formaldehyde vapour causes skin irritation as a result of skin exposures remains a question. However, several exposure studies have shown skin reactions, such as rashes, in individuals exposed to elevated airborne HCHO concentrations in mobile and other homes (Godish, 2001, cited in Spengler *et al.*, 2001). The lack of adequate exposure-response study information precludes the determination as to whether sensitization may have been caused by direct dermal contact to formaldehyde in liquids or by contact with formaldehyde gas in air. However, the widespread use of formaldehyde in cosmetics and cleaning agents suggest that the dermal route may be the more sensitizing route (ATSDR, 1999).

Human and animal studies both show that airborne formaldehyde, at appropriate exposure levels, can be irritating to the upper respiratory tract, eyes, skin and gastrointestinal tract. The evidence that airborne HCHO acts as a sensitizer of the respiratory tract is less convincing (ATSDR 1999). Additional studies on HCHO sensitization are warranted at this time because of the lack of data.

A.2.5.3 Health effects

HCHO is a reactive indoor pollutant, which irritates airways at low concentrations (Norback *et. al.*, 1995; Quackenboss *et. al.*, 1989, cited in Wieslander *et. al.*, 1997). Irritation has been reported when humans are exposed to HCHO via the inhalation pathways (ATSDR, 1999). The following health effects have been observed in acute and chronically exposed individuals (ATSDR, 1999).

- Eyes, nose, throat and skin irritation (acute effect in humans)
 - Sensitization to allergens (acute effect in humans)
 - Asthma aggravation (chronic effect in humans)
 - Upper respiratory tract cancers (chronic effect in animals)
- **Acute effects**

Exposure to airborne HCHO resulted in eye, nose and throat irritation among volunteers exposed to 0.4 ppm to 3 ppm HCHO more than eight hours (Andersen and Molhave, 1983; Bender *et. al.*, 1983; Day *et. al.*, 1984; Gorski *et. al.*, 1992; Krakowiak *et. al.*, 1998; Kulle *et. al.*, 1987; Pazdrak *et. al.*, 1993). Eye irritation is the most common symptom of HCHO exposure (ATSDR, 1999). Survey studies have shown increased eye irritation rates in humans repeatedly exposed to HCHO in homes and workplaces compared to non-exposed individuals (Horvath *et. al.*, 1988; Holness & Nethercott, 1989).

In a Canadian study, increased eye, nose, throat and skin irritation as well as sleep disorders, dizziness, fatigue, constipation and wheezing were reported among UFFI exposed workers (Arundel *et. al.*, 1986). In another study, symptoms, such as eye irritation, cough, wheeze, sputum formation, increased thirst and nasal problems were reported at 0.045 ppmv HCHO (Broder *et. al.*, 1988). Acute neurological effects such as fatigue, headaches and “heavy head” have been reported in men exposed to HCHO vapours at concentrations of approximately 1 ppm for 5.5 hours (Bach *et. al.*, 1990).

HCHO health effects	
<ul style="list-style-type: none"> • Mild eye, nose and throat irritation • Sneezing, running or bleeding nose • Coughing • Watery eyes • Sinus congestion, asthma-like symptoms • Skin rashes 	<ul style="list-style-type: none"> • Burning sensation in the throat and upper respiratory tract • Respiratory symptoms such as difficulty in breathing, wheezing and chest pain • Gastrointestinal symptoms including vomiting and diarrhea • Neurological symptoms including headaches, blurred vision, dizziness and difficulty sleeping

- **Chronic effects**

Repeated or long-term exposure to may increase an individual’s sensitivity to formaldehyde (ATSDR, 1999; USEPA 1995). Several case studies suggest HCHO is a causative agent in inducing asthma in workers (Nordman *et. al.*, 1985) exposed to 2

ppmv HCHO. The induction of asthma in exposed individuals may occur because of a specific sensitivity reaction or as an irritant response to HCHO (Burge *et al.*, 1985).

Leikauf *et al.* (1995) has reported several chemicals including HCHO as occupational asthmagens. According to Leikauf *et al.* (1995), certain irritant air contaminants are associated with asthma in occupational settings and may interact with other air pollutants to exacerbate asthma. Based on the available toxicological literature, Leikauf *et al.* (1995) reviewed and selected thirty compounds including HCHO for their ability to induce or exacerbate asthma in occupational and non-occupational settings, and to elicit an allergic response and to irritate the respiratory passages. Currently, the available data is inadequate to classify HCHO as an asthmagen in non-occupational settings.

In a European respiratory health survey, Wieslander *et al.* (1997) investigated asthma in newly painted indoor environments. A significantly increased prevalence of symptoms related to asthma but no bronchial hyperresponsiveness on testing was observed in those exposed. In addition to other VOCs, a significant increase in HCHO concentration was observed in the dwellings. Wieslander *et al.* (1997) reported that exposure to chemical emissions from indoor paint was related to asthma. They also reported that paint VOCs other than HCHO might cause inflammatory reactions in airways. Wieslander *et al.* (1997) also cited several studies where asthma was reported to be the most common lung disease associated with indoor pollutants. A relationship between nocturnal attacks of breathlessness and indoor concentrations of HCHO and VOC was reported in a study by Norback *et al.* (1995).

A.2.5.4 Genotoxicity and carcinogenicity of formaldehyde

HCHO has been shown to cause a variety of genotoxic effects such as DNA-protein crosslinks, sister chromatid exchange and mutations (IARC, 1987; Report on Consensus Workshop on Formaldehyde, 1984). The genotoxic and mutagenic properties of HCHO suggest that it is likely to be carcinogenic (Spengler *et al.*, 2001). The carcinogenic properties of HCHO have been well established in experimental animal studies. Although in humans there has been no direct evidence of carcinogenicity, several reports have shown a low to moderate increase in the risk of cancer of the buccal cavity, nasopharynx, pharynx and lung (Leibling *et al.*, 1984; Sterling & Arundel, 1985; Styner *et al.*, 1988). Based on the availability of carcinogenicity data, HCHO has been classified as a known human carcinogen and according to Section 64 of CEPA 1999 formaldehyde is considered to be “toxic” and weakly carcinogenic (WHO, 2006; Environment Canada, 2001).

A.2.5.5 Exposure

The major source of exposure to HCHO in the non-industrial indoor environment is the presence of HCHO-containing products such as composite wood, adhesives and foam insulation (Godish, 2000). UFFI insulation applied in 1980s is no longer considered a health threat because of the likely complete depletion of free HCHO reservoirs attributable to the long span of time since installation. Table A.2-17 presents HCHO emission rates for construction material, furnishings and consumer products.

Table A.2-17 Formaldehyde emissions from different products

Product	Range of emissions rates (ug/m ³ per day)
Medium-density fibreboard	17,600 – 55,000
Hardwood plywood paneling	1,500 – 34,000.
Particle board	2,000 – 25,000.
UFFI	1,200 – 19,200.
Softwood plywood	240 – 720.
Paper products	260 – 280.
Fibreglass products	400 – 470.
Clothing	35 – 570.

Source: Pickerell et. al., 1983, Mathews et. al., 1985, Grot et. al., 1985, In Samet et. al., 2001, cited in Spengler et. al. (2001), *Indoor Air Quality Handbook*, McGraw Hill publications

Historically, UFFI was used to insulate houses in North America; however UFFI use was banned in the early 1980s. Before UFFI being banned, 80,000 residences in Canada were insulated with it. As a result of the ban, current levels of HCHO in newly constructed homes are significantly lower than historical concentrations. Concentrations of HCHO in residential building in the United States and Canada do not exceed 0.10 ppmv with an average concentration of less than 0.05 ppmv. HCHO levels in office buildings rarely exceeded 0.05 ppmv. Presently, levels of HCHO in mobile homes range from 0.05 ppmv to 0.15 ppmv. However, the rate can be > 0.20 ppmv because of the pervasive presence of pressed wood products in a relatively small space (Godish, 2000). There are limited studies available on HCHO levels in new houses constructed after the 1990s (Godish, 2000).

Indoor exposure to HCHO depends on the following factors (Godish, 1989, 2000):

- Potency of the HCHO emitting products and their use
- Surface area (m²) of sources relative to the volume (m³) of the interior space
- Environmental factors, such as temperature and relative humidity
- Age of the source
- Ventilation

Smokers can be exposed to significant amounts of HCHO from tobacco smoke. Please refer to *Appendix C Environmental tobacco smoke* for more information on the hazards associated with cigarette smoke in the indoor environment.

A.2.5.6 Guidelines

- **Health Canada – residential**

Residential indoor air quality guideline – formaldehyde (2006)	
123 µg/m ³ (100 ppb)	1 hour
50 µg/m ³ (40 ppb)	8 hours

Source: Health Canada. (2006) *“Residential Indoor Air Quality Guideline – Formaldehyde”*.

Website: <http://www.bc-sc.gc.ca/ewb-semt/pubs/air/toluene/index-eng.php>

A.2.5.7 Control measures

The most effective way to control potential for HCHO exposure is to use HCHO-free products. Consumers are advised to check for the presence of other potentially hazardous compounds. The following methods can be carried out to control or reduce HCHO emissions if there is any from potential indoor sources (Calgary Health Region, 1993).

- **Ventilation**

Increasing the ventilation exchange by opening windows can be useful for reducing and relieving symptoms caused by low to moderate (0.05 ppm - 0.20 ppm) indoor HCHO levels; however, opening windows is not practical during the winter months (cited in Calgary Health Region, 1993).

- **Temperature and relative humidity control**

Temperature and relative humidity are important factors affecting the off-gassing rate of HCHO from building materials. An increase in temperature can encourage the release of HCHO and a decrease in temperature inhibits it. Research has shown that an approximate 5 °C to 6°C increase in temperature can double the HCHO emission rate. Maintaining indoor temperatures between 18°C and 21°C during the winter and between 22°C and 24°C during the summer can reduce HCHO emissions.

Relative humidity should be maintained at low levels as increases in this variable will also encourage HCHO off-gassing. For example, an approximate 40 per cent increase in indoor HCHO levels can result by increasing the relative humidity from a 30% to 70% (cited in Calgary Health Region, 1993).

- **Bake-out:**

The "baking" process uses a combination of increased temperature, relative humidity and ventilation to reduce indoor HCHO levels. This process involves emptying the building and increasing the indoor temperature, relative humidity levels and air change rate over a specified period of time, such as 24 hours to 72 hours). An indoor temperature of >30°C, relative humidity >70 per cent and an air change per hour between 1.5 and 4 will encourage HCHO off-gassing and removal and, hopefully, reduce the half-life of emissions from sources of HCHO. The "baking" process is to occur concurrently with increased ventilation to ensure that off-gassed VOCs, such as HCHO, are not sorbed onto interior surfaces. Air exchange can be enhanced by turning on building exhaust fans, continual operation of furnace fans and, if possible, for commercial buildings ensuring that the HVAC systems operate at 100 per cent of the exhaust setting.

The California State Architect for all new state office buildings has recommended the bake-out process. However, the effectiveness of the "baking" process remains unproven and bake-out cannot be used if exterior air is contaminated because of temperature inversion or the influence of a nearby industry (Calgary Health Region, 1993).

Bake-out is regarded as a general tool to control or reduce VOCs off-gasing from building materials. The effectiveness of baking out depends on the following factors:

- Building temperature: building temperature should be maintained in the range of 86°F to 95°F (30°C to 35°C).
- Bake-out duration should be at least several days.
- An optimum ventilation rate should be maintained.

It is essential to optimize temperature, duration and ventilation to achieve maximum VOC reduction from a building. However, it should be noted that maintaining an optimal temperature for the desired length of time in a building is very difficult to achieve. In some cases, supplemental heating may be required. In addition, elevated temperature may affect or damage building materials, finishes, furnishings and equipment. There may be difficulties associated with providing sufficient ventilation to flush VOCs out of the building. Various researchers have assessed the efficiency of the bake-out process and have concluded that it can reduce VOC levels in the range of 30% to 75% (Godish, 2000).

A.2.6 Polycyclic aromatic hydrocarbons (PAHs)

According to the WHO (1998), “the name ‘polycyclic aromatic hydrocarbons’ (PAH) commonly refers to a large class of organic compounds containing two or more fused aromatic rings, even though in a broad sense non-fused ring systems should be included”¹. Some authors refer to polycyclic aromatic compounds as “polycyclic organic matter.” The term “polynuclear” is often used for “polycyclic,” as in “polynuclear aromatic compounds.”

PAHs are formed during the incomplete combustion of coal, oil, gas, wood, garbage and other organic substances including tobacco and charbroiled meat (ATSDR, 1995). They are also formed under high temperatures during the processing of crude oil (Spengler *et. al.*, 2001). There are more than 100 different congeners of PAHs such as naphthalene, chrysene, benzo(a)pyrene and phenanthrene. Multiple benzene rings are grouped together to form simple to complex forms of PAHs. Three to four benzene ringed PAHs are more volatile than five to seven ringed PAHs (Spengler *et. al.*, 2001). Some of the more common PAHs and their chemical structures are provided in the following box and Figure A.2-1.

Common PAHs and their chemical structure	
• Acenaphthene	• Benzo[k]fluoranthene
• Acenaphthylene	• Chrysene
• Anthracene	• Dibenz[a,h]anthracene
• Benz[a]anthracene	• Fluoranthene
• Benzo[a]pyrene	• Fluorene
• Benzo[e]pyrene	• Indeno[1,2,3-c,d]pyrene
• Benzo[b]fluoranthene	• Naphthalene
• Benzo[g,h,i]perylene	• Phenanthrene
• Benzo[j]fluoranthene	• Pyrene

The 18 PAHs listed in the above box and in Figure A.2-1 are more relevant than other PAHs for the following reasons (ATSDR, 1995):

- More information is available on these PAHs.
- Health effects caused by these PAHs are considered representative of PAHs in general.
- These PAHs are commonly found in the environment.

Three PAHs are commercially produced in the United States: acenaphthene, acenaphthylene and anthracene (ATSDR, 1995).

Anthracene is used as an intermediate in dye production, in manufacturing of synthetic fibers and as a diluent for wood preservatives (ATSDR, 1995). In sunlight, PAHs

¹ WHO (1998), Environmental health criteria series, (202), Polycyclic Aromatic Hydrocarbons, some non heterocyclic, World Health Organization, 1998, section 1.2, page 28

undergo photooxidation (ATSDR, 1995; MOEE, 1997). Ozone, NO_x and SO_x can also oxidize airborne PAHs (Baek *et. al.*, 1991; NRC, 1983).

Of all the PAHs, benzo[a]pyrene (B[a]P) is the best known and most commonly measured PAH. It is used as an indicator for the presence of PAHs. The physical-chemical properties of B[a]P are presented in Table A.2-18.

Figure A.2-1 Structural formulae of PAHs

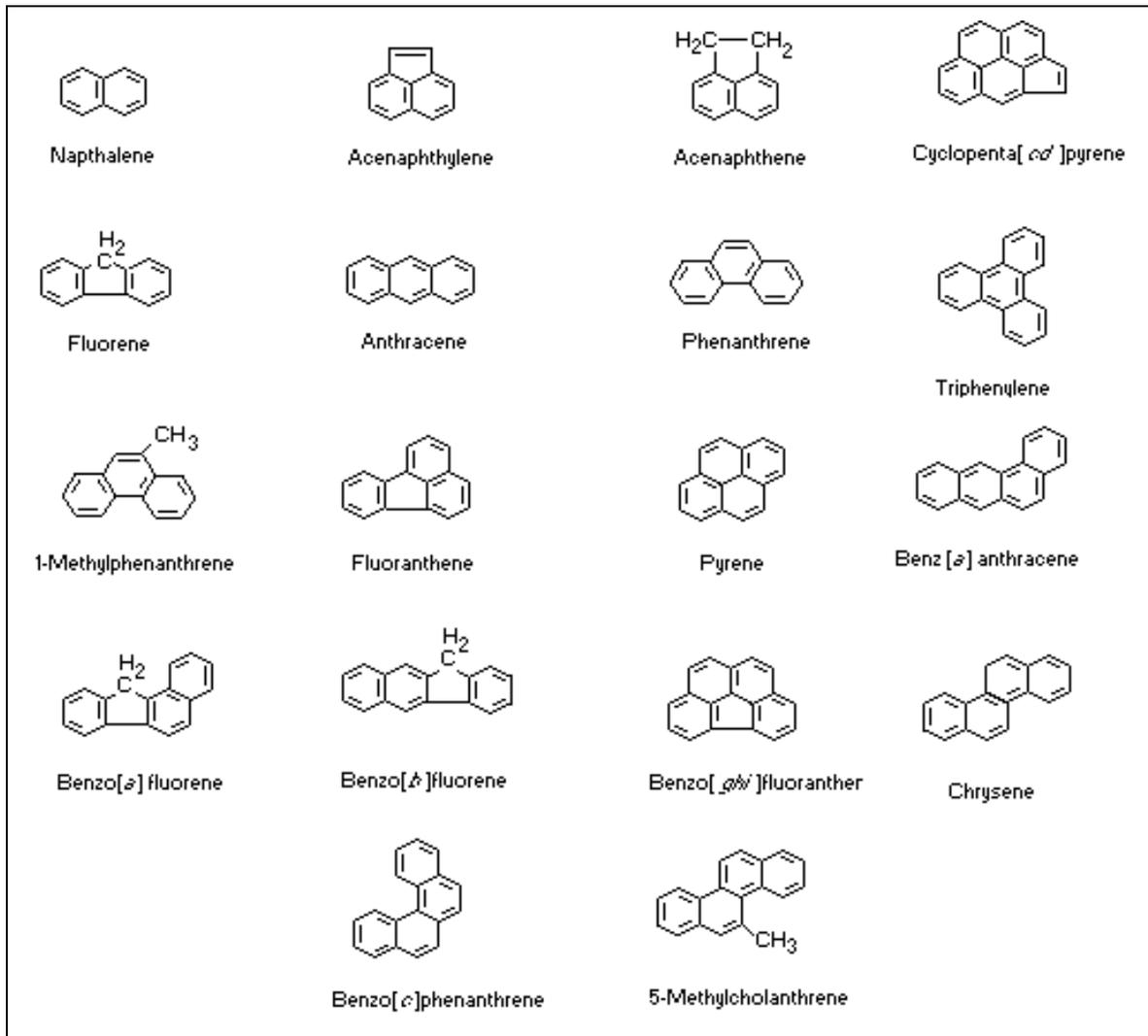


Table A.2-18 Physical and chemical properties of benzo(a)pyrene

Physical and chemical properties ^a	Benzo(a)pyrene
Molecular weight	252.3 ^b
Colour	Pale yellow
Physical state	Solid (plates or needles) ^c
Melting point	179-179.3 °C ^c
Boiling point	310-312 °C ^c (at 10 mm Hg; 495 °C ^d)
Odour: Odour threshold:	Faint aromatic odour (No odour threshold data)
Solubility	
• In water	2.3 x 10 ⁻³ mg/L ^e
• In organic solvent:	Sparingly soluble in ethanol and methanol; soluble in benzene, toluene, xylene and ether
Vapour pressure	5.6 x 10 ⁻⁹ mm Hg

Sources:

a- All data are taken from Hazardous Substances Data Bank (HSDB 2000), except where otherwise noted

b- IARC 1973

c- Weast 1987

d- Aldrich 1986

e- Yalkowsky et. al. 1993 (cited in ATSDR 1995)

• **PAHs chemistry**

The aqueous solubility of PAHs decrease as their molecular weight increases. Therefore, larger molecular weight PAHs (≥ 4 rings) tend to be bound to particulate matter and smaller molecular weight PAHs (three rings) tend to be solubilized in surface water (USDHHS 1993, cited in Muller 1997). Similarly, the vapour pressure of PAHs decrease as they increase in molecular size, ranging from 1.6 x 10⁻² Pa for phenanthrene to 2.0 x 10⁻¹⁰ Pa for coronene. Because of their low vapour pressure, almost all PAHs will associate themselves with particulate matter in the atmosphere. PAHs tend to exist in the vapour phase near the point of combustion. As exhaust emissions cool, high molecular weight PAHs (≥ 4 rings) with lower vapour pressure condense to form or sorb onto particulate matter; whereas, lower molecular weight PAHs with high vapour pressure tend to stay both in the vapour and condensed phases (USEPA 1987, cited in Muller 1997).

Chemical reactions can occur among gaseous and particulate PAHs and other reactants, such as O₃, OH radical, NO₂ or HNO₃. As a result of those reactions, more polar and water soluble PAH derivatives are formed. The stability of PAHs derivatives can vary depending on their binding molecule. For example, PAHs that are bound to high organic carbon particles may be more stable than their gas-phase counterparts (Bostrom 2002).

A.2.1.1 Sources

There are multiple sources of PAHs, both natural and anthropogenic, in the environment. Natural sources include emissions from volcanoes and forest fires (ATSDR, 1995) while anthropogenic sources include emissions from automobiles, wood fireplaces, wood or coal stoves, unvented radiant and convective kerosene space heaters,

gas cooking and heating appliances, and fumes from cooking, grilling and frying (Dubowsky *et. al.*, 1999; NTP, 1998; Schwarz-Miller *et. al.*, 1998). Residential wood burning is considered a major indoor air source of PAHs in the United States (Health Canada, 1995).

Indoor PAHs levels are influenced by outdoor PAH concentrations. These sources include emissions from automobiles and power plants. Detailed data on PAHs in Canada are available in the Priority Substances List Assessment Report (1994) - *Polycyclic Aromatic Hydrocarbons (PAHs)*. The median atmospheric concentration of PAHs for Walpole, Ontario, a rural site, was 7.2 ng/m³ with a mean concentration of 10 ng/m³ and a maximum concentration of 40.4 ng/m³ (Dann, 1990, cited in CEPA, 1994). The highest concentrations of PAHs in ambient air in Canada were measured at two aluminium smelter plant locations in Quebec where the median concentration of total PAHs was 693 ng/m³ with a mean of 1,687 ng/m³ at Jonquiere and at Shawinigan, a median of 435 ng/m³ and a mean of 1,519 ng/m³. For Jonquiere and Shawinigan, the maximum 24-hour averages were 104,000 and 16,390 ng/m³, respectively. Table A.2-19 summarizes various comparative studies on indoor and outdoor benzo(a)pyrene concentrations in different countries.

Table A.2-19 A Comparative summary of benzo(a)pyrene concentrations in indoor and outdoor air

Indoor air concentrations	Outdoor air concentrations
• 1 to 4 ng/m ³ in houses in Tokyo (Ando <i>et. al.</i> , 1996)	• 1 to 5 ng/m ³ (2.25 average) in winter in the residential areas of Tokyo (Ando <i>et. al.</i> , 1996)
• 1 to 50 ng/m ³ in houses in Beijing (Chuang <i>et. al.</i> , 1999)	• 10-70 ng/m ³ in the winter in residential areas of Beijing (Ando <i>et. al.</i> , 1996)
• 0.05-4.49 ng/m ³ (0.70 ng/m ³ average) in 24 low income North Carolina homes (Chuang <i>et. al.</i> , 1999)	• 0.04 – 2.49 ng/m ³ range; 0.46 ng/m ³ average (Chuang <i>et. al.</i> , 1999)
• Non-detect – 0.21 ng/m ³ range (0.11 ng/m ³ average) for 8 indoor personal air samples in Urban Italy (Minoia <i>et. al.</i> , 1997)	• 0.68 – 2.85 ng/m ³ (1.19 ng/m ³ average) in Urban Italy (Minoia <i>et. al.</i> , 1997)
• 0.99 ng/m ³ (average) in average smokers; 0.44 ng/m ³ average non-smokers, in 8 suburban Columbus, Ohio homes (Mitra & Ray, 1995)	• 0.23 ng/m ³ average in Winter, suburban Columbus, Ohio (Mitra & Ray 1995)
• 2.0 ng/m ³ with Kerosene Heater on; 0.24 ng/m ³ with Kerosene heater off in 1 North Carolina Mobile home (Mumford <i>et. al.</i> , 1991)	•
• 0.51 ng/m ³ average smokers; 0.20 ng/m ³ average non-smokers; 0.19 ng/m ³ 24 hour median, in 125 suburban southern California homes (Sheldon <i>et. al.</i> , 1992)	• 0.16 ng/m ³ 24 hour median, suburban Southern California (Sheldon <i>et. al.</i> , 1992)

A.2.6.1 Sensitive or vulnerable individuals

Individuals or populations with the following conditions can be more sensitive or vulnerable to the toxic effects of PAH exposure (ATSDR, 1995).

- PAHs are metabolized to active carcinogenic forms by aryl hydrocarbon hydroxylase (AHH). Individuals with high AHH are more likely to metabolize PAHs to active carcinogenic byproducts. Therefore, such individuals can be at higher risk than normal individuals.
- Individuals with deficient immune systems because of age or genetic diseases

- Individuals or populations who smoke
- People with excessive sun exposure because of the synergistic effect between PAHs and ultraviolet light for inducing skin cancer via dermal exposure
- People with liver and skin diseases
- Pregnant women and developing fetuses

Immunocompromised individuals are included in the above list based on limited evidence that suggests subpopulations under stress and experiencing circadian rhythm upsets are more sensitive to the toxic effects of PAHs (ATSDR, 1995). Most PAHs have the ability to cross the placental barrier because they are soluble in lipids (Calabrese, 1978, cited in ATSDR, 1995). Therefore, fetuses are specifically vulnerable to the toxic effects of PAHs via maternal exposure (ATSDR, 1995).

A.2.6.2 Health effects

Health effects data on PAHs in general are very limited (Health Canada, 1995).

- **Acute effects**

General health effects, such as eye irritation, photophobia and skin toxicity, such as dermatitis and keratosis, have been observed in workers occupationally exposed to PAHs (MOEE, 1997). Workers exposed to asphalt and tar pitch reported symptoms including bronchitis, cough, nose and throat inflammation, congestion and acute upper respiratory effects, such as nasal congestion, hoarseness, throat irritation and swelling (MOL, 1986). Dermatological effects, such as dermal irritation and photosensitization, have been observed in humans and experimental animals exposed to PAHs.

- **Chronic effects**

PAH-containing mixtures including soot, tars and ETS have been observed to cause cancer in humans (Rudel, 2001; cited in Spengler *et. al.*, 2001). Also, PAH-containing mixtures and some individual PAHs have shown carcinogenicity in experimental animals and in in-vitro tests (ATSDR, 1995; IARC, 1982, 1985; NTP, 1998; Schwarz-Miller *et. al.*, 1998; USEPA, 1993, 1999b). PAH-containing diesel exhausts have been shown to cause lung cancer in occupational studies (Health Effects Institute, 1999; IARC, 1989; WHO, 1996).

Inhalation exposure to PAHs has been associated with lung and bladder cancer in humans (ATSDR, 1995; Schwarz-Miller *et. al.*, 1998, cited in Rudel, 2001; Spengler, 2001). Dermal exposure has been associated with skin cancer (ATSDR, 1995; Schwarz-Miller *et. al.*, 1998).

A.2.6.2.1 Toxicological characteristics of PAHs

Some PAHs are known carcinogens, such as B[a]P) or suspected carcinogens including fluoranthene. Benzo[a]pyrene (B[a]P) is the main indicator of carcinogenic PAHs. Fluoranthene is an important volatile PAH and can be found in high concentrations in the ambient air. Fluoranthene has been proved to be an experimental carcinogen in a variety of test systems. Carcinogenicity of PAHs is associated with:

- Complexity of the molecule or an increasing number of the benzoid rings

- Metabolic activation to reactive diol epoxide intermediates and their covalent binding to critical targets in DNA (Bostrom et al. 2002)

To be carcinogenic and mutagenic, PAH molecules must consist of at least four fused benzoid rings and be arranged in such a fashion that the molecule contains a bay or fjord region (Sims and Grover 1974, Thakker et al. 1985, cited in Bostrom et al. 2002).

Benzo[c]phenanthrene has a fjord region and chrysene has a bay region. Fjord region compounds are more active as carcinogens and mutagens (Harvey 1991, Jerina et al. 1991, cited in Bostrom et al. 2002). It has been observed that methylation of PAHs can affect their biological potencies. For example, methylation at the fifth position of the chrysene molecule can greatly enhance its mutagenicity and carcinogenicity, whereas, methylation at other positions may have no effect or may reduce the potential of chrysene to be mutagenic or carcinogenic. Other structural characteristics may contribute to the mode of action for other PAHs (fluoranthene and its derivatives) that show low carcinogenic and mutagenic activity.

Table A.2-20 presents the cancer potencies of various PAHs. The table shows a general trend in that as ring number increases, cancer potency increases. This generalization may not be true for all PAHs as shown by various authors.

Table A.2-20 Relative potency of individual PAHs compared with B[a]P

PAH compound	Number of rings	Health Canada	Larsen and Larsen (1998)	Ontario, Muller (1997)
Anthracene	3		0.0005	
Phenanthrene	3		0.0005	0.00064
Benzo[a]anthracene	4		0.005	0.014
Benzo[c]phenanthrene	4		0.023	0.023
Chrysene	4		0.03	0.026
Fluoranthene	4		0.05	
Pyrene	4		0.001	0
Benzo[b]fluoranthene	4	0.06		
Benzo[j]fluoranthene	4	0.05		
Benzo[k]fluoranthene	4	0.04		
B[a]P	5	1	1	1
Benzo[e]pyrene	5		0.002	0
Dibenz[a,h]anthracene	5		1.1	0.89
Anthanthrene	6		0.3	0.28
Benzo[ghi]perylene	6		0.02	0.012
Dibenzo[a,e]pyrene	6		0.2	1.0
Dibenzo[a,h]pyrene	6		1	1.2
Dibenzo[a,l]pyrene	6		0.1	
Dibenzo[a,j]pyrene	6		1	100

A.2.6.3 Exposure

Human exposure to individual PAHs and PAH mixtures occur by (Fiala *et. al.*, 2001):

- Direct inhalation of indoor air contaminated with Environmental Tobacco Smoke, wood smoke and contaminated air from the outdoors
- Dermal contact with soot, tars and polluted soils (IARC, 1983)
- Dietary intake of fried, broiled, sautéed and barbecued foods and contaminated drinking water

In the indoor environment, inhalation can be a significant exposure route. PAHs in indoor air can originate from residential heating (wood burning) and environmental tobacco smoke at average concentrations from 1 ng/m³ to 100 ng/m³, with a maximum of 2,300 ng/m³ (WHO, 1998). Contaminated indoor air is an important source of PAH exposure for humans. In addition to other chemicals, PAHs constitute one of the major carcinogenic (not all PAHs are carcinogenic) agents in environmental tobacco smoke. The reader should refer to *Appendix C Environmental tobacco smoke* for more information on environmental tobacco smoke.

In general, however, the available data suggests the oral route is the major route of exposure to PAHs (ATSDR, 1995). The intake of individual PAHs from food has been estimated at 0.10 ng/m³ to 10 ng/m³ per person (WHO, 1998).

PAHs are also a common outdoor pollutant. Please refer to *Appendix G – Outdoor Air Factor* for more information on PAHs and outdoor air quality.

A.2.6.4 Exposure guidelines and risk estimates for PAHs in indoor air

World Health Organization

Because some of the PAHs are proven human carcinogens, no safe level can be recommended for exposure (WHO, 1998). In addition, PAHs in air are attached to particles, which may also play a role in their carcinogenicity (WHO, 2000). Although food is thought to be the major source of human exposure to PAHs, part of this contamination may arise from air pollution with PAHs. The levels of PAHs in air should, therefore be kept as low as possible (WHO, 2000).

“The potency of B[a]P in humans exposed by inhalation has been assessed on the basis of extrapolations from the results for rodents, sometimes exposed other than by respiration. Since the sensitivity to PAH is likely to differ with the route of exposure, assessments made on the basis of exposure by inhalation are preferable” (cited in WHO 1998, Environmental Health Criteria Series, EHC 202).

Chemical	Average ambient air concentration (ng/m ³)	Health end point	Unit risk (ng/m ³) ¹	IARC classification
PAH- (Benzo(a)Pyrene)	<1 – 10	Lung cancer in exposed humans	5 8.7 x 10 ⁻⁵	1

Source: WHO (2000). “*Air Quality Guidelines for Europe, 2nd Edition*”. World Health Organization website: http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf

• **United States Environmental Protection Agency (USEPA)**

A number of risk estimates have been derived for PAHs, based primarily on studies in which B[a]P was used as the index compound. The USEPA(1984d) proposed an upper-bound lifetime cancer risk of 62 per 100,000 exposed people per microgram of benzene-soluble coke-oven emission per cubic metre of ambient air. Assuming a 0.71% content of benzo[a]pyrene in these emissions, it was estimated that nine out of 100,000 (~10⁻⁴) people exposed to 1 ng/m³ B[a]P over a lifetime would be at risk of developing cancer (cited in WHO 1998)

• **Health Canada**

Health Canada has provided health based tolerable daily intake/concentrations and Tumourigenic Doses/Concentrations for PAHs. Based on the availability of data, TC_{0.5} for PAHs was derived.

Health Canada toxicological reference values (TRVS)	
3.1E-2 (mg/m ³) ⁻¹	Inhalation unit risk from TC _{0.5} ^a

a - Inhalation unit risk derived as: URInh = 0.05/TC05; TC05 from Health Canada (1996)

Source: *Federal Contaminated Site Risk Assessment in Canada, Part II: Health Canada Toxicological Reference Values (TRVs)*. (2004). Health Canada Website: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/contamsite/part-partie_ii/part-partie_ii-eng.pdf

Carcinogenic potencies of other PAHs relative to B(a)P were estimated on the basis of multistage modeling of tumor incidence (epidermoid carcinomas) in Osborne-Mendel Rats. PAHs were implanted into the left lung of those rats (Deutsch-Wenzel *et. al.*, 1983) and the potencies for each PAH relative to that of B(a)P were estimated. On this basis, relative carcinogenic potency factors are:

- Benzo(a)pyrene – 1
- Benzo(b)fluoranthene – 0.06
- Benzo(j)fluoranthene – 0.05
- Benzo(k)fluoranthene – 0.04
- Indenol (1,2,3,-cd)pyrene – 0.12

By multiplying TC_{0.5} for benzo(a)pyrene (1.6 mg/m³, derived from inhalation bioassay), the following carcinogenic potencies were derived for other PAHs.

Chemicals	Carcinogenic potency (mg/m ³)
Benzo(b)fluoranthene	0.096
Benzo(j)fluoranthene	0.08
Benzo(k)fluoranthene	0.064
Indenol (1,2,3,-cd)pyrene	0.19

Source: *Canadian Environmental Protection Act, Priority Substances List, Supporting Documentation: Health-Based Tolerable Daily Intakes/Concentrations and Tumourigenic Doses/Concentrations for Prior Substances*

A.2.6.5 Control measures

Control measures can include the following;

- Correctly installing, maintaining and operating of wood-burning stoves, fireplaces, kerosene space heaters and gas appliances
- Eliminating smoking indoors
- In wood-burning stoves and fireplaces, refraining from using wood products treated with preservatives, such as creosote
- Using exhaust fans vented to the outside when frying, sautéing, baking and broiling
- Minimizing or reducing the consumption of barbecue foods
- Constructing new structures away from busy roadways and industrial sources
- Ensuring the best available pollution control equipment is installed on industrial equipment

A.2.7 Chlorinated hydrocarbons

Chlorinated hydrocarbons are absorbed into the body principally by inhalation, but also through the skin and gastro-intestinal tract (Health Canada, 1995). Once absorbed they tend to accumulate in fatty tissues of the body (i.e. the brain, bone marrow and body fat). Recovery from the acute effects of exposure to the volatile chlorinated hydrocarbons is usually complete, but, after repeated exposures, adverse health effects can include depression of, or permanent damage to the central nervous system, irritation of the eyes and lungs, and damage to the skin, liver and kidneys (Health Canada, 1995). In the case of dichloro-methane, a metabolite is carbon monoxide, which can cause cardiovascular stress (Health Canada, 1995).

The most common chlorinated hydrocarbons are tetrachloroethylene. For the purposes of this section these two substances will be used to represent the more general category.

Table A.2-21 Physical and chemical properties of tetrachloroethylene

Physical and chemical properties	
Molecular weight	165.83
Colour	Colourless
Physical state	Liquid (at room temperature)
Melting point	-19 °C
Boiling point	121 °C
Density at 20°C	1.6227 g/mL
Odour	Ethereal
Odour threshold:	
• Water	0.3 ppm
• Air	1.0 ppm
Solubility:	
• In water at 25°C	150 mg/L
• In organic solvents	Miscible with alcohol, ether, chloroform, benzene, solvent hexane and most of the fixed and volatile oils
Vapour pressure at 25°C	18.47 mm Hg

Source: adapted from ATSDR, 1995

A.2.7.1 Sources

Large quantities of chlorinated hydrocarbons are produced and used annually worldwide. They are found in the residential environment as solvents, cleansers and aerosol propellants (Health Canada, 1995). Certain hobbies expose some individuals to relatively high levels of them (Health Canada, 1995). Chlorinated hydrocarbons may be released continuously from household products and they have also been detected in drinking water.

A.2.7.1.1 Tetrachloroethylene

The main users of tetrachloroethylene (PERC) include the dry-cleaning industry, textile manufacturing and clothing industry. PERC is also used as a chemical intermediate and metal degreasing agent. Minor uses include insulation liquid and cooling gas in transformers, adhesives aerosols, paints and coatings (NTP, 2000).

Various consumer products containing tetrachloroethylene include printing ink, glues, sealants, polishes, lubricants, silicones, paint removers, rug and upholstery cleaners, stain, spot and rust removers (ATSDR, 1996). The following box presents a percentage breakdown of tetrachloroethylene uses in the United States.

Pattern of tetrachloroethylene use in the USA, according to ATSDR¹
<ul style="list-style-type: none">• 55% for chemical intermediates• 25% for metal cleaning and vapour degreasing• 15% for dry cleaning and textile processing• 5% for other unspecified uses

¹Agency for Toxic Substances and Disease Registry

Source: Toronto Public Health (2002). "Ten Carcinogens in Toronto" prepared by ToxProbe Inc. Accessed on January 25, 2012 from the website: http://www.toronto.ca/health/pdf/cr_technicalreport.pdf

A.2.7.2 Health effects

- **Acute effects**

The most common acute effects of PERC in humans are reversible neurological effects such as headache, dizziness, nausea, difficulty in speaking and sleepiness (Toronto Public Health, 2002). Eye and throat irritation was also reported.

- **Chronic effects**

Long-term exposure to low levels of PERC has led to subtle neurological effects. Renal effects such as increased urinary lysozyme, fibronectin, albumin, brush border antigens, transferrin, and tissue nonspecific alkaline phosphatase have also been observed in humans occupationally exposed to PERC (Toronto Public Health, 2002).

A.2.7.3 Exposure

Most people spend more time indoors and as a result they tend to receive most of their exposure in this microenvironment. Furthermore, the indoor environment can be affected by products used and activities undertaken indoors. In the home, exposures occur primarily through the use of consumer products and can be of short duration, but levels may be sufficiently high to have the potential for adverse health effects.

The average PERC levels in the outdoor air in 11 Canadian cities range from 0.2 µg/m³ to 5 µg/m³. The indoor air levels were found to be about 5.1 µg/m³. Since people spend most of their time indoors, the time spent indoors makes the greatest contribution to the overall exposure to PERC. (Toronto Public Health, 2002)

A.2.7.4 Guidelines

- **Health Canada**

Health Canada has provided health-based tolerable concentrations for chlorinated hydrocarbons. Based on the availability of data, tolerable concentrations (TC) for chlorinated hydrocarbons was derived.

Tolerable concentrations (TC) for chlorinated hydrocarbons		
Chemical	TC¹	Explanation
Tetrachloroethylene	0.36 mg /m ³	Based upon non-carcinogenic effects

¹: TC: Tolerable concentrations (often expressed in mg/m³) are generally airborne concentrations to which it is believed that a person can be exposed continuously over a lifetime without deleterious effect. For a detailed explanation of derivation of TC values, the reader should refer to Health Canada

Source: Federal Contaminated Site Risk Assessment In Canada: Part II: Health Canada Toxicological Reference Values (TRVs). (2004). Health Canada website: http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/part-partie_ii/index-eng.php

A.2.7.5 Control measures

Measures to control or limit exposures to PERC can include the following;

- Know what you are buying.
- Learn about cleaning processes for your garments and know what options are available.
- Bring your clothes to professional cleaners who carefully follow safety requirements and properly maintain cleaning equipment.
- Target cleaners that offer the wet-cleaning process as an option.

To control or limit exposure to TCE consider the following:

- Choose products that do not contain TCE or are low-TCE.
- Remove household sources of TCE to the outdoors.
- Maintain adequate ventilation.

A.2.8 Chlorine disinfectant byproducts (DBPs)

Volatile halogenated hydrocarbons (VHHs) are a known contributor to indoor air pollution in indoor swimming pools. Consequently, this section will address VHHs in relation to indoor swimming pools.

Airborne contaminants can originate from many sources in indoor swimming pools, but generally they enter the atmosphere in the form of gases, vapours and aerosols from the pool water itself. In addition, a broad range of aquatic activities, such as wave pools, spas and whirlpools and water slides, can also contribute to the level of contaminants.

Over the years, there have been reports of bathers at indoor pools experiencing acute respiratory distress and eye irritation. These adverse effects have been typically attributed to the presence of chloramines, which are inorganic compounds consisting of chloramide (NH_2Cl), chlorimide (NHCl_2) and chlorine azide (NCl_3), which can be more commonly classified as monochloramine, dichloramine and trichloramine, respectively. They can be formed by the chlorination of ammonia, derived from the urine and sweat of bathers (Calgary Health Region, 1993). Chloramines are generally recognized as potent respiratory irritants because of the formation of these compounds indoors when household bleach and ammonia are inappropriately mixed, resulting in a number of poisoning cases each year (MMWR, 1991, cited in WHO, 2000). The physical and chemical properties necessary in chloramines to produce indoor air problems include volatility, chemical stability which allows for accumulation, and a method of production agreeable with the chemical conditions found in pool water (Richardson *et. al.*, 2010).

A.2.8.1 Properties of chloramines

Chloramide (NH_2Cl or monochloramine) has a low odour and low volatility. Considerable eye irritation from exposure to chloramide does not occur until a threshold concentration of 4 ppm is reached in pool water. In addition, chloramide does not exist in the presence of free chlorine, so it is usually missing from pool water (Shaw, 1986, cited in Calgary Health Region, 1993). Chlorimide (NHCl_2 or dichloramine) is slightly more volatile than chloramide; however, it is unlikely to persist in the indoor atmosphere of pools. Chlorine azide (NCl_3 or trichloramine) is highly volatile, but it is doubtful whether it will persist in the environment of an indoor swimming pool because of the humid conditions which exist in such facilities. Consequently, research has generally concluded that inorganic chloramines appear unlikely to exist in significant concentrations or to be the principal irritants that are present in indoor pool atmospheres (cited in Calgary Health Region, 1993).

Elemental chlorine (Cl_2) does not appear to be a major irritant in indoor pool atmospheres as it is completely hydrolyzed in pool water to hypochlorous acid (HOCl) and hypochlorite ion (OCl). Hypochlorous acid has a very low volatility and the hypochlorite ions has no volatility at all. Therefore, HOCl and OCl) are not considered to add to indoor air pollution in swimming pools (Calgary Health Region, 1993).

The strong chlorine-like odours present in indoor swimming pools may be produced by chlorophenols at levels of only a few parts per billion, which is well below any threshold for irritation (Shaw, 1986, cited in Calgary Health Region, 1993). However, the irritation of bathers in terms of indoor air, appears to be due to the presence of volatile halogenated hydrocarbons (VHHs) in pool water. VHHs, also known as halogen-

substituted organic compounds, are both volatile and chemically stable and their generation increases proportionately with the organic loading represented by the number of swimmers in the pool) and to the dosage of available chlorine (cited in Calgary Health Region, 1993).

Many VHHs are important eye and respiratory irritants, and some are even suspected carcinogens, such as chloroform. In addition, many of the VHHs are common, industrial, office and residential indoor air contaminants and have also been identified in chlorinated drinking water supplies (Calgary Health Region, 1993).

A.2.8.2 Sources

Chlorine is a well-known chemical disinfectant (WHO, 2000). During its use, several disinfectant byproducts (DBP) are formed which can contaminate indoor swimming pools) as well as outdoor air. Chlorine reacts with organic compounds in different ways, replacing hydrogen atoms and by several chemical reactions such as chlorination of carbon (unsaturated) bonds and oxidation reaction that do not involve chlorination. During the chlorination process, the following DBPs are formed (WHO, 2000):

- Trihalomethanes, such as chloroform and dibromochloromethane
- Haloacetonitriles, such as dichloronitrile
- Haloketones, for example., 1,1 dichloropropanone
- Halogenated hydroxyfuranone derivatives including 3-Chloro-4-(dichloromethyl)-4-hydroxy-2(5H)-furanone
- Haloacetic acids, such as trichloroacetic acid
- Chlorophenols including 2,4,6-trichlorophenol
- Aldehydes including HCHO
- Miscellaneous compounds, such as cyanogen chloride, chloral hydrate, trichloronitromethane

Other halogenated organic compounds identified in the swimming pool water include chlorobenzene, trihalomethane, bromoaniline, carbon tetrachloride and N-chloroacetamide. Chlorine gas, VOCs and chloramines including chloramide, chlorimide and chlorine azide are often regarded as the primary agents for the respiratory health problems among indoor swimming pool users (Spengler *et. al.*, 2001). Chloramines are produced by the reaction of free chlorine with urea and creatinine (not free ammonia) introduced by the users of the indoor pool. Several of those contaminants are discussed in this section of this manual.

A.2.8.3 Sensitive or vulnerable individuals

Sensitive or vulnerable individuals include people suffering from asthma. However, asthmatics are encouraged to take part in swimming-related exercises as a therapy (Spengler *et. al.*, 2001). High humidity levels in swimming pools are believed to provide some protection against exercise-induced bronchoconstriction in asthmatics relative to other exercises such as running. However, symptoms of coughing were observed in asthmatic individuals in a chlorinated indoor-pool environment with recirculated air

(Bar-Or & Inbar, 1992). Potts (1996) observed a correlation between chemical odour, respiratory irritation and breathing difficulty among swimmers in indoor pools.

The development of respiratory-related illnesses is much more significant in Olympic swimmers and pool workers and less frequent with recreational swimmers (Richardson *et. al.*, 2010) During training, these swimmers have increased breathing rates, such as 100 L/min). Lifeguards and pool workers can also be susceptible to respiratory-related problems because they spend most of their time in the swimming pool area (Potts, 1996; Richardson *et. al.*, 2010). Refer to the health effects section for additional information on other health symptoms related to asthma.

The liver and kidney are the two major organs responsible for chloroform metabolism. Individuals with hepatic and renal health problems and those who regularly consume alcohol can be regarded as more sensitive or vulnerable to chloroform toxicity (ATSDR, 1997; Wang *et. al.*, 1994). Some human clinical reports have suggested that exhaustion and starvation may increase chloroform hepatotoxicity (Townsend, 1939).

A.2.8.4 Health effects

- **Acute effects**

Chlorine gas, chloramine and chlorine dioxide are strong respiratory irritants (WHO 1999). The irritating effects of indoor pool environments can be attributed to chloramines (Spengler *et. al.*, 2001).

Health complaints associated with indoor pool use include headaches, nausea, lethargy, and eye, nose and throat irritation, coughing and allergy and asthma symptoms (C. Laverdure, University of Alberta, 1991). In another study, reviewed by Potts (1996), 14 swimmers showed allergic symptoms and bronchial hyperresponsiveness compared to the age- and sex-matched controls.

Chloroform is a central nervous system (CNS) depressant. Various inhalation exposure studies show several acute health effects in individuals exposed to chloroform. Dizziness, intracranial pressure and nausea were also observed after a 7-minute exposure to 1000 ppm chloroform, with fatigue and headache as after effects. In another study, a 30-minute exposure to 390 ppm of chloroform was associated with no adverse effects. Human exposure from 14,000 ppm to 16,000 ppm chloroform vapour caused narcosis (Torkelson & Rowe, 1981).

- **Chronic effects**

Long-term and repeated exposure to chlorine DBPs in indoor swimming pools during training and competition can contribute toward the increased occurrence of bronchial hyperresponsiveness and airway inflammation in swimmers, which may be due to the presence of DBP in pool air (Helenius *et. al.*, 1998, cited in Brauer, 2001; Spengler *et. al.*, 2001). In a Norwegian study of four young athlete swimmers, symptoms of exercised-induced asthma were correlated to swimming activities. The symptoms were observed after several years of intensive indoor-pool training. VHHs and DBPs were suspected as the causative agents (Fjellbirkeland *et. al.*, 1995).

Consumption of drinking water containing chloroforms and other disinfection byproducts are believed to be associated with increased incidence of cancer of the large intestine, rectum and bladder (ORNL 1997). The relevance of those

observations in the swimming pool exposure scenario is uncertain. However, it should be noted that USEPA has classified chloroform as a probable human carcinogen.

Limited information is available on adverse health effects in people in occupational environments following chronic inhalation of chloroform. In a study by Bomski *et. al.* (1967), 17 cases of hepatomegaly were reported in a group of 68 chloroform-exposed workers. The chloroform concentrations ranged from 2 to 205 ppm and the exposure duration was one to four years. It was also reported that those workers were highly susceptible to viral hepatitis with a 10-fold increased risk of contracting viral hepatitis when compared with the general population. The author of this study reported chloroform-induced liver toxicity as a predisposing factor for viral hepatitis (cited in California EPA, 2001). The reader should refer to ATSDR's chloroform toxicological profile and the IRIS chloroform summary for additional information on the chronic toxicity of chloroform in humans and animals.

A.2.8.5 Exposure

There are exposures to VHHs within the swimming pool environment. They are mainly in the form of inhalation of the disinfection-byproduct contaminated air that have resulted from either the treatment of water for potability as well as the treatment of the water in the pool basin as well.

Studies show that inhalation of contaminated air from showering and training, leisure or work activities, such as. Lifeguarding, within the pool enclosure can provide exposures or increased exposures to certain DBPs (Richardson, 2005; Levesque *et. al.*, 2002; Levesque *et. al.* 2000).

A.2.8.6 Guidelines

- **Agency for Toxic Substances and Disease Registry**

Minimum risk level¹ for chloroform (inhalation exposure)	
0.1 ppm	Acute duration inhalation exposure based on a NOAEL of 3 ppm for hepatic effects in mice (Larson <i>et. al.</i> , 1994c)
0.02 ppm	Chronic duration inhalation exposure based on a LOAEL of 2 ppm for hepatic effects in workers exposed to concentrations of chloroform ranging from 2 to 205 ppm for 1-4 years (Bomski <i>et. al.</i> , 1967)

1. Minimal Risk Level is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration for a given route of exposure. MRLs are derived for acute (1-14 days), intermediate (15-364 days) and chronic (365 days and longer) duration and for the oral and inhalation routes of exposure.

Source: *Toxicological Profile for Chloroform, (1997)*, Agency for Toxic Substances and Disease Registry ATSDR, website <http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=53&tid=16>

- **American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)**

Recommended outdoor air requirements for ventilation in swimming pools	
0.48 cfm/ft ² or 2.4 L/s.m ²	(ASHRAE 62.1-2010) ¹

Source: According to ASHRAE (62.1-2010), higher values may be required for humidity control

A.2.8.7 Control measures

Several engineering and management control measures can be adopted to reduce contamination of air in indoor swimming pools by DBPs.

- Maintain adequate air exchange levels in the enclosed pool buildings.
- As the production of halogenated organics is an inevitable result of common swimming pool treatment practices, different treatment processes may reduce the generation of chlorinated organics. Several European studies have shown that chlorinated organics may be substantially reduced by using complex treatment systems involving:
 - Chemical flocculation
 - Reduced rate sand filtration
 - Ozonation
 - Granular activated carbon filtration before chlorination
 - Use of high volumes of fresh replacement water to remove and dilute the organic precursors of the halogenated byproducts.

Note: These types of complex treatment systems, which are expensive and require a high rate of fresh water replacement, are not consistent with North American interests in energy and water conservation, and economizing energy costs for heating and treating pool water.

- Control organic loading
 - Ensure that pool occupancy limits are not exceeded, as the production of irritating halogenated organics is directly proportional to the number of pool users and the resulting increased organic loading.
 - An indicator of organic loading is the combined chlorine level in pool water. When combined chlorine levels reach a certain value, the pool should be shock chlorinated. Total chlorine can be used as an indicator for combined chlorine:
 - Total chlorine = free chlorine + combined chlorine
 - If tests show that the combined chlorine level is two times or greater than the free chlorine level, the pool must be treated to lower the chlorine demand or organic loading. The swimming pool regulation requires that combined chlorine levels be kept below 1.0 mg/L at all times. Treatment of elevated organics, as shown by combined chlorine, is “shock” chlorination.
 - “Shock chlorination” involves increasing the chlorine residual to at least 10 times the combined chlorine level. The increase in chlorine level will “burn off” the organic compounds, leaving only free available chlorine.
 - Superchlorination is not recommended for regular swimming pool maintenance. However, it may be a necessary treatment for algae control and infection control from fecal events. In this process, the chlorine level is increased up to 8 ppm to 50 ppm (Calgary Health Region, 2000, Swimming Pool Operator’s Course Manual).

A.2.9 Mercury vapours

Mercury exists in the environment in three different forms:

- Metallic mercury, otherwise known as elemental mercury or mercury vapour
- Inorganic mercury
- Organic mercury

In this section, we will limit our discussion to the metallic form. Metallic mercury is a shiny silver metal that is liquid at room temperature. At room temperature, metallic mercury slowly evaporates in the form of mercury vapour. Table A.2-22 describes the physical and chemical properties of metallic mercury (ATSDR 1999).

Table A.2-22 Physical and chemical properties of metallic mercury

Physical and chemical properties	Metallic mercury
Molecular weight	200.59
Colour	Silver-white (liquid metal); tin-white (solid mercury)
Physical state	Heavy, mobile, liquid metal; solid mercury is ductile, malleable mass which may be cut with a knife
Melting point	-38.87°C
Boiling point	356.72°C
Odour	Odourless
Odour Threshold	No data
Solubility in	0.28 umoles/L water at 25°C
In water	Soluble in H ₂ SO ₄ upon boiling, in lipids, readily soluble in HNO ₃ ,
In organic solvents	insoluble in HCl, soluble in 2.7 mg/L pentane
Vapour pressure	2x10 ⁻³ mm Hg at 25°C

Source: ATSDR (1999), Toxicological Profile for Mercury (Update), U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (ATSDR)

A.2.9.1 Sources

Common indoor sources of mercury can be classified under two categories (Carpi & Chen, 2001):

- Materials which contains mercury salts as an intentional additive or an accidental contaminant.
 - Examples include latex paints, contact lens solutions, nasal spray, alkali-based detergents and cleansers. Phenylmercuric acetate or phenylmercuric nitrate is used in these products to inhibit microbial growth.
- Devices that contain free mercury (Hg)
 - Sources of free mercury include thermometers, fluorescent light bulbs, compact flu bulbs and electrical tilt switches used in house thermostats, float controls in sump pumps, barometers and gas flow meters. These devices contain mercury in a special glass container or reservoir. Those containers can break easily during mishandling of the equipment or appliances.

Many people believe amalgam dental fillings to be a source of exposure to mercury; however, elemental mercury from dental fillings does not generally pose a health risk.

Another important source of metallic mercury can be mercury vapour lamps, fluorescent light tubes and compact fluorescent light bulbs. In Canada, at least 60 million mercury-containing lamps, tubes and bulbs are sold on an annual basis (CCME, 2001, cited in Canada Wide Standards). Although they are very efficient in terms of energy use, emission inventories show they are responsible for 180 kg/yr of mercury vapour release to the atmosphere during their life cycle (CCME, 2001). Mercury-containing lamps, tubes and bulbs contain 10 mg to 250 mg of mercury depending on the type and size.

Mercury is also released from coal burning activities and other processes (e.g. coal fired electrical generating stations).

A.2.9.2 Indoor and outdoor concentrations of mercury

An average of $0.01 \mu\text{g}/\text{m}^3$ to $0.02 \mu\text{g}/\text{m}^3$ of mercury was measured in the outdoor air in industrial areas with higher concentrations detected near emission sources, (such as mercury mines, refineries and agricultural fields treated with mercury fungicides) (ATSDR, 1999). Garetano et. al. (2006) reports outdoor mercury vapour concentrations averaged $5 \text{ ng}/\text{m}^3$ while indoor mercury levels were significantly higher at a mean average of $25 \text{ ng}/\text{m}^3$.

A.2.9.3 Sensitive or vulnerable individuals

The following population groups are considered to be sensitive or vulnerable to mercury exposure and associated health effects (ATSDR, 1999).

- Children born to women exposed to mercury during pregnancy can be especially sensitive to mercury exposure and adverse health effects because of developing organs and tissues, and pre-existing body loads of mercury. The organic form of mercury (methyl mercury) can cross the placental barrier.
- Individuals with extensive dental amalgams have the potential for greater susceptibility to adverse health effects than those who do not have dental amalgams because of increased body load. However, this is an area of ongoing research and investigation requiring validation.
- Individuals exposed to consumer products including skin lightening creams, soaps, tattoo dyes, finger paints and make-up paints; and medicinal products, such as medicinal herbal remedies, containing mercury.
- Individuals who eat sea fish as part their regular diet are prone to more mercury exposure than other people.
- Individuals who use mercury in religious ceremonies and ethnic practices or consume mercury-containing folk remedies (ATSDR, 1999; Wendroff, 1990, 1991). For instance, exposure can occur via the intentional sprinkling of liquid metallic mercury on floors, burning candles made with mercury, sprinkling mercury in baths and wearing small amounts of mercury-containing metal charms (ATSDR, 1999).

A.2.9.4 Health effects

- **Acute effects**

Inhalation of excessive amounts of metallic mercury vapour can have acute systemic toxic effect in both humans and animals. The kidneys and the central nervous system are the primary target organs affected by metallic mercury (ATSDR, 1999). Acute exposure to high levels of elemental mercury in humans results in CNS effects, such as tremors, irritability, insomnia, memory loss, neuromuscular changes, headaches, slowed sensory and motor nerve function, and a reduction in cognitive function and kidney effects ranging from mild transient proteinuria to acute renal failure (USEPA, 2007). Gastrointestinal effects and respiratory effects, such as chest pains, dyspnea, cough, pulmonary function impairment and interstitial pneumonitis have also been noted from human inhalation exposure to elemental mercury (USEPA, 2007).

- **Chronic effects**

The central nervous system is also the most sensitive target organ to chronic metallic mercury exposure. Various cognitive, personality, sensory and motor disorders have been observed in humans (ATSDR, 1999). Other symptoms include tremors, increased excitability (erethism) and delirium (Carpi & Chen, 2001), irritability, excessive shyness, insomnia and salivation, gingivitis, development of proteinuria (ATSDR, 1999; USEPA, 1997, 2007; WHO, 1990, cited in Mercury and Compounds; USEPA, 2002). Acrodynia is a rare syndrome found in children exposed to elemental mercury compounds. It is characterized by severe leg cramps, irritability, paresthesia (a sensation of prickling on the skin), and painful pink fingers and peeling hands, feet and nose (USEPA, 2007).

Cancer studies on elemental mercury are inconclusive because of a lack of valid exposure data and other confounding factors (ATSDR, 1999; USEPA, 1997; WHO, 1991, cited in USEPA 2002). Based on inadequate human and animal data, USEPA has classified elemental mercury as a Group D, which is not classifiable as to human carcinogenicity). Epidemiological studies have failed to show correlations between exposure to elemental mercury vapour and carcinogenicity.

A.2.9.5 Exposure

In a home with an indoor source of mercury, indoor concentrations and personal exposures are likely to be much higher during winter months when the heat is increased inside the home but ventilation from the outside is reduced because of closed windows and doors (ATSDR, 1999).

A.2.9.6 Guidelines

Indoor air quality guidelines for metallic mercury are not available. However, inhalation exposure and risk-based guidelines are available from various regulatory agencies.

- **Agency for Toxic Substances and Disease Registry (1999)**

Agency for toxic substances and disease registry (ATSDR 1999)	
0.0002 mg/m ³	Minimal Risk Level (MRL) for chronic duration inhalation exposure (365 days or more) to metallic mercury vapour. In a group of 26 mercury-exposed workers from three industries exposed to low levels of mercury for an average of 15.3 years (Range, 1-41 years) (Fawer <i>et. al.</i> , 1983)

Source: Toxicological profile for mercury, Agency for Toxic Substances and Disease Registry (1999)

A.2.9.7 Control measures

Most pesticide use of mercury was banned in 1976. In 1990, USEPA announced that use of mercury would be eliminated from interior latex paints. Paints that contain mercury carry a warning label stating the paint is for outdoor use only. In 1998, mercury based antimicrobial pesticides and mercury-based exterior paints were phased out in Canada.

Although, the use of mercury in consumer products is severely restricted, the presence of mercury in the indoor and outdoor environments can have severe health consequences. Simple control measures can be put in place indoors to eliminate or reduce mercury exposure.

- Evaluate any existing stock of paints and properly dispose of those paints that contain mercury (USEPA, 2002)
- Mercury is used in the manufacture of various lamps and lighting fixtures, wiring devices, halide and high-pressure sodium lamps, and switches. Mercury releases are associated with the manufacture, breakage and disposal of mercury lamps and light switches. Limit and reduce the use of mercury-vapour lamps and other electrical products containing mercury, or alternatively ensure proper handling and disposal, particularly avoiding breakage indoors. Redesigning the low-dose mercury lamp will help in reducing leachable mercury.
- Follow the recommendations of a fluorescent lamp stewardship program, released by Alberta Environment in June 2000. The following recommendations for mercury disposal and for recycling of mercury wastes from household hazardous products were provided. In Alberta, used fluorescent lamps intended for disposal are currently not classified as hazardous waste. However, recycling options should be considered before disposing at a landfill. Where recycling options are not available for large quantities of mercury, it has been suggested that fluorescent lamps be packaged with absorbent materials such as calcium poly-sulfide or commercially available powdered sulfur. If sulfur-based absorbent is used, it should be re-packed in a secondary container containing alkaline coating surrounding the core waste package.
- Other mercury containing wastes and materials, such as broken and obsolete instrumentation like thermometers and thermostats, should be packaged with a poly-sulfide/alkaline coating. After mercury-containing wastes and materials are pre-treated with absorbent materials, the waste materials can be disposed at any sanitary landfill after obtaining permission from the operator.
- Carefully handle mercury-containing devices to avoid breakage and spillage
- Metallic mercury evaporates slowly, so it should be stored in an airtight, closed container (ATSDR, 1999).

- To protect children against metallic mercury, educate them not to play with shiny, silver liquid droplets (ATSDR, 1999). Teachers and school staff should teach their students about the health consequences of metallic mercury (ATSDR, 1999).
- The following cleaning steps should be taken in the event of an accidental release of a small amount of mercury, such as a broken thermometer (USEPA, 2011). Public health inspectors should consult indoor air quality experts before recommending these steps to the public.
 - Wear rubber, nitrile or latex gloves.
 - If there are any broken pieces of glass or sharp objects, pick them up with care. Place all broken objects on a paper towel. Fold the paper towel and place in a zip lock bag. Secure the bag and label it as directed by your local health or fire department.
 - Locate visible mercury beads. Use a squeegee or cardboard to gather mercury beads. Use slow sweeping motions to keep mercury from becoming uncontrollable. Take a flashlight, hold it at a low angle close to the floor in a darkened room and look for additional glistening beads of mercury that may be sticking to the surface or in small cracks in the surface.

Note: Mercury can move surprising distances on hard, flat surfaces, so be sure to inspect the entire room when searching.
 - Use the eyedropper to collect or draw up the mercury beads. Slowly and carefully squeeze mercury onto a damp paper towel. Place the paper towel in a zip lock bag and secure. Make sure to label the bag as directed by your local health or fire department.
 - After you remove larger beads, put shaving cream on the top of small paint brush and gently dot the affected area to pick up smaller hard-to-see beads. Alternately, use duct tape to collect smaller hard-to-see beads. Then place the paint brush or duct tape in a zip lock bag, secure and label with the name of your local health department or fire department.
 - ▶ An optional step is to use commercially available powdered sulfur to absorb the beads that are too small to see. The sulfur does two things: (1) makes the mercury easier to see since there may be a color change from yellow to brown and (2) binds the mercury so that it can be easily removed and suppresses the vapor of any missing mercury. Powdered sulfur may be supplied as mercury vapor absorbent in mercury spill kits, which can be purchased from laboratory, chemical supply and hazardous materials response supply manufacturers.

Note: Powdered sulfur may stain fabrics a dark color. When using powdered sulfur, do not breathe in the powder as it can be moderately toxic. Also, users should read and understand product information before use.
 - ▶ If you choose not to use this option, you may want to request the services of a contractor who has monitoring equipment to screen for mercury vapors. Place all materials used with the cleanup including gloves in a trash bag. Place all mercury beads and objects into the trash bag. Secure trash bag and label it as directed by your local health or fire department.

- Contact your local municipal waste authority or your local fire department for proper disposal.
- Remember to keep the area well-ventilated, by opening windows and running exterior window fans for at least 24 hours after a successful cleanup.
- Continue to keep pets and children out of cleanup area. If sickness occurs, seek medical attention immediately.

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Appendix B1 and B2

Particulates

Introduction

Airborne particulate matter

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B. Particulates

B.1 Introduction

Smoke and soot from wood and coal burning have been an on-going concern in human history. In 1590, Queen Elizabeth I forbade coal burning near the palace at Westminster because of the offensive nature of smoke (Jones 2008). In 1661, it was proposed that factories be banned from the City of London (Evelyn 1661). More recently, excessive smoke from coal-burning was blamed for major air pollution episodes in Europe and in the United States (Firket 1931, Nemery et al. 2001 and Schrenk et al. 1949). In December, 1952, an inversion in London with heavy fog and accumulation of smoke particles and sulphur was blamed for an estimated 4000 excess deaths (Logan 1953).

Most of current particulate matter studies focus on the size and composition characteristics of airborne particulate matter (Valavanidis, Fiotakis and Vlachogianni 2008). As such, this section provides an overview of PM categories and types based on various perspectives, for example, aerodynamic sizes, evolution and chemistry. Epidemiological and toxicological studies have found a strong correlation of adverse respiratory effects with fine airborne particles (Valavanidis, Fiotakis and Vlachogianni 2008). This section provides information on health effects, guidelines, control measures associated with each category and type. The discussion primarily focuses on the PM_{2.5} and PM₁₀ fractions. A separate heading, following the above, will focus on ultrafine particles, fibers such as asbestos and natural and synthetic fibres (cellulose and man-made synthetic fibers) are also discussed in this Section. The final topic in this section is about lead. It has neurotoxic properties (e.g., causing learning and other neurobehavioural deficits in children) and lead based paints can still be found in old buildings.

B.2 Airborne particulate matter

B.2.1 Categorizations of airborne particulate matters

B.2.1.1 Solid and liquid particulate matter

Airborne particulate matter is defined as either solid or liquid matter with aerodynamic diameters ranging from 0.005 μm to 100 μm . Dusts, smokes, fumes and certain biological organisms such as viruses, bacteria, fungal spores and pollen grains can be classified as solid particulate matter. Mists and fogs can be classified as liquid particulate matter (Health Canada 1995).

B.2.1.2 Inhalable and respirable particulate matter

Particulate matters are more commonly classified based on their sizes. Total suspended particulates (TSP) and inhalable suspended particulates are defined as particles with a size $<100 \mu\text{m}$ and $<10 \mu\text{m}$, respectively (WHO 2000).

The aerodynamic diameter of a particle is associated with toxicity and is commonly used to categorize particulate matters. It is defined as the diameter of a smooth, unit density (one gm/cm^3) sphere which has the same settling velocity as the particle (settling velocity is the terminal velocity reached by a particle in the air falling under the influence of gravity). Aerodynamic diameter of a particle is dependent upon 3 factors (ACGIH 1989):

- Particle density
- Particle shape
- Particle size

Inhalable particulate matter (PM_{10}) are particles $\leq 10 \mu\text{m}$ mass median aerodynamic diameter. Inhalable particulates can be further divided into two fractions (WHO 2000):

- Coarse fraction ($>2.5 \mu\text{m}$ in aerodynamic diameter)
- Fine fraction, usually referred to as respirable particulates ($<2.5 \mu\text{m}$ aerodynamic diameter)

Generally, airborne particulate matter is not differentiated from each other chemically. Airborne measurement of particulate matter is a complex mixture of organic and inorganic substances with physically and chemically diverse characteristics. As the current definition of particulate matter does not differentiate based on chemical composition, the definition suggests that $\text{PM}_{2.5}$ from diesel exhaust is the same as $\text{PM}_{2.5}$ from road dust (Fogarty and Nelson 2001). In the scientific literature, particulate matter in the range from 0.1 to 10 micron are diversely classified and reported as $\text{PM}_{0.1}$, $\text{PM}_{1.0}$,

PM_{2.5} and PM₁₀. Particulate matter includes elemental carbon, organic carbon compounds, silicon oxides, aluminum and iron oxides, trace metals, ammonia, nitrates gas log fireplaces and sulfates (CEPA 2000). Particles that are generally less than 0.1 µm in diameter are also known as ultrafine particulate matter. Table B.2-1 presents the approximate diameters of various airborne particulates.

Table B.2-1 Size measurements of different particulates

Particulates	Approximate range of particle diameter (µm)
Rain drops	500-5000
Natural mist (water vapour)	60-500
Natural fog (water vapour) and clouds	2-60
Pollens	10-100
Ground talc	0.5-50
Bacteria	0.3-35
Plant spores	10-35
Insecticide dusts	0.5-10
Normal impurities in quiet atmosphere	0.01-1.0
Stoker fly ash	10-800
Pulverized coal, fly ash	1-50
Foundry dusts	1-1000
Cement dust	3-100
Metallurgical dust	0.5-100
Dust damaging to lungs	0.5-5.0
Oil smoke	0.1-1.0
Resin smoke	0.01-1.0
Tobacco smoke	0.01-1.0
Carbon black	0.01-1.0
Pigments (paint)	0.01-0.3
Viruses and proteins	0.003-0.05
Human hair	35-200
Red blood cells (adults)	7.2-7.8

B.2.2 Sources of particulate matter

Particulate matters can originate from either natural or anthropogenic sources (CEPA 2000). Natural sources of particulate matter include windblown dusts and minerals, volcanic dusts, sea salt spray, biological materials (i.e., pollen, spores and bacteria) and forest fires. Anthropogenic sources are related to human activities. The fine fraction (PM_{2.5}) generally originates from fossil fuel combustion and high temperature processes such as vehicle exhaust, industrial manufacturing and biomass burning. The coarse fraction (PM₁₀) is associated primarily with mechanical processes (e.g., wind erosion, crushing and grinding operations). Sources are further classified into primary and secondary. Primary sources are those sources responsible for direct emission to the indoor or outdoor environment. Secondary sources refer to emissions that undergo transformation in the atmosphere to form particulate matter. Examples of primary and secondary sources are provided in Table B.2-2.

Table B.2-2 Natural and anthropogenic sources of particulate matter (PM_{2.5} and PM₁₀)

Natural		Anthropogenic	
Primary	Secondary	Primary	Secondary
PM _{2.5} Wildfire (elemental carbon and organic carbons)	PM _{2.5} Organic carbons from biogenic VOCs Nitrates from natural NOx	PM _{2.5} Fossil fuel combustion (industrial, residential, autos) (elemental carbon and organic carbon) Residential wood combustion (elemental carbon and organic carbons)	PM _{2.5} Organic carbons from anthropogenic sources of VOCs (autos, industrial processes, solvents) Sulphates and Nitrates from anthropogenic sources of SOx and NOx (autos and power plants)
PM ₁₀ Windblown dust Sea salt spray Pollen, spores		PM ₁₀ Mineral dust from mining and extraction industries Windblown agricultural soil Road dust Tire and brake wear Dust from construction sites	

Source: Canadian Environmental Protection Act, Priority Substances Assessment List Report, Respirable Particulate Matter Less than or Equal to 10 microns, 2000

Both indoor and outdoor sources of particulate matter contribute to the indoor air contamination. Indoor sources of particulate matter include but are not limited to the following activities:

Sources of particulate matter that contribute to indoor air contamination	
<ul style="list-style-type: none"> • Outside air • Kerosene heaters • Wood stoves • Fireplaces • Some humidifiers • Cooking • Play activities 	<ul style="list-style-type: none"> • Renovation and construction • Cleaning • Ethyl acetate • Hobbies and work activities • Grooming and personal care activities • Walking and other activities

As stated above, indoor air can also be contaminated by particulate matters from outdoor sources which can be natural or anthropogenic. Natural sources include volcanoes, forest fires and wind erosion (Spengler et al. 2001). Anthropogenic sources include transportation related emissions, residential and commercial fuel and wood combustion, industry, construction, agriculture, incineration and power generation. Outdoor particulate matters can variously infiltrate into the indoor environment depending on their size (Health Canada 1995). Particulate matters from indoor sources differ in both chemical composition and size, and contain a higher fraction of organic matter (e.g., shed skin cells) in comparison to particulates originating from outdoors sources (Health Canada 1995). The mechanical ventilation system can also be a potential source of particulate pollution humidifiers, duct and pipe insulation materials in the mechanical ventilation system can generate PM and contaminate indoor air.

B.2.3 Indoor and outdoor dynamics of particulate matter

Concentrations of indoor particulate matters are determined by the dynamics between indoor and outdoor sources. Depending on temporal and spatial circumstances, either source may have a predominant influence. Once PM has penetrated through the building envelope, deposition, re-suspension and human activities can all contribute affecting the overall indoor PM exposure (USEPA 1996). The indoor and outdoor dynamics of particulate matter is complex; a detailed discussion on the dynamics and differences between ambient and indoor particulate matter, exposure and toxicological characteristics is provided in the Appendix G of the manual. Figure B.2-1 summarizes the dynamic relationship between indoor and outdoor particulate matter sources and concentrations.

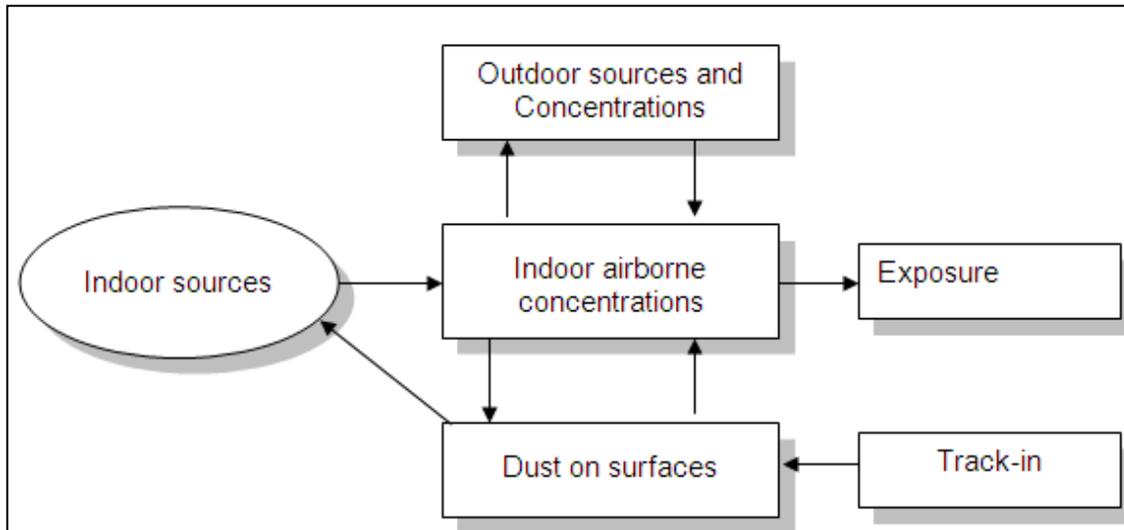
Ambient concentrations of particulate matter differ from day to day and from season to season. Higher concentrations have been recorded in polluted cities with high ambient particulate matter (Health Canada 1995). During the mid-1980s to mid-1990s, the long term PM_{10} 24-hour average concentrations in the ambient air ranged from $11 \mu\text{g}/\text{m}^3$ to $42 \mu\text{g}/\text{m}^3$ at urban sites in Canada. In the rural areas, concentrations ranged from $11 \mu\text{g}/\text{m}^3$ to $17 \mu\text{g}/\text{m}^3$ during the mid 1990s. $PM_{2.5}$ was in the range of $6.9 \mu\text{g}/\text{m}^3$ to $20.2 \mu\text{g}/\text{m}^3$ and $7.0 \mu\text{g}/\text{m}^3$ to $10.5 \mu\text{g}/\text{m}^3$ in the urban and rural areas of Canada, respectively (CEPA 2000).

People spent most of their time indoor (Health Canada 2002) and several studies including the PTEAM study have reported elevated levels of particulate matter in indoor air (CEPA 2000). The indoor air particulate matter level does not depend on outdoor sources alone, but it also depends on filtration effects, air exchange rates, decay rates and re-suspension rates (USEPA 1982, 1996, Wallace et al. 1993, Thatcher and Layton 1995)

In addition to outdoor sources, many indoor sources also contribute to the indoor PM concentration. Routine household activities such as cooking, cleaning and the use of different consumer products can contribute to the high level of indoor particulate matter (Health Canada 1995). Sheldon et al. (1989) reported that mean $PM_{2.5}$ levels in homes in New York City were twice the outdoor concentrations because of the presence of several indoor sources (i.e., kerosene heaters, gas stoves, wood stoves, fireplaces and tobacco smoke). Among these four indoor sources, smoking activities contributed significantly to $PM_{2.5}$ levels (Wallace 1996). As most individuals have daily routines in relatively consistent day-to-day indoor environments, unlike the ambient PM

concentration, the indoor PM concentration or an individual's exposure to PM is likely highly correlated over time (Princeton University 1999).

Figure: B.2-1 Transport of dust and airborne particles in the indoor environment



Source: modified from Spengler et al., 2001, *Indoor Air Quality Handbook*, Page 64.4

B.2.4 Susceptible groups

A critical review of epidemiological studies (Sacks et al. 2011) has concluded that personal characteristics and underlying health condition of population groups may render them more susceptible to particulate matter-related health effects. Factors leading to increased susceptibility include life stage, genetic polymorphisms, pre-existing cardiovascular and respiratory diseases, SES and additional characteristics, such as obesity and diabetes. Individuals in these studies did not necessarily represent all susceptible groups (Huang and Ghio 2009); further studies are necessary to identify additional susceptible groups and factors.

Evidence has suggested that certain sub-populations are particularly sensitive to acute PM exposure. Children are generally more susceptible to health impairments (e.g., asthma and other respiratory illnesses) from PM_{2.5} exposure than adults because of immature and less developed physiological systems (e.g., immune and respiratory). In addition, children inhale up to 50 per cent more air and hence air pollutants, on a per unit body weight basis than an adult (USEPA 2001). Several controlled human exposure studies also show that asthmatic children and adolescents are highly responsive to concentrations of acidic aerosols found in ambient air (approx. 35 µg H₂SO₄/m³ for 40 minutes) (Koenig et al. 1989, 1992, Hanley et al. 1992).

The elderly and people with cardiopulmonary disease are also at higher risk. In the aforementioned 1952 London fog episode mentioned in the *Appendix B Introduction* the 4,000 deaths involved mostly elderly persons, most of whom were people with chronic heart and lung disease (Logan 1953). It is unclear why PM affects people with cardiopulmonary disease even though several hypotheses have been proposed (USEPA 1996):

- PM may impair ventilation causing increase secretion or viscosity of mucus

- PM may cause inflammatory responses
- PM may increase susceptibility to pulmonary infectious disease
- PM may cause cardiac arrhythmia resulting in mortality
- PM may exacerbate existing asthmatic condition

B.2.5 Toxicology and mechanism of action

PM toxicity is generally linked to the aerodynamic size and how deep the PM can travel inside the respiratory system. Particulate sizes that are of health concern range from 0.1 to 10 μm in aerodynamic diameter. Particles in the coarse fraction that are of 2.5 to 10 μm are generally deposited in the nasopharyngeal region (Health Canada 1995). Fine fraction, $\text{PM}_{2.5}$ or respirable PM, is more toxic than the coarse fraction because it can reach the deep respiratory region (Oberdorster et al. 1994). After deposition deep in the unciliated tracheobronchial or alveolar regions of the lungs, $\text{PM}_{2.5}$ can potentially reside for a long period of time or chemical constituents can enter into the blood stream (Offermann 1985).

Several mechanisms have been proposed to explain the health effects associated with PM exposure: increased blood coagulation, airway irritation and inflammatory response. A detailed discussion of these mechanisms is beyond the scope of this manual. However, a brief discussion on some of the cardiopulmonary mechanisms has been provided below based on current understandings.

Several studies have reported experimental evidence for the biological plausibility of cardiovascular effects as a result of increased blood coagulation, platelet activation and endothelial dysfunction associated with particulate matter exposure. The important parameter for the validity of biological plausibility is the need to identify the components of airborne particulate matter responsible for adverse health effects as well as the identification of population at risk. In the past, researchers strongly questioned the plausibility of the association between particulate matter and increases in morbidity and mortality because the adverse cardiopulmonary effects have been observed at very low particulate matter concentrations and at concentrations that did not show adverse effects in laboratory animal studies (Gordon and Reibman 2000).

Based on reviews of selected key studies on particulate matter and health (1997-2001), the American Lung Association (2001) reported several laboratory animals and human studies where cardiac responses to particulates were shown, thus elucidating a possible biologic mechanism for mortality as described above. Bates (2000) concluded that all the causality criteria such as coherence, consistency, strength of association, temporality, analogy and biological plausibility have been met and the new data strengthened the case for a causal relationship between particulate matter and mortality.

Peters et al. (1999) associated increased plasma viscosity with an inflammatory response to PM exposure as a mechanism restricting blood flow to the heart, which in turn may cause death in individuals with severe coronary heart disease. He concluded that increased plasma viscosity may be part of the pathophysiological chain linking high ambient air pollution to increased mortality and hospital admissions for cardiovascular diseases.

Based on several experimental studies, biological mechanisms have provided a basis for several cardiovascular toxicity endpoints related to PM exposure. Researchers have demonstrated that a particular component of particulate matter (i.e. soluble metals) may mediate an array of injuries to the cardiopulmonary system in both healthy and at-risk (e.g., animals with prior cardiac conditions) animal subjects. Acute inflammatory responses, evidence of lung inflammation, were recorded in test animals (Costa and Dreher 1997). Both healthy dogs and at-risk dogs (i.e., with induced coronary disease) showed health effects, with an increased health effect in dogs. Electrocardiogram of the at-risk dogs showed more rapid development of ischemia and an inadequate flow of blood through the heart. As concluded by Godleski et al. (2000), inhalation of ambient particulates may produce responses in the cardiac and respiratory systems that can form the basis of plausible mechanisms by which exposure to increased levels of particulate matter could lead to fatal outcomes in predisposed individuals (Godleski et al. 2000).

B.2.6 Health effects

Health effects associated with PM depend on the following factors (Offermann 1985):

- Size of the particulate
- Chemical composition and toxicological characteristics of the particulate (e.g., lead and PAHs)
- Site of action in the human body (e.g., respiratory system, blood, cardiac systems)
- Properties of particulate matter carriers (e.g., adsorbed toxic substances such as BaP, HCHO)

Carbon or soot particulates produced in combustion processes can act as carriers for toxic gases, such as SO₂, into the lungs (Offermann, 1985)

Several studies show exposure to different levels of particulate matter can cause both acute and chronic health effects in individuals and populations (USEPA 2001, CEPA 2000, HEI 2000). The health effects data provided below are based on ambient air particulate matter.

- **Acute effects**

Health effect can be expressed as “*relative risk*”. Each 10 µg/m³ increase in the PM₁₀ was associated with an unweighted and weighted mean increase in daily mortality of 0.8% and 0.5%, respectively. For black smoke (PM₅), each 10 µg/m³ increase is associated with a daily increase in mortality of approximately one per cent on average (CEPA 2000). For PM_{2.5}, each increase of 10 µg/m³ 24-hour average is associated with a 1.5 per cent increase in daily mortality. In all those cases, the cause of mortality has been attributed to respiratory and cardiovascular diseases. In the famous Harvard Six Cities study, relative risks for both COPD and pneumonia related deaths were found to be higher than total deaths because of other causes (CEPA 2000).

Acute effects of indoor air contamination

- | | |
|-----------------------------------|---|
| • Asthma | • Cardiovascular disease |
| • Acute bronchitis | • Congestive heart failure |
| • Acute lung inflammation | • Respiratory-related mortality |
| • Pneumonia | • Increased hospitalization and emergency department visits |
| • Eye, nose and throat irritation | |

Morbidity effects because of particulate matter exposure have been reported. Each 10 µg/m³ 24-hour average increase in PM₁₀ has been associated with increased respiratory and cardiac hospitalizations and emergency department visits (CEPA 2000). WHO (2000) also has reported similar acute effects (i.e., increased respiratory related diseases, respiratory related mortality and cardiac effects) associated with PM₁₀, PM_{2.5} and acid aerosols. The following box summarizes reported acute effects associated with particulate matter exposure (CEPA 2000, WHO 2000).

Experimental animal studies have provided evidence and mechanisms for several health effects (i.e., respiratory and cardiorespiratory) which confirms that the cardiorespiratory system is the primary target for particulate matter induced health effects. Respiratory effects such as decreased ventilatory function and airway hyperresponsiveness have been observed in guinea pigs and rabbits (Chen et al. 1990, 1991b, 1992a, El-Fawal and Schlesinger 1994). In other studies, mortality was observed in rats following exposure to $250 \mu\text{g PM}_{2.5} / \text{m}^3$ for six hours per day for three days. Pulmonary inflammation was also observed in those animals (Godleski et al. 1996). Cardiopulmonary effects have been observed in several experimental animal groups. The reader should refer to the “Toxicology and Mechanism of Action” subsection above for additional information on the different mechanisms of cardiopulmonary toxicity.

- **Chronic effects**

Increased mortality, increased respiratory diseases and decreased lung function can be attributed to long-term ambient particulate matter exposure. In an ambient monitoring and exposure study over a one-year to 20-year period, humans were found to be exposed to annual average concentrations of PM_{10} and $\text{PM}_{2.5}$ that ranged from $18 \mu\text{g}/\text{m}^3$ to $47 \mu\text{g}/\text{m}^3$ and $11 \mu\text{g}/\text{m}^3$ to $30 \mu\text{g}/\text{m}^3$ respectively. In another study, an 18 per cent increase in chronic bronchitis cases was reported among older adult populations (associated with each increase in $10 \mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$ averaged over 10 years) (CEPA 2000).

Limited data point to an increased incidence of lung cancer in individuals with exposure from $11 \mu\text{g}/\text{m}^3$ to 29.6 (annual concentrations) of $\text{PM}_{2.5}$. A 19.9 per cent increase in lung cancer mortality was reported for each $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ (CEPA 2000). The following box summarizes the chronic effects of particulate matter exposure.

Acute effects of particulate matter exposure	
• Chronic bronchitis and asthma	• Pulmonary fibrosis in animals
• Decreased lung function	• Lung cancer
• Chronic pulmonary inflammation in animals	• Respiratory cancer (limited and inconclusive data)

In a metropolitan study in the United States involving 51 cities and more than 500 million participants, increased risk cancer and cardiopulmonary mortality risk was observed for chronic $\text{PM}_{2.5}$ and SO_2 exposure (Pope et al. 2002). The average relative risk for each $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ was ~ 1.08 for cancer mortality and ~ 1.05 for cardiopulmonary cancer mortality, after adjustment for confounding factors such as smoking, education, marital status, Body Mass Index, alcohol consumption, occupation and dust exposure and diet. Weaker and less consistent mortality observations were observed for PM_{10} and PM_{15} . Coarse fraction PM, TSP, ozone, carbon monoxide and nitrogen dioxide were not associated with increased mortality.

F.1.1 Exposure

The primary route of indoor exposure to particulate matter is inhalation (Godish 2000, CEPA 2000). However, dermal contact and ingestion can be possible routes of exposure. A complex relationship exists between personal exposure, ambient and indoor particulate matter. The reader should refer to the *Appendix G Outdoor air factors* for a detailed discussion on correlations between personal exposure, ambient and indoor particulate matter.

F.1.2 Guidelines for PM_{2.5} in indoor air

The current indoor Canadian PM_{2.5} guidance (Health Canada 1995) is being revised and will be rescinded. In August, 2011, the Government of Canada advised the public that under the *Canadian Environmental Protection Act, 1999*, the Minister of Canada was revising the 1987 *Exposure Guidelines for Residential Indoor Air Quality* (Government of Canada 2011). The new guidance would consider and incorporate the most up-to-date science. The indoor PM_{2.5} concentration is influenced by the highly variable ambient concentration; it is not practical to set a numerical limit. As such, there will be no new numerical exposure limit in the making. Rather, the proposed guidance will aim at reducing the PM_{2.5} indoor/outdoor concentration ratio to below 1 using four reduction strategies:

- Cessation of smoking
- Use of a stove top fan while cooking
- Installation of high quality furnace filters or use of portable air cleaners
- Adequate ventilation

F.1.3 Control measures

Several measures can be carried out to control indoor particulate levels. They include:

- Replace filters on furnaces, air conditioners and air cleaners as specified by the manufacturer.
- Do regular house-cleaning.
- Avoid installing wall-to-wall carpets.
- Have a trained professional annually inspect, clean and tune up of the chimneys and flues.
- Have properly fitting and functioning doors on all wood stoves.
- Vent all furnace combustion gases outside.
- Cease tobacco smoking indoors.
- Reduce or eliminate other indoor sources of particulates including wood- or coal-burning stoves, gas log fireplaces and natural gas stoves if these stoves are not exhaust ventilated and (USEPA 2001)
- Avoid use of pressurized consumer products that aerosolize contents.

- Install timed exhaust ventilation in attached garages.
- Control emissions from hobbies and renovation activities.
- Construct buildings away from outdoor sources, such as gravel roadways and industrial sources
- Remove shoes at home foyer.
- Install vacuflow systems that exhaust to the outside or use HEPA vacuums.

To reduce exposure to elevated ambient particulate matter, the following steps can be taken (USEPA 2001):

- Stay indoors and keep windows and doors closed. In a tightly sealed building, this may provide short-term protection as indoor source may lead to an overall decline of indoor air quality. In addition, with time the indoor space will equilibrate with outdoor air. Filtration may provide some reductions, depending upon particulate capture efficiencies and airflow rate.
- Inspect and change filters often, upgrade if possible.

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Appendix B3

Particulates

Asbestos

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B Particulates

B.3 Asbestos

B.3.1 Introduction

Asbestos fibrous materials, either natural organic or synthetic, are used extensively in modern buildings, primarily as acoustic or thermal insulating products (Vallarino 2001, Spengler 2001). In terms of fibrous materials' relationship to indoor air quality, they can be classified under two major categories.

- Asbestos
- Natural organic and synthetic fibres

This appendix focuses on asbestos.

Asbestos is a common name given to a six naturally occurring hydrated mineral silicates that can be easily separated into long flexible fibres. The word “asbestos” is derived from the Greek word meaning “unquenchable or indestructible.” Based on the rock type which form asbestos, there are two main mineralogical asbestos classifications—amphiboles and serpentine. In the following box, each of these two classifications is further subdivided based on mineral composition.

Two main mineralogical classifications of asbestos	
<i>Amphibole</i>	<i>Serpentine</i>
<ul style="list-style-type: none">• Fibrous tremolite• Fibrous anthophyllite• Fibrous actinolite• Amosite• Crocidolite	<ul style="list-style-type: none">• Chrysotile

Source: Government of Alberta 2011

Serpentine asbestos consists of only “chrysotile,” which is otherwise known as “white asbestos.” White asbestos is a hydrated magnesium silicate with long, wavy fibres that are white or off-white in colour (Government of Alberta 2011). Amphibole asbestos consists of the following types of asbestos materials: fibrous tremolite, fibrous anthophyllite, fibrous actinolite, amosite and crocidolite.

Amosite is also known as brown asbestos, and crocidolite as blue asbestos (Government of Alberta 2011). Amosite and crocidolite have much straighter and shorter fibres than chrysotile.

B.3.2 Properties of asbestos

Asbestos is incombustible, flexible and resistant to heat and chemicals and has a high tensile strength. When combined with cement or plastic, asbestos can act as an effective reinforcing or binding agent (Government of Alberta 2011). Some of the important physical properties of asbestos include:

Important properties of Asbestos	
• Flexibility	• High tensile strength
• High stability	• Sound asborency
• Resistant to friciton, corrosion, fire, and chemical attack	• High durability
	• Waterproof

These characteristic are unique to asbestos and have proven difficult to duplicate in man-made fibres or other natural fibres. As a result of these properties, asbestos fibres have had many industrial, commercial and consumer product applications.

There are two generally descriptive classifications of ACMs: friable and non-friable. Friable materials are those capable of being easily crumbled and reduced to powder, when dry, by hand pressure. Sprayed-on asbestos-containing insulations and fireproofing are often classified as friable. On the other hand, vinyl tiles can be classified as non-friable because they are not easily crumbled by hand pressure (Government of Alberta 2011).

Intact and properly maintained asbestos containing materials (ACMs) do not create an unsafe condition unless disturbed and released. When asbestos fibres are disturbed or handled, airborne fibres are easily generated. The underlying crystalline structure of asbestos is such that larger fibres easily fracture into thinner and thinner fibres (Spengler et al. 2001). Friability is a subjective measure of the fibre release potential of asbestos. This ability of asbestos to generate airborne fibres with handling or disturbance is a physical characteristic that significantly contributed to asbestos being recognized as a public health hazard. Therefore, in order to ensure the health and safety of building occupants and the public, any work or activity that might disturb ACMs must be performed only by certified and trained personnel. Sawing, sanding, cutting, moving, drilling, boring or otherwise disturbing ACMs may present a health risk if asbestos fibres to be released where they can be inhaled or ingested.

B.3.3 Uses and sources of asbestos

The use of asbestos in Canada was common during between 1930 and the early 1980s. Historically, asbestos-containing materials have had applications in building construction, industry and various consumer products. Asbestos can be found in other non-construction industry-related products such as plastics, textiles and catalyst support, gaskets, packing materials and brake linings (Government of Alberta 2011).

Use of friable forms of asbestos was restricted in Canada in the late 1970s while the less friable forms of asbestos, such as the backing behind vinyl sheet floor and vinyl floor tiles, continued to be sold into the mid 1980s. Building products, such as sprayed insulation, stucco and joint cements, manufactured in Canada and the United States no longer contain asbestos in an unbound form (Government of Alberta 2011). Limited cementitious forms of asbestos containing materials (ACMs) are still available for use in industrial and construction applications, such as rain water leaders. Based on the Alberta Building Code, the restriction imposed on the use of asbestos occurred over a period of time. Also, the Hazardous Products Act (1985) prohibited the use of drywall joint cements and spackling and patching compounds. Table B.3-1 presents the historical timeline of asbestos use in.

Table B.3-1 Limitations and restrictions on asbestos use

Year	Limitations and restrictions on asbestos use
1977	Supply and return air may not pass over surfaces containing asbestos fibres, except for fire stop surfaces
1981	No product that has a potential for releasing asbestos fibres in a building may be installed apart from asbestos cement board and asbestos cement pipe.
1985	Asbestos use in air distribution systems or equipment is prohibited.
1991	Spraying of asbestos fibres or material containing asbestos fibres is not permitted in buildings, Buildings being altered, renovated, or disturbing of any materials having the potential for releasing Asbestos fibres must be encapsulated, enclosed or removed in buildings being renovated where there is a the potential for asbestos being disturbed or released into the environment. Use of crocidolite asbestos is not permitted

Source: Alberta Asbestos Abatement Manual, prepared by Employment and Immigration, Government of Alberta 2011

About 80% to 95% of the asbestos that was used in the building construction industry was in the form of chrysotile (Government of Alberta 2011), (Langer and Nolan 1988). Asbestos was also used in products such as textile duct wrap, asbestos-cement, brakes, textiles, packing, gaskets and asbestos-reinforced plastics (USEPA 2001a). The following box lists additional indoor sources of asbestos have the potential to contaminate indoor air .

Additional possible indoor sources of asbestos	
<ul style="list-style-type: none"> • Old electrical equipment, such as old wiring insulation, lamp socket collars, electrical boxes and liners for recessed lighting • Instruments in school and university chemical labs • Hair dryers and portable heaters containing coil, wrapping and insulation 	<ul style="list-style-type: none"> • Old ovens and dishwashers that may have been wrapped in insulating blankets containing asbestos • Incandescent light fixtures with reflective surfaces and fibrous backings • Water heaters • Old freezers

Table B.3-2 lists common indoor products that might have contained asbestos in the past and may be in use.

Table B.3-2 Products containing asbestos

Uses and sources of products containing asbestos–	
Pipes, boilers and furnace ducts	Insulated with an asbestos blankets, mudding compounds or asbestos paper tape; may release asbestos fibres if damaged, repaired, or removed improperly
Resilient floor tiles	Vinyl asbestos floor tiles, asphalt; the backing on vinyl sheet flooring and adhesives used for installing floor tiles; Fibres can be released due to damage, repair activities, sanding and removal
Cement sheet, millboard and paper	Used as insulation around furnaces and wood burning stoves; repairing or removing appliances may release asbestos fibres; cutting, tearing, sanding, drilling, or sawing insulation can release fibres into the air
Door gaskets	In furnaces, wood stoves and coal stoves, worn seals can release asbestos fibres during use
Soundproofing or decorative material such as ceiling texture coats (spackle)	Sprayed on walls and ceilings; loose, crumbly, or water damaged material may release fibres; sanding, drilling, or scraping the material will release asbestos
Patching and drywall joint compounds and textured paints	Used in walls and ceilings; Sanding, scraping, or drilling the surfaces of walls or ceilings can release the asbestos
Asbestos cement roofing, shingles and siding	These products are not likely to release asbestos fibres unless sawed, drilled, or cut
Artificial ashes and embers	These products were sold for use in gas-fired fireplaces
Fireproof gloves, stove-top pads, ironing board covers	These products also have the potential to release asbestos
Automobile brake pads and linings, clutch facings and gaskets	These products contain asbestos that are used in applications other than construction

Source: Consumer Products Safety Commission, United States of America, 2001

B.3.4 Analytical asbestos measurement methodologies

Various testing methods have been developed to detect, measure and monitor for the presence of asbestos. The test method used largely depends on the type of media being analyzed, such as airborne asbestos, bulk building materials, settled dust, soil and sediment, water and other aqueous samples.

Asbestos measurements are reported in different units based on the analytical methodology employed. The two main types of tests for measuring asbestos in air samples in many of the provinces in Canada, (Government of Manitoba 2008, Government of Alberta 2011, Government of Ontario 2011, Worker's Compensation Board of B.C. 2006) and approved by the US National Institute for Occupational Safety and Health (NIOSH), are:

- Phase contrast microscopy (PCM), which uses a light microscope.
- Transmission electron microscopy (TEM), which uses an electron microscope

Phase contrast microscopy (PCM) is widely used to measure fibre concentrations of air samples. This is routinely done at asbestos abatement sites and can be applied for environmental monitoring, personnel monitoring and clearance testing in abatement projects. However, PCM can not distinguish between asbestos from non-asbestos fibres, such as a cotton fibre, a fibreglass fibre, a carpet fibre and a wood fibre. All fibres that satisfy the counting criteria are included in the measurement and assumed to be asbestos fibres. Fibres are counted according to the counting rules specified for analytical method 7400 in the *NIOSH Manual of Analytical Methods*. Results are expressed in fibres per cubic centimeter (f/cc).

For greater accuracy, electron microscopy or transmission electron microscopy (TEM) is used. Only confirmed asbestos fibres are counted using TEM. Fibres are counted according to the counting rules specified for analytical method 7402 in the *NIOSH Manual of Analytical Methods*. Results are expressed as an asbestos fibre count. The type of asbestos present is also reported. In both methodologies, fibre counts are determined by using the same counting criteria; that is, fibres <5 µm long, <3 µm diameter and aspect ratios >3:1 or 5:1). However, analytically, the detection limits for TEM are much lower than PCM. The PCM methods cannot detect asbestos fibres that are less than 0.3 µm in diameter whereas the TEM method can detect asbestos fibres as small as 0.01 µm (ATSDR 2001).

B.3.4.1 Outdoor and indoor asbestos levels

Ambient outdoor air levels of asbestos have been reported in the range of 0.001 ng/m³ to 0.1 ng/m³ (3 x 10⁻⁸ to 3 x 10⁻⁶ PCM f/cm³ or 1.8 x 10⁻⁴ to 1.8 x 10⁻² TEM f/cm³, respectively) (NRC 1984). However, elevated levels up to 100 ng/m³ (1.8 x 10⁻¹ TEM f/cm³) have been reported in the ambient air in the presence of a significant localized source. Outdoor air levels in the range of 50 ng/m³ to 5,000 ng/m³ have also been reported in the areas of industrial operations involving asbestos (ATSDR 2001). Recent analysis by the Health Effects Institute, reported ambient air levels of asbestos in rural and urban areas as 1x10⁻⁵ TEM f/cm³ (2x10⁻⁷ PCM f/cm³) and 1x10⁻⁴ TEM f/cm³ (2x10⁻⁶ PCM f/cm³), respectively (HEI 1991). In Canada, mean chrysotile concentrations at 12 Metropolitan Toronto locations ranged from <0.002 to <0.045 fibres/cm³ (measured by TEM). Mean concentrations in 12 other southern Ontario locations ranged from <0.002 fibres/cm³ to 0.033 fibres/cm³. In rural Canadian locations, the chrysotile concentrations were found to be below the detection limit (<0.002 fibres/cm³) (Chatfield 1983).

Indoor air measurements show varying levels of asbestos fibres because of the influence of building maintenance activities that disturb asbestos-containing materials, such as insulation, spray-on, ceiling tiles and floor tiles). The United States Environmental Protection Agency (USEPA) reported asbestos levels in different public buildings ranging from 0 TEM f/cm³ to 0.2 TEM f/cm³ (3x10⁻³ PCM f/cm³). Several studies have reported asbestos levels in the indoor air ranging from 1 to 200 ng/m³ (3x10⁻⁵ PCM f/cm³ to 6x10⁻³ PCM f/cm³ or 1.8 x 10⁻³ to 3.6 x 10⁻¹ TEM f/cm³, respectively). Generally, the amount of asbestos in indoor air depends on the amount, type and condition (friable or non-friable) of the asbestos-containing materials (ATSDR 2001).

In general, the comparison between the outdoor and indoor levels of asbestos indicates that the typical indoor level of asbestos is low compared to outdoor levels when indoor asbestos containing materials are not disturbed. However, in other instances, indoor levels may be higher than outdoors (Chesson et al. 1990).

B.3.4.2 Susceptible groups

According to ATSDR (2001), a susceptible population group or individuals exhibit a different response to asbestos exposure than the general population. Genetic make-up, age, health and nutritional status are some of the general factors which can be responsible for different degrees of hypersusceptibility among individuals. Variability in susceptibility to asbestos-related respiratory diseases can be related to individual genetic differences and the ability to detoxify the pulmonary deposition of asbestos fibres (ATSDR 2001).

Individuals who are exposed to asbestos during the early part of their life are more susceptible to asbestos-related respiratory diseases than those exposed to asbestos later in life. Asbestos fibres are retained in the lungs for a long time and there is a long latency period between exposure and the onset of chronic health effects (ATSDR 2001).

B.3.5 Mechanism of toxicity

The exact mechanism of toxicity by which asbestos fibres cause toxic injury has not yet been determined (ATSDR 2001). However, cell-mediated mechanisms or direct interaction between cellular components and asbestos fibres appear to be involved in the toxic injury. Also, the size of the fibres plays a major role in the toxic injury mechanism. The “critical fibres” are $>5 \mu\text{m}$ in length and $<3 \mu\text{m}$ in diameter with a length: width ratio greater than 3:1 or 5:1 (Sawyer 1979).

There are three mechanisms possible with respect to asbestos-induced toxic injuries: direct interaction, active oxygen mechanism and other cell-mediated mechanism.

- **Direct interaction**

Asbestos fibres can adsorb to different cellular macromolecules, such as proteins, lipids, RNA and DNA (ATSDR 2001). Chrysotile fibres bind to cytochrome P-450 and decreases mono-oxygenase activity (Khan et al. 1992).

- **Active oxygen mechanism**

Several authors have reported that the production of reactive oxygen species, such as hydrogen peroxide (H_2O_2) and superoxide radical anion (O_2^-), have been linked to asbestos-induced lipid peroxidation, cytotoxicity, cell proliferation, genotoxicity and apoptosis (ATSDR 2001).

- **Other cell-mediated mechanism**

In response to asbestos exposure, alveolar macrophages, pleural mesothelial cells and lung cells release a number of cellular factors. These factors mediate different cellular reactions, such as inflammation, macrophage recruitment and cell proliferation (ATSDR 2001). However, these mechanisms are poorly understood. The inflammatory response is believed to play an important role in the development of asbestos-induced pulmonary fibrosis or asbestosis (IARC Expert Panel 1996).

B.3.6 Health effects

Usually, asbestos-related health effects are manifested after long-term exposure to asbestos fibres. However, limited studies have indicated asbestos having the potential to cause short-term (acute) health effects in the experimental animals (ATSDR 2001).

Chronic health effects of asbestos can be either non-carcinogenic or carcinogenic.

- **Acute effects**

Limited studies were identified on the acute health effects of asbestos in animals or humans. However, one study indicated fibrosis in the lungs of animals during an acute duration exposure to asbestos (ATSDR 2001). No exposure duration or asbestos levels were reported for the above acute effect study.

- **Chronic non-carcinogenic effects**

- ▶ Asbestosis:

- ◊ Shortness of breath

- ◊ Difficulty in breathing

- ◊ Coughing

- ◊ Impairment of lung function

- ◊ In severe cases, death because of respiratory function impairment.

Other chronic non-carcinogenic health effects include pulmonary hypertension and immunological effects, such as depression of cellular immune system. Impaired immune surveillance can contribute to the increased incidence of cancer in individuals that are exposed to asbestos. Alterations of lymphocyte distribution have been reported in some studies. Some experimental studies suggest a decrease in the number and activity of natural killer cells in mice. However, it is still unclear if there is a strong association or correlation between immunological effects and asbestos-induced disease (ATSDR 2001).

- **Chronic carcinogenic effects**

Exposure to asbestos through inhalation can cause asbestosis, lung cancer and mesothelioma in humans (USEPA United Air Toxics website 2001a, Spengler et al. 2001). Mesothelioma is a rare form of cancer which affects the mesothelial cell membrane linings of the abdominal cavity and surrounding internal organs (USEPA 2001c, Spengler et al. 2001).

Evidence suggests that different types of asbestos fibres differ in site specificity and carcinogenic potency relative to one another. Some evidence also suggests that the exposure to crocidolites increase the risk of mesothelioma than exposure to other forms of asbestos, such as amosite or chrysotile. However, the evidence is limited by lack of scientific data on the exposure of individuals to the different types of mineral fibres (USEPA IRIS 2001). The following carcinogenic health effects are observed in the individuals exposed to asbestos (Spengler et al. 2001).

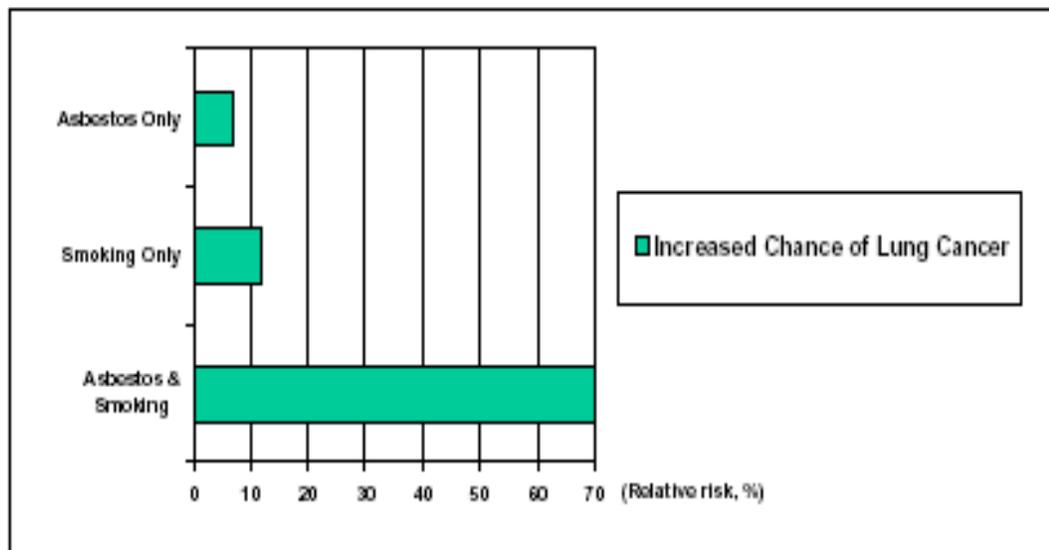
► **Lung cancer**

Evidence suggests that the latency period between asbestos exposure and lung cancer is approximately 15 years to 20 years in humans. It has been suggested that the exposure to asbestos fibres for an intermediate duration of four months to six months is enough to induce lung cancer among exposed individuals. Also, it has been observed that the risk of asbestos-related cancer is significantly increased among smokers versus non-smokers (ATSDR 2006 Government of Alberta, 2011).

Figure B.3-1 compares the risk of cancer for three different groups of people:

- ◇ Those who were exposed to asbestos but do not smoke
- ◇ Those who smoke but have not been exposed to asbestos
- ◇ Those who smoke and have been exposed to asbestos

Figure B.3.1 Increased risk of lung cancer caused by the combination of smoking and asbestos exposure



Source: Government of Alberta 2011, Alberta Asbestos Abatement Manual, Alberta Workplace Health and Safety.

► **Mesothelioma**

Mesothelioma is a rare form of cancer involving the mesothelial cell linings of the pleural (lungs) and peritoneal (abdomen) cavities. Airborne asbestos causes pleural and peritoneal mesothelioma after a long latency period between 20 and 40 years.

Evidence suggests that all types of asbestos have the potential to cause some form of mesothelioma (Rom 1998). But, the greatest risks of mesothelioma have been observed in individuals exposed to the crocidolite form of asbestos (Spengler et al. 2001). Chrysotile has been reported to induce mesothelioma in 2 per cent of exposed individuals whereas crocidolite forms

induce mesothelioma in 10 per cent of the exposed workers (National Research Council 1984).

▶ **Other forms of cancer**

Cancer of the stomach, intestines, larynx, esophagus, kidneys and pancreas have been observed in individuals exposed to asbestos in different occupational settings. However, the evidence is less conclusive and the incidence of these cancers is very low (Spengler et al. 2001). Although these types of cancer are rare, autopsies have shown the presence of asbestos in cancerous tissues (Government of Alberta, 2011).

B.3.7 Exposure

Inhalation is considered as the primary route of exposure to asbestos in humans (ATSDR 2001) which is of significant health importance as prolonged exposure to elevated levels can cause asbestosis, mesothelioma, lung cancer, non-malignant pleural diseases and may cause laryngeal cancer or lead to gastrointestinal tract cancer.

Individuals can also be exposed to asbestos by ingesting asbestos-contaminated drinking water or by inhalation through the aerosolization while showering (ATSDR 2001).

B.3.8 Guidelines

Indoor air quality guidelines for asbestos are generally specified as “clearance” measurements that are required before re-occupying a building that was mitigated because of asbestos contamination or asbestos-containing materials. The clearance criterion is 0.01 f/cm³ for NIOSH Method 7400 (*NIOSH Manual of Analytical Methods 1994*, Government of Alberta 2011, Spengler et al. 2001).

Specific indoor air guidelines for asbestos are not recommended because IARC and USEPA regard asbestos as a proven human carcinogen. In other words, there is no safe level of exposure to a carcinogen. Exposure to asbestos should be avoided or be kept as low as possible. However, several risk estimates have been developed by the regulatory agencies, such as WHO 2000, Government of Alberta, 2011, with respect to asbestos exposure.

Several researchers have derived lifetime exposure estimates with respect to asbestos and public health protection. The “best estimate” is that lifetime exposure to 1000 F/m³ (0.0005 F*/cm³ or 500 F*/m³, F* = fibres counted with an optical microscope) in a population where 30 per cent are smokers and the excess risk because of lung cancer would be in the range of 10⁻⁶ to 10⁻⁵. The corresponding mesothelioma risk for this population would range from 10⁻⁵ to 10⁻⁴. These values have been proposed to provide adequate health protection to the public. However, the validity of those risk estimates is critical to judge (WHO 2000). More recently WHO’s (WHO 2006) is committed to work with countries by establishing the following strategic directions to eliminate asbestos-related diseases:

- Stop the use of all types of asbestos.
- Replace asbestos with safer substitutes and develop economic and technological mechanisms to stimulate its replacement.
- Establish protocols to prevent asbestos exposure during abatement.
- Improve early diagnosis, treatment, social and medical rehabilitation of asbestos-related diseases and establish registries of people with past and current exposure to asbestos.

B.3.8.1 Agency for Toxic Substances and Disease Registry 2001

Asbestos is a proven human carcinogen, minimal risk levels (MRLs) are not available. However, several risk estimates are available and were reported in the *Toxicological Profile for Asbestos* (ATSDR 2001). Table B.3-3 presents lung risk estimate data for male and female smokers and nonsmokers with respect to lifetime exposure to 0.0001 f/cm³. It is also important to note that the fibres concentrations reported here are for PCM (Phase Contrast Microscopy) and not TEM (Total Electron Microscopy).

Table B.3-3 Risk assessment for asbestos-associated lung cancer

Parameters	Smokers			Nonsmokers		
	Male ^a	Female ^a	Average ^b	Male ^a	Female ^a	Average ^b
Lung cancer risk from lifetime exposure to 0.0001 f/cm ³	2.4 x 10 ⁻⁵	1.5 x 10 ⁻⁵	2.0 x 10 ⁻⁵	0.2 x 10 ⁻⁵	0.2 x 10 ⁻⁵	0.2 x 10 ⁻⁵
Concentration (f/cm ³) corresponding to lifetime excess risk level of 10 ⁻⁴			0.0005			0.005
Cumulative dose (f-yr/ cm ³) for a 70-year exposure corresponding to 10 ⁻⁴ risk level			0.035			0.35

^BAverage of males and females

Note: The concentration corresponding to lifetime excess risk level and the cumulative dose for a 70 year exposure risk level were calculated on the basis of 10⁻⁴ risk level. However, 10⁻⁵ (1 in 100,000) or 10⁻⁶ (1 in 1 million) risk level is usually considered acceptable in Canada. Adjustment in the calculations should be made for the purpose of comparison between 10⁻⁴, 10⁻⁵ and 10⁻⁶ levels of risk.

^ASource: ATSDR, 2001 (Original Source: EPA (1986a))

Table 3-4 Integrated risk information system (USEPA, 2000)

Inhalation unit risk estimate and air concentrations at specified risk levels, IRIS 2001	
Inhalation unit risk ¹	2.3 x 10 ⁻¹ per (PCMf/cm ³) ¹
Risk level	Concentration
10 ⁻⁴ (1 in 10,000)	4 x 10 ⁻⁴ f/mL
10 ⁻⁵ (1 in 100,000)	4 x 10 ⁻⁵ f/mL
10 ⁻⁶ (1 in 1,000,000)	4 x 10 ⁻⁶ f/mL

¹Unit Risk is the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to 1 pcm fibre/cm³. For asbestos, the unit risk value is calculated for the additive combined risk of lung cancer and mesothelioma and is calculated as a composite value for males and females. The unit risk value is based on risks calculated using general population cancer rates and mortality patterns without considering smoking habits of populations in USA. The unit risk is based on fibre counts made by phase contrast microscopy (PCM) and should not be applied directly to measurements made by other analytical techniques. The unit risk uses PCM fibres because PCM is used in the occupational environment.

B.3.8.2 Health Canada

Health Canada states that the asbestos content of a product does not indicate its health risk. Health risks exist only when fibres are in the air that people breathe.

Health Canada has encouraged provincial occupational health authorities to adopt stringent workplace exposure limits for asbestos. The sale of pure asbestos and certain high risk consumer products that are composed of or contain asbestos fibres is strictly regulated by Asbestos Products Regulations under the Canada Consumer Product Safety Act 2010. In addition, the emissions of asbestos into the environment from mining and milling operations are subject to the Canadian Environmental Protection Act 1999 (Health Canada 2008).

Health Canada recognizes the importance of reducing the exposure to asbestos fibres. During home renovations and maintenance activities, precautions should be taken to minimize the inhalation of asbestos. In addition, materials and products containing asbestos should be examined periodically for signs of deterioration. Before, removing or disturbing any asbestos-suspect materials, information and advice should be sought from government agencies and/or consultants.

B.3.9 Asbestos abatement methods and control measures

The Government of Alberta's, *Alberta Asbestos Abatement Manual* (2011) focuses on many facets of asbestos hazard-assessment and mitigation. For further information, the reader is advised to refer to the Government of Alberta manual, available online at <http://employment.alberta.ca/documents/Asbestos-Abatement-Manual.pdf>.

The control strategies to address the presence of ACM in buildings should be developed on a site-specific basis. The first step is to conduct a building survey especially in situation where a building was constructed prior to 1980. The survey must evaluate factors such as:

- Accessibility
- Type and nature of asbestos
- Condition of the materials (i.e. friability)
- Frequency of contact
- Damage status
- Function
- Cost of the proposed method for controlling asbestos exposure

B.3.1.1 Three basic asbestos control measures

Asbestos control measures can range from source removal, encapsulation and enclosure to implementation of asbestos management plan. These basic approaches are described below.

1. Removal of ACMs

Asbestos containing materials (ACMs) are removed from a building and buried in an approved landfill site. Removal of ACMs is mandatory during building demolition and, depending on circumstances, during renovation. There are both advantages and disadvantage associated with removal. Removal eliminates both ACMs from a building and the need for a long-term surveillance program. However, it is an expensive method and can interrupt the day-to-day building activities. Asbestos workers and normal building occupants have the highest potential for exposure during removal. Removal protocols can generally be classified as low, moderate or high risk according to their potential for generating airborne asbestos fibres. A brief outline of these classifications is presented below in Table B.3-5. All removal protocols follow the same four principles:

- Isolate the work area.
- Protect workers.
- Minimize the release of asbestos fibres.
- Ensure adequate clean-up and decontamination.

Table B.3-5 Alberta asbestos removal protocols

Recommended removal work procedure	Type of asbestos product and activity
Low risk	Installing or removing non-friable ACMs manufactured products, in good condition, without cutting, breaking, sanding or vibrating the materials. This includes handling gaskets, floor tiles, asbestos cement exterior cladding and asbestos cement boards. Note: If the product is or becomes extensively damaged during the removal process, the use of moderate risk procedure is recommended
Moderate risk	Handling, disturbing, removing, hand cutting, hand drilling, etc., small amounts of friable asbestos products such as pipe insulation and any amount of low or non-friable product. Small amounts being less than 0.09 m ² (1 ft ²). Removal of 9.3 m ² (100 ft ²) or less of contiguous ceiling tile containing asbestos or sheet vinyl flooring/vinyl floor tiles having an asbestos backing. Note: If difficulty is encountered in removing sheet flooring (i.e., the flooring becomes badly damaged) the use of high risk work procedure is recommended.
High risk	Handling, disturbing, removing large amounts of friable asbestos products such as pipe or furnace insulation or sprayed-on applications or where occupational exposures are likely to exceed the 8-hour OEL: (a restricted area)

Alberta Workplace Health and Safety should be contacted for assistance regarding asbestos issues. Also, asbestos contractors and professionals can be contacted for further assistance.

Source: Government of Alberta (2011)

2. Encapsulation

During this process, friable sprayed-on asbestos applications are coated with an approved bonding or encapsulating agent. Encapsulants penetrate into the spray-applied material to produce a hard, protective coating. Encapsulants are usually applied using low-pressure airless spray equipment to reduce the potential of fibre release.

One of the major disadvantages of this process is that the source of ACMs will always be present. Encapsulation is limited to those areas where sprayed-on asbestos is in good condition and not subject to further damage by contact. Continued long-term inspection and constant maintenance is a requirement of encapsulated surfaces.

3. Enclosure

Enclosure is the installation of a physical barrier that physically isolates the asbestos from other areas of the building. Often, this can be accomplished using drywall construction for spray-applied products, or metal pipe cladding in the case of pipe insulation. A suspended ceiling does not constitute an acceptable or effective barrier. Enclosure is regarded as a rapid, economical and uncomplicated method of controlling exposure. However, because the asbestos remains in the building, a long-term asbestos management program is required to ensure the long term integrity of enclosed asbestos.

B.3.10 Implementation of asbestos management plan

Generally an asbestos management plan, or an operations and maintenance plan, is implemented for the long-term management of asbestos-containing materials in buildings. Generally a long term management plan is requirement whenever ACMs are present in a building. The design of an effective management plan should be in writing and address the following issues:

- Inventory of asbestos-containing materials in the building
- Inspection frequency and procedures
- Training requirements for maintenance staff and others who may come into contact with the materials or work in proximity to the materials
- Procedures to follow in the event of damage or other emergency situations
- Procedures to follow should the condition of the materials change or work routines be altered
- Notification procedures for occupants and others in the building
- Labeling of asbestos containing materials

In addition, all building tenants and occupants need to be informed of the presence of asbestos-containing materials and of precautionary measures, such as no unauthorized ceiling access in the case of sprayed-on structural fireproofing.

Occupational Health and Safety legislation does not apply to privately owned residences. However, public health officials should recognize that asbestos is classified as a proven human carcinogen and that homeowners should minimize their exposures as much as possible by following the workplace procedures established by Alberta Occupational Health and Safety. If the homeowner hires a contractor to do any asbestos abatement work, the contractor must fully comply with workplace regulations and guidelines regarding asbestos. Similarly, provincial regulations apply if asbestos is located in any public or business facility, such as day cares, swimming pools, ice arenas, office towers, malls etc.). For further information on abatement procedures, the reader should refer to the *Alberta Asbestos Abatement Manual*.

B.3.11 Vermiculite insulation containing asbestos

Vermiculite is the name given to any naturally occurring group of micaceous minerals consisting mainly of hydrated laminar magnesium-aluminum-ironsilicate (USEPA 1995). Flakes of raw vermiculite have the property of expanding eight to 30 times their original size into worm-like accordion shaped pieces when heated rapidly at temperatures around 1,000°C or higher (CCOHS 2006). This expansion property is known as exfoliation (Potter 2000). The expanded material becomes silvery or gold in color, depending upon its chemical composition and the furnace temperature. The resulting product is a soft, fluffy, pliable, lightweight, fire-resistant, absorbent, chemically inert and odourless material. These properties allow the expanded vermiculite to be used in the construction, agricultural, horticultural and industrial markets in products such as loose-fill insulation, acoustic finishes, spray-on insulation, fireproof wallboards, concrete mixes for swimming pools, brake and clutch linings, animal feedstuffs and potting mixes and soil conditioners. (USEPA 2000, NIOSH 2003).

Vermiculite is produced from ore mined in different parts of the world. The largest suppliers of vermiculite are the United States, Australia, Brazil, China, Egypt, India, Russia, South Africa, Uganda, Zimbabwe and Kenya (USGS 2012). All vermiculite ores, depending on their geographic location, contain a range of other minerals, including in some cases asbestos. Asbestos is not a major vermiculite contaminant and only a few ore deposits have been found to contain more than trace amounts of asbestos minerals.

B.3.1.1 The rise and fall of the Libby mine

While in operation from 1920 through 1990, the vermiculite mine in Libby, Montana, may have produced about 70 per cent of the world's supply of vermiculite. For Canadian use, the raw product from the Libby mine was shipped to various exfoliation plants in Canada. At these plants the vermiculite was processed and sold as insulation under the brand name Zonolite® Attic Insulation. Zonolite®'s praised fire-resistant and has strong insulation properties made it widely used in buildings in Canada to insulate attics, walls or around chimney liners until the early 1990's. It was installed in hundreds of thousands of homes across the country. In fact, in the late 1970s and early 1980s, the federal government even offered a grant to people who installed insulation products including Zonolite® in their homes as part of federal government's Canadian Home Insulation Program (CHIP). It is estimated that about 300,000 Canadian houses have some type of vermiculite insulation.

But then Libby mine workers and local townspeople began developing respiratory illnesses. It turned out that vermiculite ore mined from Zonolite Mountain in Libby was contaminated with minerals, crystalline silica, talc and a toxic form of naturally-occurring amphibole asbestos called “tremolite-actinolite asbestiform mineral fibres) (ATSDR 2008; USGS). The raw Libby ore was estimated to be 21% to 26% asbestos by weight; and the vermiculite concentrate shipped to numerous processing plants in the United States, Canada and other countries was 0.3% to 7.0% asbestos before expansion (EPA 1982).

This news generated serious public concern because exposure to airborne asbestos particles has been linked to respiratory ailments, including cancer, among workers at the Libby mine and residents of Libby (Sullivan 2007, ATSDR 2002).

B.3.11.1 Health Canada's response to the Libby mine asbestos-contaminated vermiculite

These findings prompted Health Canada to issue an advisory on April 2004 to inform Canadians about potential health risks posed by some vermiculite insulation that may contain asbestos, mostly sold under the brand name Zonolite (Health Canada 2004). Some of the key points of the advisory are listed below:

- The insulation material made from vermiculite ore produced by the Libby Mine was not widely used after the mid-1980's.
- The insulation material made from vermiculite ore produced by the Libby Mine has not been sold on the market in Canada for more than 10 years.
- In the absence of evidence to the contrary, assume that vermiculite insulation material produced before 1990 may contain some asbestos.

There is currently no evidence of a risk to health if the insulation remains sealed behind wallboards and floorboards, isolated in an attic, or otherwise kept from exposure to the interior environment.

This product can present health risks if disturbed during maintenance, renovation or demolition.

According to the Health Canada advisory "Vermiculite Insulation Containing Amphibole Asbestos" (Health Canada 2009), the best way to minimize your risk of asbestos exposure is to avoid disturbing vermiculite-based insulation. If vermiculite-based insulation is contained and not exposed to the home or interior environment, it poses little risk.

If you know you have, or believe you may have, vermiculite-based insulation in your attic, the following precautionary steps are recommended:

Precautions to take with vermiculite insulation in an attic

- Seal all cracks and holes in the ceilings of the rooms below the insulation. For example, apply caulking around light fixtures and the attic hatch to prevent insulation sifting through.
- Restrict access to the attic. Do not allow children to play in an attic with open areas of vermiculite-based insulation.
- Make sure everyone working in the attic knows about the possible presence of asbestos.
- Do not use the attic for storage if retrieving items may disturb the attic insulation.
- If you must go into the attic, walk on boards in order to minimize disturbance of the insulation and use an appropriate respirator mask. Common dust masks are not effective protection against asbestos fibres. Half-face N, P, or R-100 respirators can be used and are available from retailers who sell safety equipment.
- Do not remain in the attic any longer than necessary.

If you suspect that you have vermiculite-based insulation in your walls, as a precautionary step, seal all cracks and holes. For example, apply caulking around window and door frames, along baseboards and around electrical outlets.

If you decide to have vermiculite-based insulation removed, or if you are planning renovations, speak to a professional qualified in dealing with asbestos. You should not attempt to remove the insulation yourself, unless you have been properly trained and have the necessary specialized equipment. Any vermiculite insulation known or suspected to be contaminated with asbestos must be treated as an asbestos containing material, even if the asbestos concentration in the product is less than one percent. For further information on handling or removal of vermiculite containing asbestos procedures, the reader should refer to the *Alberta Asbestos Abatement Manual*.

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Appendix B4

Particulates

Man-made mineral fibres

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B. Particulates

B.4 Man-made mineral fibres (MMMFs)

B.4.1 Introduction

Natural and synthetic fibrous materials are ubiquitous in modern buildings. They are primarily used in acoustic or thermal insulating products (Vallarino 2001, Spengler 2001). Synthetic fibres are now commonly used to replace the natural asbestos in the building industry. The term “man-made mineral fibres (MMMF)” includes a wide variety of manufactured inorganic fibrous materials. These inorganic manufactured fibres are synonymously known as man-made vitreous fibres (MMVFs) or glass fibres (GFs) (Vallarino 2001). However, MMMFs or MMVFs does not include naturally occurring silicate fibres, such as asbestos, nor do they include man-made organic fibres, such as nylon and rayon. Synthetic fibres or synthetic vitreous fibres (SVF) consist of different types of amorphous fibrous products (Vallarino 2001) with a broad range of chemical compositions (IARC 2002). They are of a woolly consistency and are normally made of molten glass, rock or slag. Individually they may be known as ceramic fibres, mineral wool, fibrous glass, glass wool, rock wool or slag wool, according to the materials from which they are manufactured.

B.4.2 Types and uses

More than nine million tonnes of MMMFs are produced around the world annually (IARC 2002). Most of them are found in the following thermal and acoustic insulation building materials (Vallarino 2001, Spengler et al. 2001):

- Spray-applied fire proofing
- Ceiling tiles
- Thermal insulation
- Sound insulation products
- Fabrics
- Filtration components
- Plasters
- Acoustic surface treatments

MMMFs are traditionally classified into two categories based on their carcinogenic potential (Vallarino 2001, Spengler et al. 2001):

- **Continuous filament glass fibre**

This fibre is not classified as a human carcinogen (IARC 2001); and

- **Glass, rock, slag wool and ceramic fibres**

These fibres are classified as confirmed animal carcinogens with unknown effects on human beings. The National Toxicology Program (NTP 1994) has identified respirable glasswool and ceramic fibres as carcinogenic in animals and as suspected carcinogens for human beings.

More recent studies are changing this classification approach. MMMFs including insulation glass wool, rock (stone) wool, and slag wool are now not classified as to their carcinogenicity to humans (Group 3) (IARC 2001, NTP 2010). Only the more biopersistent fibrous materials such as refractory ceramic fibre (RCF) have remained as possible human carcinogens (Group 2B) (IARC 2002).

B.4.3 Physical and chemical properties of MMMFs

MMMFs have different physical and chemical characteristics. They are coated with various chemical binders, such as phenol formaldehyde resins, mineral oils, organometallic compounds, microvermiculite and high temperature polymers for their specific applications (Spengler et al. 2001, Vallarino 2001, TIMA 1991).

The primary source of material is erosion of fibres from the parent insulating material inside a building's ventilation system (Vallarino 2001). Unlike the natural asbestos fibres, MMMFs break along their diameters resulting into shorter fibres, easily $<1.0 \mu\text{m}$ in length. However, MMMFs have wider diameters than asbestos. As a consequence of their wider diameters, MMMFs do not travel relatively far from their source before settling out when compared with asbestos (Spengler et al. 2001).

B.4.4 Exposure

The primary route of exposure to MMMFs is through inhalation. MMMF can become airborne when disturbed during their production, use and removal phases. One study, which measured airborne MMMFs concentration in work places, noted MMMF levels in trades and bystander areas were low, ranging from 0.01 to 0.68 fibres/cm³. These levels were below the detection limit for the potentially carcinogenic refractory ceramic fibres (RCF) (Verma et al. 2004). While the sample size in this study was small, this finding nevertheless suggested that MMMF exposure for people not directly involved in the work processes might not be a significant concern.

B.4.5 Health effects

The biopersistence (the ability of a fibre to remain in the lung) and the dimensions of a fibre are significant in determining its toxicity (Hammad 1984, Berstein et al 1996, Hart et al. 1994). Recent studies have suggested a variety of respiratory and dermal acute and carcinogenic chronic health effects in humans and experimental animals exposed to MMMFs. Inhalation of MMMFs may lead to inflammatory and fibrotic processes which may in turn promote cell proliferation in a dose-related fashion.

- **Acute effects**

Acute effects such as transient skin irritation, mucous membrane irritation, and respiratory diseases have been reported in building occupants exposed to MMMFs

(Hedge et al. 1993, Sainmi 1990, Spengler et al. 2001). World Health Organization (2000d) have reported that MMMFs $>3 \mu\text{m}$ can cause transient irritation and inflammation of the skin, eyes and upper respiratory airways.

MMMFs are also associated with “office eye syndrome,” collective dermatitis and upper respiratory tract irritation (Valarino 2001, Spengler et al. 2001). These symptoms have been observed in new employees in an office setting (Vallarino 2001).

- **Chronic and carcinogenic effects**

Recent studies have provided epidemiological data on MMMFs (Vallarino 2001, Spengler et al. 2001). Statistically, higher risks of lung cancer and other respiratory cancers have been observed in mineral fibre manufacturing facility workers (Enterline 1987, Simonato et al. 1987, Spengler et al. 2001). However, several investigators have attributed these lung cancers to other cofactors, such as smoking, but not to MMMFs (Chiazze et al. 1995). IARC evaluated the evidence in 2002 and only kept the more biopersistent materials, such as refractory ceramic fibre (RCF) as possible human carcinogens (Group 2B). Other MMMFs including insulation glass wool, rock (stone) wool, and slag wool are now no longer classified as to their carcinogenicity to humans (Group 3). The 2002 IARC evaluation is supported by more recent studies. Lipworth and co-workers in 2009 (Lipworth et al. 2009) conducted a systematic review and meta-analysis and argued against a carcinogenic effect of rock wool or glass wool. NTP (2010) has similarly concluded that there is inadequate evidence to suggest glass wool fibres are carcinogenic.

B.4.6 Guidelines and standards

Occupational guidelines have been established for non-carcinogenic fibres, and exposure limits are recommended for potential carcinogenic fibres. For regulatory purpose, a particle is considered as a fibre when the length (L) is $>5 \mu\text{m}$ and the diameter (D) $<3 \mu\text{m}$, and a L:D ratio $>3:1$. Fibres correspond to the respirable fraction of particular matters that is able to enter the alveolar region of humans.

- **Fibres with no indication for carcinogenicity**

More commonly used vitreous fibre wools including insulating glass wool, such as fibreglass, rock (stone) wool and slag wool are now considered as non-carcinogenic to humans (Group 3) (IARC 2001). Based on reviews and published articles, the Scientific Committee on Occupational Exposure Limits for Man-made Mineral Fibres (European Commission 2012) has recommended the following occupational guidelines for fibres with no indication for carcinogenicity and not specified elsewhere.

Table B.4-1 Fibres with no indication of carcinogenicity

Recommended guidelines	Recommended concentration
8 hour TWA	1 fibre/ml
OEL	1 fibre/ml
STEL (15 minutes)	---

Source: European Commission 2012.

The Government of Alberta Occupational Health and Safety Code (Government of Alberta 2009) has established guidelines for fibres that have no indication for carcinogenicity.

Table B.4-2 Government of Alberta guidelines for fibres with no indication of carcinogenicity

Types of synthetic vitreous fibres	8-hour OELs
Glass fibres, continuous filament	1 fibre/cc
Glass fibres, continuous filament, total particulate	5 mg/m ³
Glass fibres, special purpose	1 fibre/cc
Rock wool fibres	1 fibre/cc
Slag wool fibres	1 fibre/cc

Source: Government of Alberta Occupational Health and Safety Code

- **Fibres classified as possible human carcinogens**

While most MMMF are non-carcinogenic, IARC (2001) has classified refractory ceramic fibres (RCF) and some special purpose glass wools that are not used as insulating materials as possible human carcinogens (Group 2B). Lung inflammation contributes to cancer development (de Visser et al, 2005) and that inflammation occurrence is determined by doses (particles and fibres) (Schins 2002), it is therefore assumed that fibre toxicity and carcinogenicity of RCF has a threshold. The World Health Organization (2000d) has suggested unit risks and excess lifetime cancer risk for the biopersistent refractory ceramic fibres based on dose/concentration

Table B.4-3 Lifetime cancer risk for biopersistent refractory ceramic fibres based on dose concentration

Number of fibres/1,000 cm ³	Excess lifetime cancer risk
100	1 in 10,000
10	1 in 100,000
1	1 in 1,000,000

Source: World Health Organization (2000d), *Man-made Vitreous Fibres, Air Quality Guidelines for Europe*

Because refractory ceramic fibres are suspected human carcinogen, the American Conference of Governmental Industrial Hygienists (ACGIH 2000) has recommended a lower threshold limit value-time-weighted average of 0.2 fibres/cc, while all other fibres have a higher TLV-TWA of 1 fibre/cc.

Table B.4-4 ACGIH recommended TLV-TWA

Fibres	ACGIH TLV-TWA
Refractor ceramic fibres (RCF)	0.2 fibres/cc

Source: American Conference of Governmental Industrial Hygienists (ACGIH). 2002. *Documentation of TLV for synthetic vitreous fibres. In: Chemical Substances TLVs and BEIs. 7th edition. Cincinnati. Ohio.*

The Alberta Government has established OEL for RCF. The limit considers the RCF carcinogenicity classification of A2 (a suspected human carcinogen) based on the ACGIH classification (Government of Alberta 2009).

Table B.4-5 Government of Alberta’s established OEL for RCF

Fibres	8-hour OEL
Refractor ceramic fibres (RCF)	0.2 fibres/cc

Source: Government of Alberta. 2009. Occupational Health and safety Code.

B.4.7 Assessment and monitoring

The International Labour Organization (ILO 2000) recommends that whenever assessment or monitoring is applicable it should be carried out “in accordance with the requirements of the competent authority.” Adherence to this recommendation is important for occupational health and safety applications. Environmental public health professionals should also consider this recommendation when obtaining environmental samples. Standardized procedures and methodologies are available. Results are reported as fibres per millilitre of air (fibres/ml) or as weight per unit volume of air ($\mu\text{g}/\text{m}^3$) (ILO 2000). The World Health Organization has established a universally accepted occupational health and safety reference method using phase contrast optical microscopes. Another method of analysis recommended by ACGIH is the NIOSH method 7400. This method is also required by the Alberta Occupational Health and Safety Code (Government of Alberta 2009).

When using innovative methodologies, caution must be taken. New methodologies should be referenced against an established method for appropriate quality control. Kauffer and coworkers (2003) evaluated and compared two direct-reading instruments with phase contrast optical microscopy to measure the number concentration of airborne fibres. They found that the response of the instruments was highly dependent on the nature of the fibres. Moreover, proper calibration is not always feasible as services from a specialized laboratory are usually required.

B.4.8 Control and management measures

MMMF exposure is mostly an occupational health concern; little information is available about environmental exposure in community settings. Education, prevention, material selection and source control are the most effective strategies in minimizing occupational exposure. Likewise, home owners and building occupants can apply similar principles for health protection. The control measures for man-made mineral fibres (MMMF) include the prudent selection of renovation or maintenance procedures, such as limited sanding, cutting, and drilling of MMMF materialism, that will reduce the release of fibrous glass, ceramic and mineral wool fibres into indoor air. In addition, exposed fibreglass insulation should not be present inside a ventilation system. Fibreglass insulation should be covered with a barrier such as an aluminized fabric covering. Routine inspection and maintenance of ventilation systems should ensure that damaged coverings are repaired and that there is no exposed insulation subject to air erosion.

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Appendix B5

Particulates Lead

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B. Particulates

B.5 Lead

B.5.1 Introduction

Lead (Pb) is a bluish or silvery-grey naturally occurring ubiquitous heavy metal that is rarely found in its elemental form. It is found in the earth's crust in rocks, water, soil and air in different mineral forms, primarily as the mineral galena (PbS), and to a lesser extent as anglesite (PbSO₄) and cerussite (PbCO₃). Natural lead is a mixture of four stable isotopes, ²⁰⁸Pb (51% to 53%), ²⁰⁶Pb (23.5% to 27%), ²⁰⁷Pb (20.5% to 23%), and ²⁰⁴Pb (1.35% to 1.5%) (WHO 2000, Godish 2000). Lead isotopes are the stable decay product of three naturally radioactive elements: ²⁰⁵Pb from uranium, ²⁰⁷Pb from actinium, and ²⁰⁸Pb from thorium (ATSDR 2007).

B.5.2 Sources of lead in the environment

Lead is released into the air mainly through mining and smelting of lead ores. However, in the past, the major contributor of lead in the ambient air was through the combustion of fuels with alkyl lead additives. Prior to the 1970s and 1980s, approximately 80% to 90% of the lead in ambient air was derived from the combustion of leaded gasoline (WHO 2000e). More than 90 per cent of the automotive lead emissions were in the form of inorganic particulate matter, such as lead bromochloride, and the remaining 10 per cent in the form of organovapour or alkyl lead. By the late 1980s, automotive emissions were no longer considered a major source for lead in the atmosphere because of the regulated reformulation to lead-free gasoline. Currently, the largest volume of organolead vapours that are released to the atmosphere has resulted from industrial processes such as primary and secondary nonferrous metal smelting (ATSDR 2007).

In Canada, concentrations of lead in the ambient air have declined significantly since the introduction of unleaded gasoline in 1975. The prohibition of leaded gasoline for use in automobiles in the 1990s has caused further decline in atmospheric lead concentrations (Health Canada 1999b, Health Canada 2011). Between 1973 and 1985, airborne lead decreased by 76 per cent. Based on lead data from 1990, reported concentrations of lead in the ambient air in most Canadian cities dropped below the detection limit and closely matched the lead concentrations found in the rural communities (Environment Canada 1991). Between 1984 and 2008, average levels of lead declined by more than 99 per cent. In addition to the phase-out of lead in gasoline, the imposition of greater controls by the government on lead emissions from mining and smelting operations has further reduced levels of lead in ambient air to averages that are now consistently below 0.02 µg/m³ (Environment Canada 2010).

In spite of effective controls of leaded gasoline, the following sources of lead can significantly affect indoor air or personal exposure (USEPA 1998, CDC 2002, ATSDR 2007, CDC 2009, Health Canada 2011):

- The historical use inside and outside older homes and buildings of paint and other coatings containing lead, such as lead chromate and lead oxide
- Tracking lead-contaminated soil from the outdoors into the indoor environment from nearby lead mines, smelters or other industries that release lead into the air, adjacent highways and house paint scrapings
- Storage of lead-acid batteries used in motor vehicles, storage of used motor oil that may contain lead and other heavy metals picked up from the engine
- Lead in brass, bronze and pewter
- Children's paint sets and art supplies
- Toys and furniture painted before 1978
- Sheet lead and solder
- Other indoor sources, such as lead-glazed ceramics, metal coatings, ballasts and lead-coated containers
- Lead jewelry ornaments
- Horizontal PVC (plastic) mini-blinds imported from Mexico and few Asian countries contain lead (Health Canada 1999) and
- Lead used in hobbies, such as stained glass making and pouring lead shot.
- Cigarette smoking and second-hand smoke (Apostolou et al. 2012 Mannino et al. 2003 Froehlich TE et al. 2009)
- Residues of lead arsenate -based pesticides (PbHAsO₄), used to control agricultural pests in fruit orchards until late 1950s, may be bound to the soil and treaded indoors. Lead arsenate continued to be used in some locations into the 1970s and was not officially banned until 1988 (Focus, 2006).
- Lead acetate in progressive hair dyes
 - Progressive hair dyes formulated with lead acetate can be a potential source for lead poisoning both by accidental ingestion and by hand-to-mouth activity following contact with lead-contaminated surfaces including the dyed hair of adults (Mielke 1997). According to the U.S. Food and Drug Administration lead acetate is not absorbed through the skin but it is an ingredient banned from hair dyes and personal care products by Canadian and the European Union health authorities (ATSDR 2007, U.S. FDA 2002, Health Canada 2006)
- Residues of lead arsenate-based pesticides (PbHAsO₄)

Additional indoor sources of lead can include the burning of lead-painted wood in fireplaces. Individuals employed by smelting industries or automotive battery recyclers can carry lead from the workplace into the home. Lead fumes and particles can be released during firearms target practice in indoor firing ranges, resulting in lead exposure among the facility users and other employees, if the premises are poorly ventilated. In

residential buildings where the stripping and sanding of old lead-based paints and coatings has occurred without following adequate abatement procedures, lead dust levels can be 10 to 100 times greater in these homes than those without these activities (Rabinowitz et al. 1985, Marino et al. 1990, Shannon, 1992, Clark et al. 2004)

B.5.3 Susceptible groups

The effects of lead exposure are a health concern for all humans. Children, especially those six years of age and under living in older housing, are classified as a high-risk group because of their increased susceptibility to lead toxicity. Children can take in more lead per unit body weight than adults. Lead absorption in children's gastrointestinal tract is approximately 50% to 53% compared to adult absorption of 10% (WHO 2000e). Therefore, children who exhibit pica, an eating disorder that is typically defined as the persistent and compulsive ingestion of non-nutritive and non-food items are at greatest risk. In addition, children have developing and growing bodies that can incorporate lead more actively than adults (Health Canada 2011). Because of their shorter height and higher breathing rate, children are more likely to breathe in more lead-contaminated soil, dust and fumes than adults (ATSDR 2007). Children also have a lower threshold for hematological and neurological effects than adults (WHO 2000e).

The fetus is also in the high-risk group with respect to lead exposure. Lead is known to cross the placental barriers and reach developing tissues and organs of the developing fetus when their mothers carry high concentrations of lead in the bodies. The last trimester of pregnancy is the most critical time during gestation (Health Canada 1995). Fetuses exposed to lead in the womb may be born prematurely and have lower birth weights. Lead exposure in the womb, during infancy, or in early childhood can slow down mental development and cause lower intelligence later in childhood. There is evidence that these effects may persist beyond childhood (ATSDR 2007)

B.5.4 Mechanisms of toxicity

Lead may enter the body through the mouth, the lungs and the skin; nevertheless, inhalation and ingestion are considered the main routes of exposure. The toxicity of lead is non-dependant of the route of exposure, once inside the body it is absorbed through the blood into tissue, affecting almost every organ or physiological systems in the body. The most sensitive areas for lead toxicity are the nervous system, specially the developing brain, and the cardiovascular, renal and hematological systems (Health Canada 2009, Sander et al. 2009, ATSDR 2007). Various biochemical mechanisms are briefly discussed below with respect to lead induced toxicity.

- **Respiratory system**

Inorganic lead primarily in particulate aerosols can deposit in the respiratory tract during inhalation. The amount of lead deposited in the respiratory tract is influenced by the size of the inhaled particles, individual breathing patterns, such as nose or mouth breathing, and airstream velocity within the respiratory tract. Larger lead particles (aerodynamic diameter $>2.5 \mu\text{m}$) are deposited in the nasopharyngeal tract. In the nasopharyngeal tract, high airstream velocities and airway geometry facilitate inertial impaction of lead particulates. Smaller particles (aerodynamic diameter $<2.5 \mu\text{m}$) are deposited in the tracheobronchial and alveolar regions characterized with

low airstream velocity. As breathing patterns vary greatly between a child and an adult, deposition of lead particulates in the various compartments of the respiratory system can be quite different. The intake of organic lead is different. Organic lead vapours behave as gases in the respiratory tract; therefore, deposition and absorption of organic lead vapours is significantly different from inorganic lead particles (ATSDR 2007).

- **Hematological system**

The Agency for Toxic Substances and Disease Registry (ATSDR 2007) has stated that lead can partition between plasma and red blood cells. Almost 90% to 99% of lead is associated with red blood cells (RBC). Lead affects the synthesis of heme by changing the activity either by stimulating or inhibiting different enzymes, such as ALAS, ALAD and ferrochelatase. Reduction of hemoglobin concentrations is observed as a result of lead induced interference in heme synthesis. Decreased production of hemoglobin and increased erythrocyte or red blood cell destruction leads to anemia. ATSDR also quoted several studies that have observed low hemoglobin levels and anemia in lead workers (ATSDR 2007).

- **Nervous system**

Several studies have focused on the relationship between the effect of lead on neurotransmitter systems and neurobehavioral function (Cory-Slechta 1995). Lead has the potential to substitute for calcium as a neural impulse messenger in neurons. Lead blocks the calcium channel inhibiting the influx of calcium and the subsequent release of neurotransmitters (Goldstein 1993).

Lead can also act as a calcium substitute in the activation of protein kinase C which is important in cell growth and in differentiation of brain endothelial cells. Premature activation of protein kinase C by lead may impair vascular formation in the brain, which in turn can impair brain function. High levels of lead exposure may account for defects in the blood-brain barrier (BBB, contributing to acute lead encephalopathy. At low levels of exposure, dysfunction of the BBB may contribute to subtler neurobehavioral deficits in children because protein kinase C is also thought to have some role in memory storage (Goldstein 1993). The specific vulnerability of fetuses and infants to the neurotoxicity of lead may be because of in part to the immaturity of the blood-brain barrier and to the lack of a high-affinity lead-binding protein in astrocytes (CNS cells). The reader should refer to the *Toxicological Profile for Lead* (ATSDR 2007) for a detailed explanation of neurotoxicological mechanisms of lead.

B.5.5 Health effects

B.5.5.1 Acute effects

Acute effects differ in children and adults (Godish 2000). In general, a blood lead level greater than 2.92 $\mu\text{mol/L}$ (60 $\mu\text{g/dL}$) can produce acute effects, such as appetite loss, colic pain, constipation, vomiting, fatigue, shock, severe anemia, muscle pain, sleeplessness, unconsciousness, nervousness, kidney damage, irritability, headache, seizures, irreversible brain damage, cardio-respiratory failure, coma and even death (Health Canada 2007).

Other acute symptoms associated with high levels of lead poisoning are abdominal pain, diarrhea and vomiting, metallic taste in the mouth, convulsions, coma, and possibly death (Health Canada 2011). However, cases of acute lead poisoning are very rare and consequently, long-term, low-level lead exposure appear to be a more serious health concern.

B.5.5.2 Chronic effects

The general chronic symptoms and health effects of low lead exposure are (USEPA 1998, ATSDR 2007):

- Nervous system and kidney damage
- Damage to nervous systems and RBCs
- Learning disabilities, attention deficit disorder, and decreased intelligence
- Speech, language and behaviour problems
- Decreased memory and attention span
- Decreased mental abilities
- Irritability
- Sleeplessness
- Headaches
- Hearing damage
- Anemia
- Fatigue
- Poor muscle coordination
- Decrease sensation
- Lack of appetite
- Loss of coordination
- Decreased muscle and bone growth
- Abdominal pain
- Constipation
- Possible increased blood pressure

In children, chronic, low-level lead exposure can lead to neurobehavioral deficits, such as deficits in learning, social integration and memory including IQ deficits (ATSDR 2007). Table B.5-1 lists the various blood lead levels associated with health and physiological impairments in children and adults.

Table B.5-1 Blood lead levels and associated health and physiological effects in children and adults

Blood lead level (µmol/L)	Blood lead level (µg/dL)	Children	Adults
< 0.24	< 5	Deficits in cognitive and academic skills (as concluded by Lanphear et al. 2000, 2005, Bellinger & Needleman 2003, Canfield et al. 2003, Jusko et al. 2008).	Early signs of hypertension ALA-D inhibition
0.48 – 0.72	10 - 15	Crosses placenta Neuro-developmental effects ALA-D inhibition Impairment of IQ Increased erythrocyte protoporphyrin Reduced gestational age and birth weight	
0.72 – 0.97	15 - 20		Increased erythrocyte protoporphyrin
0.97 – 1.45	20 - 30	Altered CNS electrophysical response Interference with Vitamin D metabolism	
1.45 – 1.93	30 - 40	Reduced hemoglobin synthesis Peripheral nerve dysfunction	Systolic hypertension Altered testicular function Peripheral nerve dysfunction
1.93 – 2.41	40 - 50		Reduced hemoglobin synthesis Overt subencephalopathic neurologic symptoms
2.90	60	Peripheral neuropathy	Reproductive effects in females
3.38	70	Anemia	
3.86 – 4.83	80 - 100	Encephalopathy symptoms Chronic nephropathy Colic and other gastrointestinal symptoms	Anemia Chronic nephropathy Encephalopathy symptoms

Source: Adapted from Godish (2000), *Indoor Environmental Quality*, Lewis Publishers, 2001

B.5.6 Exposure

The primary exposure routes for lead to enter the body are:

- Inhalation
- Ingestion
- Dermal (indirect)

Once lead enters the body it travels in the bloodstream and some of it is absorbed into soft tissues, such as kidneys, pancreas, lungs, brain, spleen, muscles and heart, and the rest may be stored for long periods of time in teeth and bones. Adults store 94 per cent while children store 73 per cent of the lead in their bodies in the bones. The stored lead may be released again into the bloodstream, especially in times of calcium deficiency or calcium stress, such as pregnancy, lactation or osteoporosis.

- **Lead exposure in children**

Direct and indirect exposures to lead-based paint can be a predominant contributor to blood lead levels $\geq 0.48 \mu\text{mol/L}$ ($\geq 10 \mu\text{g/dL}$)* in children (Godish 2000). Both ingestion and inhalation are important indoor exposure pathways (Figure B.5-1). Exposure to lead among children can be described by using an exposure model (Godish 2000). The model, Figure B.5-1, displays the various factors leading to elevated blood lead levels in children. Based on epidemiological investigations, 41 per cent of the lead in house dust was linked to paint and 18 per cent to soil transported indoors from outdoors by individuals and pets. House dust and lead in the soil are directly linked to elevated blood lead levels in children. Children ingest significant amounts of dust and paint flakes through their natural habit of putting things, including fingers, in their mouths. If these lead particles have aerodynamic diameters $< 10\mu\text{m}$, they can be inhaled (Godish 2000).

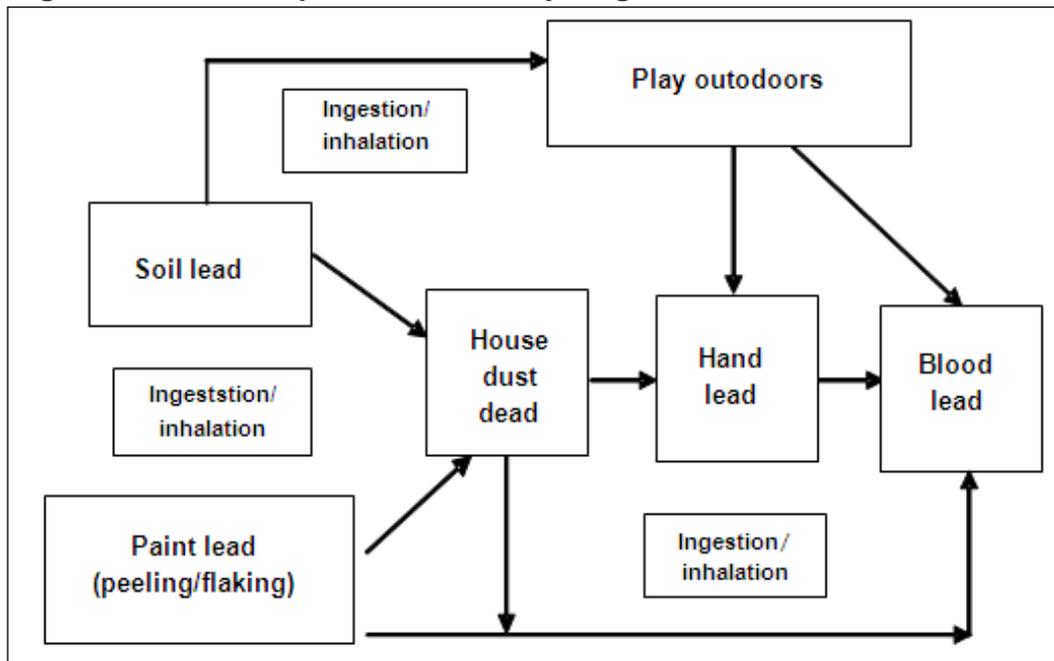
*Previous “high” blood lead levels were determined by the CDC. The current level has been halved to $0.24 \mu\text{mol/L}$ ($\geq 5 \mu\text{g/dL}$).

B.5.6.1 Biomarkers of exposure

Lead concentration in whole blood is the traditional biomarker used to monitor lead exposure. The blood lead level is an appropriate indicator of recent lead absorption. Although most of the body’s lead is stored in bones and only about one per cent of the total body burden of lead is stored in the blood (Godish 2000), the blood lead level correlates most closely with recent environmental exposure (Godish 2000). The half-life of lead in blood is short and is approximately 36 days \pm 5 days. During the early phases of exposure, blood lead levels rise rapidly indicating recent lead exposure.

Urinary lead concentrations also have been used to assess exposure. However, its use as a potential biomarker is not common because of the varying concentrations of lead in the excreted urine (ATSDR 1999). It is more appropriately used in occupational settings where lead exposures can potentially be very high.

Figure B.5-1 Lead exposure model for young children¹



¹Exposure to lead in this model can occur through both the inhalation and ingestion pathways
 Source: Godish (2000), *Adapted and modified From Chapter Two Inorganic Contaminants: asbestos/radon/lead, Indoor Environmental Quality GodishT. (2000), Lewis publishers.*

B.5.6.2 Standards and regulations for lead

Health Canada’s current blood lead intervention level is 10 micrograms per deciliter (µg/dL) or 0.48 micromoles per litre (µmol/L). This concentration should not be interpreted as a threshold for toxicity. For blood lead level concentrations ≥ 10 µg/dL or ≥ 0.48 µmol/L, actions are recommended to reduce lead exposure.

Health Canada, who created this guideline in 1994, began the process to review the guideline in 2011. In July 2011, Health Canada released a *Proposed Risk Management Strategy for Lead and Draft Human Health State of the Science Report on Lead*. As this guideline is used by all provinces, consultation between Health Canada and the provinces will occur through 2012 to reach a common agreement on the science and policy direction for a new guideline. The new guideline is expected in 2013. See the following links: http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/prms_lead-psgr_plomb/index-eng.php#aes and <http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/dhhssrl-rpecscepsh/index-eng.php>

Other lead exposure and lead concentrations from other regulatory agencies and organizations include:

- **Blood lead**

- In 1991 a blood lead level of 0.48 µmol/L (10 µg/dL) was adopted by U.S. Centers for Disease Control and Prevention (CDC) as an action level for children, making it necessary to establish environmental and educational intervention to eliminate high exposure to lead (CDC 1991). In 2012, CDC

lowered the lead action level to 0.24 $\mu\text{mol/L}$ (5 $\mu\text{g/dL}$) based on a recommendation from their Advisory Committee on Childhood Lead Poisoning and Prevention (ACCLPP) and on emerging evidence provided by various research groups (Lanphear et al. 2000, Lanphear et al. 2005, Bellinger & Needleman 2003, Canfield et al. 2003, Jusko et al. 2008). Studies have found several health effects, such as cognitive and academic skills deficits, can occur in children with blood lead levels < 0.48 $\mu\text{mol/L}$ (< 10 $\mu\text{g/dL}$).

- The Australian Government through the National Health and Medical Research Council (NHMRC) recommends a blood lead level below 0.48 $\mu\text{mol/L}$ (10 $\mu\text{g/dL}$) for all Australians (NHMRC 2009).
- The U.S. Centers for Disease Control and Prevention recently agreed to the recommendation from their Advisory Committee on Childhood Lead Poisoning and Prevention (ACCLPP) to cut its threshold level for defining lead poisoning in children to 0.24 $\mu\text{mol/L}$ (5 $\mu\text{g/dL}$) from 0.48 $\mu\text{mol/L}$ (10 $\mu\text{g/dL}$), marking the first such reduction in 20 years (ACCLPP 2012, CDC 2012a, 2012b).
- In Alberta, a worker with either a blood lead level greater than 2.5 $\mu\text{mol/L}$ or symptoms diagnosed as a result of lead exposure is considered to have lead poisoning. The Director of Medical Services must be notified if a worker has a blood lead level of 2.5 $\mu\text{mol/L}$ or greater. Female workers of childbearing age who are pregnant or considering becoming pregnant should be monitored. Female workers need to have a health assessment at the same frequency as other workers. However, the blood lead level should be kept below 0.5 $\mu\text{mol/L}$ (Government of Alberta 2009).

- **Occupational exposure**

OSHA (Occupational Safety and Health Administration) Lead Standard (US OSHA 1997) limits the amount of lead in the air in the workplace. Under the OSHA regulation, if any employee is exposed above the action level, the employer must set up an air monitoring program to determine the exposure level of all exposed workers. They are as follows:

- ▶ Action level (AL) of 30 $\mu\text{g/m}^3$ of lead as an average over an eight-hour day. Action Level means employee exposure, without regard to the use of respirators.
- ▶ Permissible exposure limit (PEL) of 50 $\mu\text{g/m}^3$ averaged over an eight-hour workday. This is the highest level of lead in the air which you may be legally exposed.
- ▶ Under this program, the blood lead level of all employees who are exposed to lead above the action level of 30 $\mu\text{g/m}^3$ is to be determined at least every six months. A blood lead level of 1.93 $\mu\text{mol/L}$ (40 $\mu\text{g/dL}$) will require a written notification and medical exam, a blood lead level of 2.90 $\mu\text{mol/L}$ (60 $\mu\text{g/dL}$) is cause for medical removal from exposure.

- **Indoor lead**

- Health Canada has not established any standards or criteria for indoor lead parameters but supports minimizing exposure by developing regulations that restrict the use of lead in consumer products.
- The Government of Canada amended the Surface Coating Materials Regulations in 2010 to significantly lower the level of total lead in paints and other surface-coating materials, including the surface-coatings of materials applied to furniture and other articles for children, such as toys, equipment and other products, from 600 mg/kg to 90 mg/kg. This new level is equivalent to a lead concentration of 0.009% (Hazardous Products Act 2010).
- To help protect small children, the U.S. Consumer Product Safety Commission set the acceptable limit for lead indoor paints available to the public at $\leq 0.009\%$ (w/w). Products designed or intended primarily for children 12 years old and younger cannot contain more than 300 ppm of lead as of August 14, 2011 (US CPSIA 2008).
- U.S. Department of Housing has developed the Residential Lead Hazard Standards (Toxic Substance Control Act section 403) (USEPA 2001e) for dust-lead clearances. They are as follows:
 - ▶ Floor: 431 micrograms of lead in dust per square metre ($\mu\text{g}/\text{m}^2$) or 40 micrograms of lead in dust per square foot ($\mu\text{g}/\text{ft}^2$)
 - ▶ Window sills: 2,691 $\mu\text{g}/\text{m}^2$ or 250 $\mu\text{g}/\text{ft}^2$ of dust on interior window sills

- **Ambient air**

- The Alberta Ambient Air Quality Objective (AAQO) for lead, effective since 1999 is 1.5 $\mu\text{g}/\text{m}^3$ one hour average (AESRD 2011).
- The Ontario Ministry of Environment (MOE 2007) set the following Ambient Air Quality Standards for Lead and Lead Compounds:
 - ▶ A 30-day ambient air quality criterion (AAQC) of 0.2 $\mu\text{g}/\text{m}^3$ of air for lead and its compounds, based on neurological effects in children
 - ▶ A 24-hour AAQC of 0.5 $\mu\text{g}/\text{m}^3$ of air for lead and its compounds, based on neurological effects in children
 - ▶ A half-hour standard of 1.5 $\mu\text{g}/\text{m}^3$ of air for lead and its compounds, based on neurological effects in children.
- The USEPA issued a final ruling in 2008 that revised the National Ambient Air Quality Standards (NAAQS) for lead, setting the standard as 0.15 $\mu\text{g}/\text{m}^3$ rolling three-month average. However, the 1978 lead standard of 1.5 $\mu\text{g}/\text{m}^3$ as a quarterly average remained in effect until one year after an area was designated for the 2008 standard. However, in areas designated non-attainment for the 1978, the 1978 standard remains in effect until plans to attain or maintain the 2008 standard are approved (USEPA 2008).
- The European Union set the lead health based Air Quality Standard as 0.5 $\mu\text{g}/\text{m}^3$ (annual average) (EU Environment 2012, Environmental Protection UK 2009).

- WHO's ambient air quality standard for lead, established in 1987, ranges from 0.5 µg/m³ to 1.0 µg/m³ (annual average) (WHO 2000).
- **Soil lead**
 - Alberta Environment and Sustainable Development (2010) Tier 1 criteria for lead-contaminated soils in residential areas is 140 ppm, based on the chronic health risks associated with incidental soil inhalation and ingestion associated with soil disturbance, such as play activities.

B.5.7 Control measures

To minimize the exposure and absorption of airborne lead, especially in children, observe the following steps (CDC 2009, Health Canada 2007, Health Canada 2011):

- Keep areas where children play dust-free and clean. Wash toys often.
- Leave lead-based paint undisturbed if it is in good condition; do not sand or burn off paint that may contain lead.
- Clean up paint chips and peeling paint by wet washing.
- Seek professional help during renovations when removing lead paint.
- Use proper safety measures when renovating or remodeling older homes:
 - Keep children and pregnant women away from work areas until renovations are complete and the area has been thoroughly cleaned.
 - Use heavy plastic below the work area to contain dust and paint chips.
 - Wet the surface before sanding.
 - Change clothes and shoes, and wash hands before leaving the work area.
 - Clean the work area with water containing detergent.
- Do not bring lead dust into the home. If your work or hobby involves lead, take measures to avoid bringing lead particles indoors. For example, remove shoes and change clothes when coming indoors so lead dust is not tracked inside.
- Launder work clothes separately from the rest of other clothes.
- When using lead or lead products, such as indoor hobbies including stained glasswork, ensure the area is well-ventilated and always wear a HEPA filter. Wash floors, counter tops and window sills often with an all-purpose detergent.
- Whenever possible, replace lead solder with no-lead solder:
- Remove from the house any horizontal PVC (plastic) mini-blinds made in Asia or Mexico, especially if there are children six years of age or under.
- Ensure you and your family eat a balanced diet that is rich in calcium, iron and vitamin C to minimize lead absorption.
- Wash children's hands, mouth and face before eating and drinking.
- Do not smoke and avoid second-hand smoke.

B.5.8 Renovation and repair for lead-based paint in homes

Lead was used as a white pigment in paint until the mid-1950s. Some paints contained as much as 50 per cent lead by weight in the dried film. Even after the introduction of titanium-based pigments, lead was still used in smaller amounts as a drying agent in alkyd paints.

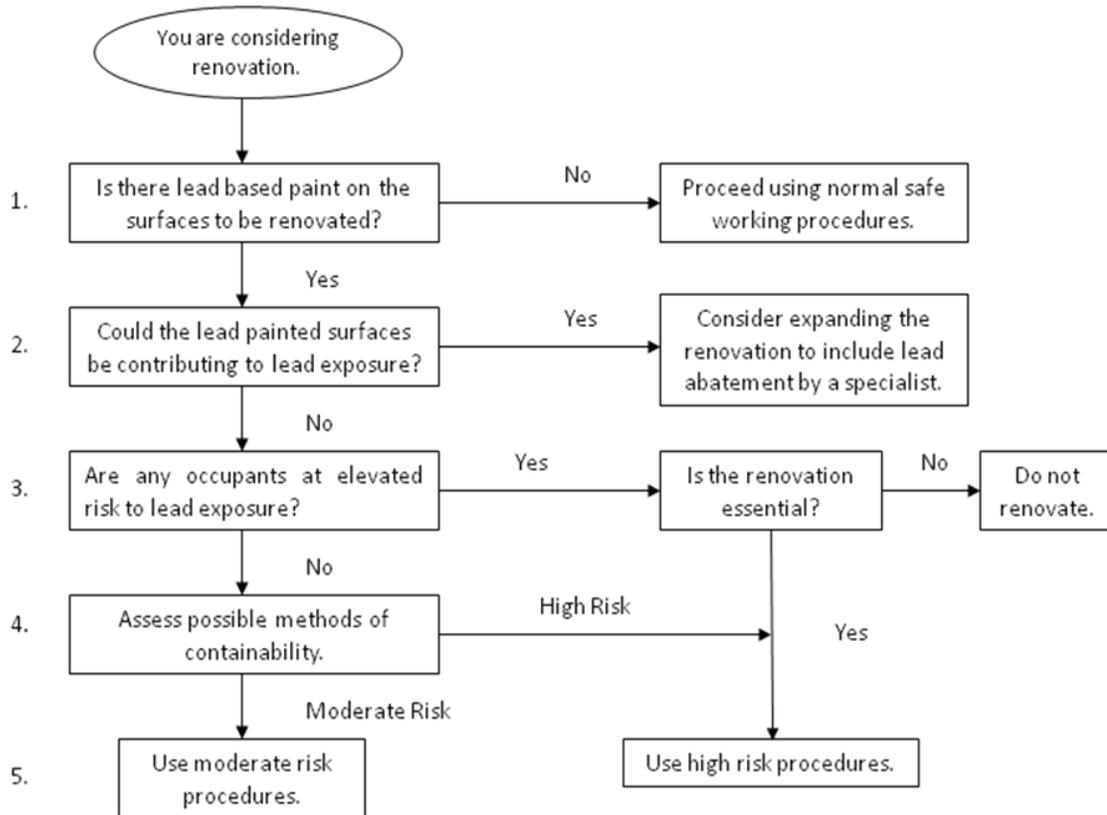
In 1976, the federal government passed regulations under the Hazardous Products Act limiting the amount of lead in interior paint to 0.5 per cent by weight, allowing higher concentrations of lead in exterior paints as long as a warning label was present in the product. In 1990, members of the Canadian Paint and Coating Association agreed to eliminate all added lead from their products.

Virtually none of the paint available to consumers today contains any added lead. For buildings constructed prior to 1950, the presence of lead-containing paints should be assumed, unless they have already been renovated. Smaller amounts of lead are also a possibility in buildings constructed between 1950 and 1980. In October 2010, the Government of Canada amended the Surface Coating Materials Regulations to significantly lower the level of total lead in paints and other surface coating materials, including the surface coatings of materials applied to furniture and other articles for children, such as toys, equipment and other products, from 600 mg/kg to 90 mg/kg - which is equivalent to a lead concentration of 0.009 per cent (Hazardous Products Act 2010).

Surveys in the United States have found that 74 per cent of privately owned housing built before 1980 contains some lead-based paint (USEPA 1995, Stevenson 1992, CMHC 2004). In 2011, Health Canada completed a statistically representative national baseline study for lead concentrations in dust sampled from urban households, entitled *The Canadian House Dust Study*, to provide a national baseline for lead concentrations in urban house dust to support its risk assessment and risk management activities. *The Canadian House Dust Study*, conducted between 2007 and 2010, found that only one per cent of homes had a wipe sample that exceeded the USEPA regulation for lead in floor dust of 431 $\mu\text{g}/\text{m}^2$ (40 $\mu\text{g}/\text{ft}^2$) (USEPA 2001e). Other results show that 90 per cent of urban Canadian homes have dust lead levels below 250 ppm. Of all those homes, 33 per cent were built before 1960, which indicates that renovations in older homes to remove lead paint and other sources of exposure have been effective. The study also revealed that lead is not only found in older homes, as 10 per cent of homes with lead concentration above 250 ppm were built after 1980. (McDonald et al. 2010, 2011; Rasmussen et al. 2011)

If lead-based paint is in good condition or covered by newer lead-free paint, the best choice may be to leave it alone. Disturbing the paint may result in lead-dust production. The Canada Mortgage and Housing Corporation (CMHC) created a diagram of a decision making process for hazard identification and harm reduction steps related to paint removal and renovations of private homes. This decision tree (Figure B.5-2) helps homeowners plan the most appropriate steps to follow when considering renovating an older home (CMHC, 1992).

Figure B.5-2: Decision-making process for homeowners considering renovation of an older home



Source: Canada Mortgage and Housing Corporation (CMHC). *Lead Precautionary Measures*, 1992. All rights reserved. Reproduced with the consent of CMHC. All other uses and reproductions of this material are expressly prohibited.

If doing nothing is not an option, any of the following lead abatement methods can be followed: encapsulation, replacement, enclosure and paint removal (CMHC, 1992, USEPA 2004).

- **Encapsulation**

Encapsulation is the process used to seal off the lead-based paint surfaces by providing a barrier between the lead-based paint and the environment. The barrier is formed by applying a liquid coating or an adhesively bonded covering material to reduce occupant exposure. One of the disadvantages of this method is that lead paint dust can become a problem if the encapsulated surface suffers damage or undergoes future renovations.

- **Replacement**

Replacement consists on removing any lead-based painted building part, such as windows, frames, doors, trim, and replacing it with a new one, painted with lead-free paint. One disadvantage of this method is that can create dust because it can involve some demolition work. To keep lead dust levels down proper dust control measures, such as wet misting the area and using a HEPA (high efficiency particulate air) vacuum

- **Enclosure**

Enclosure means creating a solid, dust-tight barrier around the lead-based surface or structure. An enclosure keeps the lead-based paint away from the rest of the building and its occupants. Materials used to build enclosures include: tile, vinyl, underlayment, aluminum, paneling, fiber board, plywood, drywall, acrylic sheets.

- **Paint Removal**

Remove lead-based paint using one or more of the following methods:

- Wet scraping down to the substrate
- Wet planning
- Using electric heat guns
- Using local-exhaust hand tools
- Chemical stripping
- Vacuum and water blasting (exterior only)

Removal methods will generate a lot of dust and waste. To keep lead dust levels down it is essential to wet mist work areas and the use of a HEPA (High Efficiency Particulate Air) vacuum. The debris should be cleaned up as work goes on.

Lead abatement requires specialized knowledge and it is always best to hire a licensed contractor, especially when abatement involves large areas. Homeowners can repair minor problem areas by following the safety rules and procedures outlined below¹:

- **Safety precautions for small renovation projects**

When doing small-scale renovation projects, such as one room, or any project involving repair, enclosure, or demolition, the following safety precautions should be taken:

1. Isolate the work area using plastic sheets or tarps to create an air-tight seal. Cover all recesses and cavities where dust may accumulate. Cover carpets with ripstop plastic sheets sealed along the perimeter edges using tape.
2. Once the work has begun, wear disposable overalls, footwear and head coverings. Alternatively, clothing can be washed providing that they are washed twice and air-dried. HEPA-cartridge respirators should be worn at all times inside the work area. Remove contaminated clothing in the work area—except respirators—and wash hands, face and respirator. Do not wet filters immediately upon re-entry into a clean area. Keep susceptible population groups out of the work area, such as pregnant women, children, especially those six years of age and under, and people with high blood pressure.
3. Do not use a heat gun or sander to strip surfaces coated with lead-based paint. Sanding sends a cloud of lead-laden dust throughout the home and stripping with a heat gun vaporizes the paint, creating lead fumes. Alternative stripping methods include scraping by hand or the use of paint removers.

¹ Adapted from the following publications: Lead Precautionary Measures, CMHC 1992; Residential Lead-Based Paint Abatement. USEPA 2004; About Your House: Lead in Older Homes, CMHC 2005.; Steps to Lead Safe Renovation, Repair and Painting, USEPA 2011

4. If possible use a high-efficiency particulate air (HEPA) filter-equipped vacuum cleaner with the motor located outdoors or indoors to create negative pressure in the work area. If locating the HEPA filter-equipped vacuum cleaner indoors, ensure that the integrity of the filter and filter assembly have been tested, such as the DOP test.
5. Do not eat, drink, or smoke while removing the paint, and practice good hygiene habits, such as thorough handwashing.
6. Follow other specified precautions when using paint remover. For example, do not use paint removers that have solvents or that may be an explosion or inhalation hazard. Instead, the use of non-toxic, nonsolvent paint removers is recommended.
7. During paint removal, mist the air with a fine spray of water to reduce airborne lead-dust levels. Turn off electrical items to reduce the risk of electrocution.
8. Clean the area thoroughly after completing the work, such as removing all dust and paint chips. Other cleaning tasks include:
 - ▶ Use a HEPA-filter-equipped vacuum to clean all work area surfaces.
 - ▶ Wash all work area surfaces with a five percent solution of trisodium phosphate (TSP).
 - ▶ Allow surfaces to dry and vacuum them again.
9. Apply sealer, paint or primer to all surfaces in the work area. Sealers used in the asbestos industry are appropriate and can be purchased from local safety supply retailers.
10. After drying, clean all surfaces:
 - ▶ HEPA vacuum the work area.
 - ▶ Wash all work area surfaces with TSP.
 - ▶ HEPA vacuum.
11. If you do not have a HEPA filter-equipped vacuum cleaner, the use of a wet vacuum cleaner is acceptable, but the surfaces being cleaned must be wet and the vacuuming must occur at the end of the two wash cycles rather than in the middle. The wet vacuum cleaner will be contaminated with lead dust after use and therefore decontamination is recommended.
12. As an option, area dust samples can be collected to confirm the work area is ready for re-occupancy. Collect a sample by wiping a 900 cm² template (one square foot) with a commercially available wet-wipe or moistened towelette and place it in a re-sealable plastic bag. Wear disposable gloves when collecting the sample.
13. Remove all polyethylene sheeting; the area is now ready for re-occupancy. As a precaution, wash the area immediately with a mild solution of TSP, approximately once each week for four weeks.
14. Call appropriate authorities, such as the municipality or provincial environment department before disposing of lead-containing waste products. Homeowners

may dispose lead-containing materials by double-bagging them in regular garbage bags and labeling them appropriately. The garbage collector should be made aware of the lead-containing waste products. However, contractors should dispose of lead waste appropriately at approved landfill facilities.

- **Procedures for enclosure, encapsulation and minor repair of localized damaged paint:**

- Turn off the ventilatory system.
- Tape a polyethylene sheet below the repair area to capture any debris. Seal all openings and cracks in the vicinity where dust might accumulate.
- Ensure other occupants do not have access to the room where the repair work is being done.
- Wear protective equipment, such as a HEPA respirator.
- Lightly mist the area to be repaired with water.
- Complete the repair work. During work, mist the air frequently with water so that airborne dust will settle onto the surface of the polyethylene.
- Bag waste immediately and clean the work area and vicinity thoroughly. Wash with TSP twice. Dispose of the polyethylene drop sheet as contaminated waste.
- Wash hands, face and respirator after all work is completed.

- **Procedures for large-scale removal projects**

For large-scale projects involving a whole house or multiple rooms, the following safety precautions, in addition to those recommended for small-scale removal projects, apply:

15. Install a clean change room and a dirty room between the work area and non-contaminated area, with S-shaped curtain doorways between each room. The dirty room is used for removing contaminated clothing and washing hands and face before leaving the work area (Leave the respirator on). The clean room is used for re-washing hands and face and for storing street clothing. Workers should take a shower at the end of each day's work.
16. Create negative airflow in the work area, if required, by installing a negative air fan unit equipped with a HEPA filter to exhaust inside air outside.
17. The use of specialized contractors is recommended to complete large-scale projects.

The general mitigation procedures for lead are similar to the protocols developed for asbestos. The reader should refer to *Alberta Asbestos Abatement Manual* (Government of Alberta 2011) for more information. For additional information on lead-based paint, their control and abatement, the reader is also advised to refer to an Alberta Health Services pamphlet titled *Recommended Guidelines for the Removal of Lead-Based Paints* (Alberta Health Services 2011) and the publication *Lead at the Work Site*, from Workplace Health and Safety-Work Safe Alberta (Government of Alberta 2009).

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Appendix C

Environmental tobacco smoke

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C. Environmental tobacco smoke (ETS)

C.1 Introduction

Environmental tobacco smoke (ETS) refers to exposure to tobacco smoke—not from direct smoking—but from being exposed to someone else's cigarette, cigar or pipe smoke. ETS can also be described as the substances in indoor air that originate from tobacco smoke.

Breathing in ETS is known as passive smoking, second-hand smoke or involuntary smoking (CCOHS, 2011).

ETS is a complex mixture of gaseous, volatile, semivolatile and nonvolatile combustion byproducts consisting of up to 4,000 compounds. Many of these compounds are known or suspected carcinogens, toxicants, asphyxiants and irritants (USEPA 2012). Some of the toxic contaminants isolated from ETS include tar, nicotine, CO, NO₂, HCN, acrolein, nitrosamines and formaldehyde. Approximately 50 chemicals are classified as known or suspected carcinogens, including vinyl chloride, 2-naphthylamine, benzene, benzo(a)pyrene, formaldehyde and nitrosamines (Health Canada 1995, 2002).

ETS exposure consists of both mainstream and sidestream smoke. The smoke that is inhaled and then exhaled from the smoker's lungs is called mainstream smoke (MS). Sidestream (SS) smoke is the smoke that comes from the burning end of a cigarette, cigar or pipe (OOCHS, 2011). SS smoke and MS smoke differ in their physical and chemical characteristics. SS smoke is produced at lower temperatures than MS smoke and under strong chemically reducing conditions. SS smoke comprises approximately 85 per cent of the total mass of a consumed cigarette. Because of lower temperatures, chemical contaminant concentrations are higher in SS smoke than in MS smoke. For example, emissions of n-nitrodimethylamine are 20 to 100 times greater in SS smoke than in MS smoke (Godish 2000). ETS undergoes physical and chemical changes as it ages. For instance, volatilization from the particulate phase of ETS results in a decrease of the mass median diameter of smoke particles. As a consequence, there is increased lung deposition in both non-smokers and smokers (Godish 2000). Also, NO is converted to the more toxic NO₂.

The 2006 US Surgeon General's report concludes that there are increased risks of coronary heart disease morbidity and mortality among men and women exposed to second-hand smoke. This conclusion is further supported by CDC in its October 2009 report, *Second-hand Smoke Exposure and Cardiovascular Effects*, indicating that there is about a 25% to 30% increase in the risk of coronary heart disease from exposure to second-hand smoke.

Exposure to ETS can cause lung cancer in adults who do not smoke and causes approximately 3,000 lung cancer deaths per year in non-smokers in United State and also increases the risk of heart disease. Living with a smoker is associated with an estimated 20 % to 30 % increased risk of lung cancer (USEPA, 2012). It is estimated that exposure to

second-hand smoke causes between 1,100 and 7,800 deaths per year in Canada (Collishaw & Meldrum, 2002).

Among children, exposure to ETS has been reported to increase the risk of childhood cough and wheeze, admission to hospital for respiratory illness and sudden infant death syndrome. Exposure to ETS also slows lung growth (US Surgeon General's report, 2006). It is also important to know that chemical residue is still present on surfaces even after the smoke clears. Normal childhood behaviours, such as putting objects in their mouths, can increase the risk of children being in contact with these ETS residues (Saskatchewan Prevention Institute, 2002).

C.2 Toxicology and mechanisms of toxicology

The mechanism of ETS toxicity is complex because of the large number of both carcinogenic and non-carcinogenic chemical constituents. Several possible mechanisms have been reported on the relationship between ETS exposure and coronary heart disease (Kawachi 1998, cited in Repace *et.al.* 1999). Those mechanisms include carboxyhemoglobinemia, increased platelet aggregability and increased fibrinogen levels (Penn and Snyder 1996, cited in Repace *et.al.* 1999) in blood. Refer to the "Health Effects" section for other toxicological effects of ETS.

Synergistic interactions among ETS constituents are believed to occur but are difficult to demonstrate, especially in humans. Takayami *et.al.* (1989) explored synergistic interactions in an animal study involving the dietary exposure to a mixture of 40 known carcinogens. These carcinogens were administered daily to male rats at 1/50th of the TD₅₀ (the acutely toxic dose producing 50 per cent mortality) over a two-year period. The synergistic effects of these carcinogens were manifested by the unanticipated increases in the number of liver and thyroid tumours observed in test animals. Of the forty carcinogens, 20 were identified as liver carcinogens and 5 were thyroid carcinogens. The tumours were observed in spite of the fact that each carcinogen was administered at a dose where no tumours were expected in test animals (Krewski and Thomas 1992).

C.3 Health effects

C.3.1 Diseases and conditions

Second-hand smoke contains more than 7,000 chemicals. Hundreds are toxic, and about 70 can cause cancer (U.S. Department of Health and Human Services, 2010). In children, second-hand smoke can cause ear infections, more severe asthma, respiratory infections, and sudden infant death syndrome (SIDS). In adults who have never smoked, second-hand smoke can cause heart disease and/or lung cancer (U.S. DHSS, 2006).

Since 1992, six major scientific reviews of the health effects of second-hand tobacco smoke have been published (U.S.EPA, 1992; the Australian National Health and Medical Research Council, 1997; California EPA, 1997; the United Kingdom Scientific Committee on Tobacco and Health, 1998; WHO, 1999; the US. DHSS. National Toxicology Program, 2000). These include four developmental diseases or conditions, seven respiratory diseases or conditions, three cancers and coronary heart disease. Other recent research pointed to previously unrecognized effects of exposure to second-hand smoke, including risks for cerebrovascular disease (You *et.al.*1999, Bonita *et.al.*1999) and breast cancer (Johnson *et al*, 2000).

The above scientific reviews have identified 15 major disease groups or conditions as known or suspected to be caused by exposure to second-hand smoke (See Table C-2). These diseases and conditions can be grouped according to different health effects including developmental effects, respiratory effects, cancers and coronary heart disease. From Table C-2 it is clear that there is a remarkable scientific consensus that exposure to second-hand smoke is a known or suspected cause of a variety of diseases and conditions.

C.3.2 Developmental effects

- **Fetal growth including low birth-weight or small for gestational age**

The adverse effects of parental smoking on fetal growth have been well known and documented for some time (WHO 1999). Exposure of pregnant non-smokers to ETS is causally associated with reduced fetal growth (WHO 1999, USEPA 1992). More than thirty research studies have reported adverse effects on fetal growth in non-smoking pregnant women exposed to ETS. This health effect is supported by several experimental animal studies (Witschi 1997, WHO 1999).

- **Sudden infant death syndrome (SIDS)**

Infants whose mothers smoked during pregnancy and those exposed to second-hand smoke after birth have an increased risk of SIDS. The risk of SIDS increases with the number of smokers in the household, the number of cigarettes smoked and the proximity of the smokers to the infant. There were 113 deaths from SIDS in Canada in 2007 (Statistics, 2011). Research has shown that in 2002 nearly one-third of SIDS deaths were because of smoking <http://www.hc-sc.gc.ca/hc-ps/tobac-tabac/legislation/label-etiquette/death-mort-eng.php> - note7. Infant bed-sharing increases the risk of SIDS, particularly among infants of mothers who smoke. Some of the chemicals in tobacco smoke alter the development of an infant's brain and the lungs. This in turn affects how an infant breathes and may be responsible for SIDS. (Health Canada 2007).

- **Spontaneous abortion**

Epidemiology studies suggested that non-smoking pregnant women exposed to ETS are at increased risk of spontaneous abortion. (George *et.al.*, 2006; Blanco-Muñoz *et.al.* 2009). Tobacco contains several components that are toxic for the developing embryo: nicotine, carbon monoxide, and mutagens (Stillman *et.al.*1986). Nicotine has a vasoconstricting effect that reduces the flow to the placenta (Economides & Braithwaite, 1994). Carbon monoxide attaches to hemoglobin and displaces oxygen, which causes maternal as well as fetal hypoxia. Tobacco has also been associated with inhibition of the aromatization of granulose cells and, as a consequence, with insufficiency of the corpus luteum (Gocze *et.al.* 1999). All of these mechanisms could decrease the viability of the product and increase the risk of spontaneous abortion.

- **Adverse effect on cognition and behaviour**

Although the effects of prenatal and postnatal ETS exposure on cognition and behaviour remain unclear, when compared to children of non-smokers, children of smokers perform more poorly in school. They also have lower scores in cognitive functioning tests, in particular, language and auditory processing, and have more behavioural problems including conduct disorders, hyperactivity and decreased attention spans. Cognitive and behavioural deficits in children have lifelong consequences and result in increased costs for education and social services (WHO, 1999).

C.3.2.1 Respiratory effects in children

- **Acute lower respiratory tract infections in children, such as bronchitis and pneumonia**

Many studies have provided evidence that ETS is causally associated with an increased risk of lower respiratory-tract infections among infants and very young children of smoking parents (USEPA 1992, WHO 1999). Spengler *et.al.* (2001) summarized several studies that demonstrated a significantly increased frequency of bronchitis and pneumonia in infants during their first year.

- **Asthma induction and exacerbation**

Exposure to ETS can cause asthma in children. Increased incidence of lower respiratory tract infection in early age and inflammation of the respiratory epithelium, associated with ETS exposure in children, can lead to asthma. Infants, whose mothers have smoked during the pregnancy, had increased airways responsiveness (a characteristic of asthma), compared with those born of non-smoking mothers. Although, a clear mechanism has not yet been established, epidemiological data strongly associates ETS exposure to the development of childhood asthma (Cal EPA 1997, cited in Samet and Wang 2001).

- **Exacerbation of cystic fibrosis**

Children with cystic fibrosis are likely to be more sensitive than healthy individuals. Several studies of patients with cystic fibrosis, a disease characterized by recurrent and chronic pulmonary infections, suggest that ETS can exacerbate the condition (U.S. National Cancer Institute, 1999).

- **Respiratory symptoms**

Common respiratory symptoms, such as cough, phlegm and wheezing, have been reported in the children of smoker parents (Cal EPA 1997, USDHHS 1986, cited in Samet and Wang 2001). In a large study of 10,000 children from six cities in the United States, an increased incidence of coughing, persistent wheezing and phlegm was reported among those exposed to ETS from their smoker parents (Samet and Wang 2001).

- **Middle ear disease in children**

Otitis media or middle-ear disease is one of the common diseases diagnosed in children. Various forms of middle ear disease include acute, persistent or recurrent forms and involve fluid discharge into the middle ear (behind the ear drum) that can lead to hearing loss (Samet and Wang 2001). Based on several case control and cohort studies, California EPA (1997) and WHO (1999) concluded that there is a causal association between ETS exposure and acute and chronic middle-ear disease (Samet and Wang 2001).

- **Decreased pulmonary function**

ETS exposure affects lung growth in the maturing lungs of children whose parents smoke, a decreased expiratory flow rate also has been observed among these children (Samet and Wang 2001, Spengler *et.al.* 2001). USDHHS (1984) concluded that the children of smoking parents had small reductions of lung function in comparison with those of non-smoker parents.

C.3.2.2 Carcinogenic effects

- **Lung cancer and nasal sinus cancer**

Based on several epidemiological studies, Hackshaw *et.al.* (1997) concluded that “the epidemiological and biochemical evidence on exposure to environmental tobacco smoke, with the supporting evidence of tobacco specific carcinogens in the blood and urine of non-smokers exposed to environmental tobacco smoke, provides compelling confirmation that breathing other people’s tobacco smoke is a cause of lung cancer.” (Hackshaw *et.al.*, 1997)

As ETS smoke contains compounds of known or suspected carcinogenicity, exposed non-smokers are at increased risk for a variety of cancers. Lung and sinus cancer rates in non-smokers are elevated by ETS exposure (US Surgeon General 1986, WHO 1999, NCI 2000). There are other cancers associated with ETS exposure. Cigarette and cigar smokers are at increased risk for cancer of throat, mouth, tongue, lip, larynx, pharynx, urinary bladder and renal pelvis (part of the urethra that receives urine from the kidney), kidney and pancreas (US National Cancer Institute 2000, cited in Baker *et.al.*, 2000, NIEHS 2001). ETS is also associated with cancers of the stomach and cervix. However, additional epidemiological evidence is required to causally associate ETS to the other forms of cancer described above (Colman 2001).

- **Cervical cancer**

ETS is a probable cause of cervical cancer in women (IARC, 1986; U.S. DHHS, 1989). The epidemiological and biochemical evidence suggests that exposure to ETS may increase the risk of cervical cancer. Positive associations were observed in epidemiology studies. Findings of DNA adducts in the cervical epithelium as well as nicotine and

cotinine in the cervical mucus of ETS-exposed non-smokers provides biological plausibility (US National Cancer Institute, 1999).

C.3.2.3 Cardiovascular effects

- **Coronary heart disease (CHD)**

Many epidemiologic data conducted in diverse populations, in males and in females, in western and eastern countries, are supportive of a causal association between ETS exposure from spouses and CHD mortality in non-smokers. Clinical studies also suggest various mechanisms for a causal association between ETS and heart disease. In non-smokers exposed to ETS, the concentration of endothelial prostacyclin (PGI₂) required to inhibit platelet aggregation increased 40% to 70%. There was also an increase in the number of desquamating endothelial cells in non-smokers exposed to ETS (US National Cancer Institute, 1999). The U.S. Surgeon General's Report 2006 also concludes that available evidence is sufficient to infer a causal relationship between exposure to ETS and increased risks of CHD morbidity and mortality among both men and women. Pooled relative risks from meta-analyses indicate a 25% to 30% increase in the risk of CHD from exposure to ETS (CDC, 2009).

Table C-1 Summary of conclusions of six major reviews concerning exposure to second-hand smoke as a cause or possible cause of various diseases and conditions

Summary of conclusions of six major reviews concerning exposure to second-hand smoke as a cause or possible cause of various diseases and conditions						
<i>Disease or condition</i>	<i>1992 US EPA</i>	<i>1997 Australian NHMRC</i>	<i>1997 Cal EPA</i>	<i>1998 UK SCOTh</i>	<i>1999 WHO</i>	<i>2000 US National Toxicology Program</i>
Development effects						
Fetal growth: low birth weight or small for gestational age		✓ ?	✓		✓	
Sudden infant death syndrome (SIDS)		✓	✓	✓	*	
Spontaneous abortion			*			
Adverse effect on cognition and behaviour			*		*	
Respiratory effects						
Acute lower respiratory tract infections in children (e.g. bronchitis and pneumonia)	✓	✓	✓	✓	✓	
Asthma exacerbation in children	✓	✓	✓	✓	✓	
Asthma induction in children	*	✓	✓		* ?	
Respiratory symptoms	✓	✓	✓	✓	✓	
Middle ear disease in children	✓	✓	✓	✓	✓	
Decreased pulmonary function	✓	✓	*		*	
Exacerbation of cystic fibrosis			*			
Carcinogenic effects						
Lung cancer	✓	✓	✓	✓		✓
Nasal sinus cancer		*	✓			✓ ?
Cervical cancer			*			
Cardiovascular effects						
Coronary heart disease		*	✓	✓		

A check mark (✓) indicates that the review concluded the relationship to the disease or condition was causal.

As asterisk (*) indicates that the review concluded the relationship was possibly causal.

In both cases protective public health action is warranted.

A blank cell indicates that the relationship was reviewed only briefly or not at all.

A question mark (?) indicates some inconsistency or ambiguity in the report's conclusions as to whether the relationship is causal or not

Source: Collishaw, N. & Meldrum, H. (2002). Protection from Second-Hand Smoke in Canada: Applying Health Science to Occupational Health and Safety Law. Ottawa: Physicians for a Smoke-Free Canada

C.3.3 Sensitive or vulnerable individuals

Those who are most at risk from ETS exposure include the fetus, neonates, young children and those with compromised pulmonary or cardio-vascular function (Witschi *et.al.* 1997). Davis (1998) has stated that virtually everyone in the United States is at some risk of harm from exposure to ETS. Nearly everyone is exposed to tobacco smoke, and there is no evidence of a threshold or safe level of exposure to ETS. Those populations who live with smokers and those who work where smoking is allowed are at a greater risk of harm from ETS exposure (Davis 1998).

- **Infants and children**

The effects of smoking and ETS can continue to affect children after birth. Witschi *et.al.* (1997) reported that the most troublesome effects of passive smoking are found in children. Children raised in homes with smokers have more ETS-related symptoms and respiratory illnesses than children raised in non-smoker homes. Also, asthmatic children who are exposed to ETS have more severe asthma and greater airway reactivity to histamine, cold air and exercise (Witschi *et.al.* 1997). The reason infants and children are more susceptible to ETS is that their lungs and other respiratory tissues are still developing. In addition, children are also more prone to illness from ETS because of their higher respiratory rate than adults, actively growing bodies, developing tissue and organ systems, and a developing immune system that results in a greater absorption of contaminants per unit body weight and greater sensitivity to those contaminants than adults (Davis 1998). There is also evidence that ETS adversely affects on cognition and behaviour among children (WHO 1999).

It is also important to know that chemical residue is still present on surfaces even after the smoke clears. Normal childhood behaviours, such as hand-to-mouth behaviour, can increase the risk of children being in contact with these ETS residues (Saskatchewan Prevention Institute, 2002).

- **Pregnant women**

Non-smoking pregnant women exposed to ETS are more likely to have low birth-weight babies with increased risk of disease in infancy and early childhood (USEPA 1992). WHO (1999) in its consultation report concluded that ETS exposure in pregnant non-smokers is causally associated with reduced fetal growth.

- **Individuals with chronic diseases**

Individuals with certain chronic conditions are more likely to suffer from ETS-related illnesses. Persons suffering from allergies, chronic obstructive pulmonary disease, chronic heart disease and peripheral vascular disease are more likely to experience aggravation of their illnesses with ETS exposure (Davis 1998).

- **Hospitality industry workers**

Hospitality industry workers, such as waiters and bartenders can be exposed to high concentrations of ETS in casinos, pubs, bars and restaurants where smoking is allowed (Davis 1998). Several studies have demonstrated a 50 per cent excess risk of lung cancer among food-service workers attributable to ETS exposure (Brooks and Davis 1995, cited in Davis 1998). Food service workers also have a higher risk of chronic respiratory and cardiovascular illnesses attributed to ETS exposure.

C.4 Sources and indoor levels of environmental tobacco smoke

Tobacco smoking is the only source for ETS, although the individual constituents comprising ETS may have other sources. Tobacco smoking increases levels of respirable particles, nicotine, PAHs, CO, acrolein, NO₂, and other chemical compounds in indoor air (Spengler *et.al.* 2001, Samet and Wang 2001). Tobacco smoking can be considered as one of the most important contributors to respirable particulate levels in indoor environments. High respirable particulate concentrations have been measured in smokers' residences and in buildings where smoking is allowed (Godish 2000).

Total Exposure Assessment Methodology (TEAM) studies by USEPA have provided extensive data on the distribution of volatile organic compounds in homes across several communities in United States. Elevated levels of benzene, xylenes, ethyl benzene and styrene have been recorded in homes with smokers compared to homes without smokers. The TEAM study cited smoking as a significant contributor of benzene in homes (Spengler *et.al.* 2001, Samet and Wang 2001). Wallace (1987) estimated that MS smoke contributed 1.8 mg of benzene per day to the average smoker's intake, based on a respiration rate of 20 m³/day and a benzene concentration in smoker homes of 90 µg per m³. The average non-smoker's passive exposure to ETS contributed 0.06 mg to 0.09 mg of benzene per day. TEAM study findings suggested that the total benzene exposure for the 50 million actively smoking Americans was equal to the total benzene exposure from all other sources for the rest of the population. Homes where smokers were living in the United States (Wallace 1987) and Germany (Krause *et.al.* 1987) had benzene concentrations of 3 µg/m³ to 4 µg/m³ higher than homes without smokers. Based on the data from measurements of benzene in 200 homes in the United States, Wallace (1989) reported that tobacco smoking contributes an additional 3 µg/m³ to the concentration of benzene already present in the residential indoor air.

In his background paper on ETS, Rickert (1999) cited a study by Coultas *et.al.* (1990) that reported respirable-suspended particulates (RSP) and nicotine concentrations in the range of 32.4 µg/m³ to 76.9 µg/m³ and 0.6 µg/m³ to 6.9 µg/m³, respectively in 10 U.S. smoking homes. In comparison, smoking-related respirable-suspended particulates in non-smoking Canadian homes reported by Rickert (1999) were found to be virtually absent, but reached a high concentration of 32 µg/m³ in smoker homes. Although the results for nicotine were not provided for this study, the author reported a similar correlation between nicotine concentrations in the homes of non-smokers and smokers.

Significant indoor air contamination from ETS can occur in buildings, such as restaurants, bars and arenas, where there are no restrictions in smoking (Godish 2000). Table C-2 provides contaminant levels in buildings where there are no smoking restrictions.

Table C-2 ETS-related contaminants in different buildings

Contaminant	Building type / facilities	Contaminant levels	Controls from non-smoking buildings
CO	Room with 18 smokers	50 ppmv	0.0 ppmv
	15 restaurants	4 ppmv	2.5 ppmv
	Arena (11,806 people)	9 ppmv	3.0 ppmv
RSP	Bar and grill	589 µg/m ³	63 ug/m ³
	Bingo hall	1140 µg/m ³	40 ug/m ³
	Fast food restaurant	109 µg/m ³	24 ug/m ³
NO ₂	Restaurant	63 ppbv	50 ppbv
	Bar	21 ppbv	48 ppbv
Nicotine	Room (18 smokers)	500 ug/m ³	Not Available
	Restaurant	5.2 ug/m ³	Not available
Benzo(a)pyrene	Arena	9.9 ng/m ³	0.69 ng/m ³
Benzene	Room with 18 smokers	0.11 mg/m ³	Not available

Source: Godish (2000), In Indoor Environmental Quality, Lewis Publishers, 2001

Indoor air is rarely still. Generally, it is moving at net local speeds that range from a fraction to several tens of a cm/s. This motion can be induced by several means, including fans in mechanical ventilation systems, wind-induced flow through openings in the building shell, and natural convection resulting from heat exchange at surfaces. These motions often exhibit turbulent fluctuations superimposed on a systematic and structured mean flow. The mean flow can cause organized transport of pollutants; the turbulent fluctuations tend to disperse or spread pollutants so that the concentrations become more uniform throughout the interior space. ETS gases, vapours and particulates are sufficiently small to be distributed throughout a common room by convective air currents (Nazaroff & Klepeis, 2003) Therefore, the simple separation of a single room or space into smoker and non-smoker areas will not eliminate exposure to ETS among non-smokers. Migration of ETS from outdoors to indoors is possible in restaurants or pubs with outdoor designated smoking areas, such as patios, through adjacent open doorways and windows.

C.5 Exposure to environmental tobacco smoke

The inhalation pathway is the primary route of exposure to ETS (Samet and Wang 2001), although, dermal exposure can be another significant exposure route.

Non-smokers can be exposed to ETS in settings where there are no smoking restrictions or limited bans on smoking such as in offices, restaurants, bars, indoor bowling alleys and homes (Miller 1991, cited in Ninth Report on Carcinogens, Spengler 1999). ETS exposure depends on many factors, such as the degree of internal air mixing, building surface to volume ratios, air exchange rate, smoker density and smoking rate. Exposure to fresh ETS or recirculated ETS can occur in different indoor settings (Spengler 1999). It is important to note that aged ETS differs from fresh ETS, since ETS undergoes physical and chemical changes as it ages; for example, the conversion of NO to more toxic NO₂. Volatilization of chemicals from the particulate phase can also occur as ETS ages (Godish 2000).

In facilities where smoking is permitted, such as bars, restaurants and clubs, ETS exposure among smokers and non-smokers are higher than in facilities where smoking is completely banned. In one study, levels of ETS in restaurants were found to be approximately 1.6 to 2.0 times higher than other office places and 1.5 times higher than in residences where only a single smoker was present (Lambert *et. al.* 1993, cited in ETS, Ninth Report on Carcinogens Spengler 1999). Another study by Siegel (1993) reported that levels of ETS in bars were 3.9 to 6.1 times higher than in office workplaces and 4.4 to 4.5 times higher than in residences (Siegel 1993, cited in ETS, Ninth Report on Carcinogens (Spengler 1999) also reported that highest exposures to ETS occur in bars, taverns and nightclubs, followed by residential buildings, apartments and offices. In another study, Meisner *et.al.* (1989) reported exposure levels to RSPs in non-smoking offices of up to 30 µg/m³, whereas levels in restaurants and bars ranged up to 140 µg/m³. The difference in concentrations between RSPs in these indoor environments suggests that ETS exposure can be significantly higher in restaurants and bars than in offices. Eisner *et.al.* (1998) studied the association between ETS exposure and the respiratory health of bartenders before and after California's ban on smoking in all bars and taverns. He concluded that the establishments of smoke-free bars and taverns were associated with an improvement in the respiratory health of bartenders.

C.5.1 Dangers of second-hand smoke exposure in cars

A study done by Sly *et.al.* (2007) has demonstrated that exposure to ETS in cars was found to be associated with increased incidence of persistent wheeze in 14-year-olds. Although there are few studies of the health effect of ETS exposure in cars, it is clear that the smoking in cars leads to an extremely high concentration of smoke because of the very small spatial volume within the interior of a car. For example, in one study using PM_{2.5} measurements in cars under varying conditions, in motionless cars with all the windows closed, the level of PM_{2.5} was equivalent to 100 times the U.S EPA's 24-hour standard for fine particle exposure, or, stated otherwise, more than 11 times the levels of ETS in the average pub that allows smoking (Sendzik *et.al.* 2009; Connolly *et.al.*, 2009). It is important to note that smokers recognizing the potential hazard of their smoking in cars often take measures that they believe will reduce the hazard. However, in a systematic experiment of the impact of these measures, researchers at the University of

Waterloo demonstrated that even with a window open or with the use of the vehicle's ventilation system in an attempt to clear the smoke, the levels of ETS were still very high (Sendzik *et.al.* 2009). For example, in a condition when a single cigarette was smoked in a car with all windows closed but with air conditioning (very common during a Canadian summer and, with heat rather than air conditioning, very common during a Canadian winter), the average PM_{2.5} level was almost 2.5 times higher than in a smoky bar (Sendzik *et.al.* 2009; Connolly *et.al.*, 2009). Even with full ventilation and airflow, driving with all four windows down all the way, the average PM_{2.5} level was more than four times greater than the average outdoor values measured at baseline and at a level considered unhealthy to children and other sensitive groups with prolonged exposure (Sendzik *et.al.* 2009). Other studies investigating smoking in vehicles under a variety of conditions have found similar results (Edwards *et.al.* 2006; Jones *et.al.* 2009; Ott *et.al.* 2008; Rees & Connolly 2006; Vardavas *et.al.* 2006). In general, these studies have found that ETS levels in cars persist even if compensatory measures are attempted, such as opening a window, increasing speed or using the vehicle's ventilation system or air conditioning. These air quality measurement studies demonstrated that second-hand smoke exposure in cars constitutes a significant health hazard, and one for which measures should be taken to reduce.

C.6 Biomarkers of exposure

Biomarkers are important tools for quantifying human exposure to ETS and for assessing health risks. Several biomarkers are available to describe the degree or intensity of exposure to ETS (Benowitz 1999). Based on a review of several biomarker studies, Samet and Wang (2001) concluded that “involuntary exposure to ETS leads to absorption, circulation and excretion of tobacco smoke components.”

The most sensitive and effective biomarkers available to determine exposure to ETS are nicotine and cotinine in urine, blood serum or saliva. Nicotine and cotinine are usually not found in high concentrations in the human body in the absence of ETS. However, nicotine and cotinine levels in the body can be influenced (not significantly elevated) by the ingestion of nicotine-containing foods such as eggplant, tomato and other artificially nicotine-flavoured food items (Idle 1990, cited in Samet and Wang 2001). Other common nicotine containing products for human use or consumption include moist or dry snuff, chewing tobacco, nicotine gum, transdermal patches, nicotine nasal sprays and nicotine inhaler rods (Gwaltney-Brant and Richardson 2002).

The circulating half-life of nicotine inside the body is two hours (Benowitz 1999, Rosenberg *et.al.* 1980). Therefore, nicotine concentrations in body fluids confirm very recent exposure to ETS (Samet and Wang 2001).

Cotinine has an in vivo half-life of approximately 20 hours, and is typically detectable for several days (up to one week) after the use of tobacco. The level of cotinine in the blood is proportionate to the amount of exposure to tobacco smoke, so it is a valuable indicator of tobacco smoke exposure, including secondary (passive) smoke (Florescu *et.al.* 2009; Benowitz 1999; Samet and Wang 2001; Mannino *et.al.* 2001). Levels of cotinine in the blood confirm more prolonged ETS exposures (Samet and Wang 2001). At present, cotinine is regarded as the most specific and the most sensitive biomarker for determining ETS exposure (Benowitz 1999). Samet and Wang (2001) have cited several studies on elevated levels of cotinine in the body fluids, such as urine and saliva of children of smoking parents. Table C-3 presents comparative studies on cotinine concentrations in adults, children, non-smokers and smokers. As shown in the table, there is a marked difference in urinary and salivary cotinine levels in subjects living with smokers and non-smokers.

Table C-3 Geometric mean cotinine concentrations in non-smokers and smokers

Smoking status	Exposure to ETS	Plasma or serum cotinine (ng/mL)	Urine cotinine (ng/mL)	Salivary Cotinine (ng/mL)	Subjects Tested	Reference
Non-smokers	Lives alone or with non-smoker	-	4.4	-	158	Thompson <i>et.al.</i> (1990)
Non-smokers	Lives with smoker	-	11.4	-	26	
Non-smoker, aged 4-11 yrs	Home ETS exposure	1.13	-	-	713	Pirkle <i>et.al.</i> (1996)
Non-smokers, aged 12-16 yrs	No home ETS exposure	0.11	-	-	379	
Non-smokers, aged 12-16 yrs	Home ETS exposure only	0.81	-	-	268	
Non-smokers, aged ≥ 17 yrs	No home or work ETS exposure	0.12	-	-	3154	
Non-smokers workers, aged ≥ 17 yrs	No home or work ETS exposure	0.13	-	-	1332	
Non-smokers, workers aged ≥ 17 yrs	Work ETS exposure only	0.32	-	-	779	
Non-smokers, workers aged ≥ 17 yrs	Home ETS exposure only	0.65	-	-	315	
Non-smokers, workers aged ≥ 17 yrs	Home and work ETS exposure	0.93	-	-	246	
Non-smokers, aged 5-7 yrs	No smokers in home	-	-	0.29	1260	Cook <i>et.al.</i> (1994)
	Mother smoker	-	-	2.2	293	
	Father smoker	-	-	1.2	521	
	Both parents smokers	-	-	4.0	553	

Source: Adapted and modified from Samet and Wang (2001), In Spengler et al (2001), Indoor Air Quality Handbook, McGraw Hill publications, 2001.

C.7 Control measures

The biologic mechanisms review in the Surgeon General's report (2006) indicates that any exposure to ETS will increase risk for adverse health outcomes, including a wide range of acute and chronic adverse health effects in infants, children and adults.

The only means of effectively eliminating health risks associated with indoor ETS exposure is to ban smoking activity.

The Institute of Medicine (IOM) report *Second-hand-Smoke Exposure and Cardiovascular Effects: Making Sense of the Evidence* (2009) confirms that eliminating smoking in workplaces, restaurants, bars and other public places is an effective way to protect Americans from the health effects of second-hand smoke, particularly on the cardiovascular system. The IOM also concluded that the evidence is compelling that even brief second-hand smoke exposure could trigger a heart attack.

ETS has been classified as a Group A carcinogen under EPA's carcinogen assessment guidelines. International Agency for Research on Cancer (IARC) also classifies ETS as a Group 1 agent, carcinogenic to humans with a well-established link to lung cancer. There is no safe level of exposure to known human carcinogens.

Because there is no safe level of exposure to ETS, the only effective means to reduce cancer risk associated with ETS exposure is to eliminate smoking activities in indoor environment. The following control measures are presented for discussion purpose but are not recommended or viable options in real practice.

C.7.1 Dedicated environmental tobacco smoke areas

US Surgeon General's report (2006) concluded that "eliminating smoking in indoor spaces fully protects non-smokers from exposure to second-hand smoke. Separating smokers from non-smokers, cleaning the air, and ventilating buildings cannot eliminate exposures of non-smokers to second-hand smoke." The supporting evidences include:

- Conventional air cleaning systems can remove large particles, but not the smaller particles or the gases found in second-hand smoke.
- Current heating, ventilating, and air conditioning systems alone do not control second-hand smoke exposure. In fact, these systems may distribute second-hand smoke throughout a building.
- Even separately enclosed, separately exhausted, negative-pressure smoking rooms do not keep second-hand smoke from spilling into adjacent areas.

ASHRAE, the U.S. standard-setting body on ventilation issues, does not completely prohibit smoking in all building classifications. It provides some requirements for building containing ETS areas and ETS-free areas in section 5.17.1 through 5.17.8. The requirements include pressurization, separation, air transfer flow rate, recirculation, exhaust system, signage and classification (ASHRAE 62.1 -2010). However, meeting these requirements do not "purport to achieve acceptable indoor air quality in ETS areas." (ASHRAE 62.1 2010, page 10).

In addition, some exposure to ETS tars and other compounds is likely to occur during cleaning and maintenance of the dedicated smoking room and the maintenance of the exhaust-only ventilation system. These exposures will occur via inhalation and through dermal contact (cleaning). Consequently, an unacceptable exposure risk may still exist for some staff or workers who are involved in cleaning and maintenance activities. The construction and maintenance cost may be prohibitive for small businesses, which again introduces an element of economic inequity or unfairness in the application of a policy that allows separately ventilated smoking rooms. Such a policy discriminates against smaller businesses that may not have the same economic resources compared to large business establishments.

The health risks associated with cleaning and maintenance activity can only be described qualitatively. During smoking, tars and other semivolatile compounds are deposited on surfaces in a room, including the interior of ventilation ducts and on duct fans. At the end of the smoking activity, tars and other semivolatile compounds will re-emit hazardous compounds into the air because of equilibrium phenomena. In addition, cleaning and maintenance workers will be exposed to those hazardous compounds by dermal contact.

The following example illustrates the potential health risks to cleaning and maintenance staff from smoking tars deposited in two scenarios: (1) a partitioned smoking and non-smoking restaurant and (2) a dedicated smoking room. The example also illustrates why municipal bylaws aimed at allowing smoking only during certain hours of the day are not feasible. It also demonstrates the potential health risk to patrons, especially to children who commonly exhibit hand-to-mouth behaviour in a restaurant where smoking either area-partitioned or temporally segregated is permitted.

- **Two-scenario analysis**

- Two smokers smoking two cigarettes per hour, eight hours per day in a 30 m² x 30 m² room will deposit approximately one kg of toxic tars every four years. Where there is smoking, ETS tars will be deposited on all surfaces inside the room including windows, countertops, tables, walls, ceilings, clothing, food and inside ventilation ducts.
- If a 100 m² restaurant has occupancy of 70 persons, as per the ASHRAE Standard 62-1999, an average occupancy factor of 50 per cent, and a smoking prevalence of one in three, there will be a daily average of about 12 smokers. Assuming the restaurant is open 360 days per year and that each cigarette emits 14 mg of tar, about 60,000 mg of tobacco tar will be liberated into the space, of which perhaps 25 per cent will be deposited on the room surfaces. Thus, 15,000 mg of a semi-volatile mixture of organic material which has evaporation times ranging from days to months, will be deposited and out-gassed on room surfaces annually. Eventually, the building will become just like a toxic waste dump. Non-smokers will be exposed to re-emitted tobacco tar. There is also the risk of dermal contact in these buildings (Repace J., personal communication).

C.7.2 Ventilation

Alternative procedures, such as installing improved ventilation, electronic air filters and other air filtration technology and the separation of smokers and non-smokers, can be organized in buildings to control or reduce ETS exposure. However, these control measures will only reduce but not eliminate exposure to ETS. Since smoking generates such diverse and toxic quantities of pollutants, natural or mechanical ventilation methods are not capable of removing them from the indoor environment, as fast as they build up or to the degree that would render them harmless (USEPA 1995).

“Ventilation provides no solution to the problem of exposure to second-hand smoke.”

—*Protection from Second-Hand Tobacco Smoke in Canada: Applying Health Science to Occupational Health and Safety Law (Collishaw & Meldrum, 2002)*

Most commercial and residential buildings in Alberta and Canada are ventilated by furnaces or air handling units. These systems are classified as “dilution ventilation,” operating on the principle of introducing outdoor air into indoor environments to dilute levels of indoor contaminants. Dilution ventilation is an acceptable practice for handling relatively non-toxic indoor air. However, it is not considered acceptable for handling toxic environments, such as chemical contaminants generated by industrial workplaces or ETS contaminated spaces. General or dilution ventilation can only reduce the indoor concentration of ETS by diluting it with conditioned outdoor supply air but cannot prevent ETS exposure. In addition, an HVAC system can redistribute ETS contaminated return air throughout a building to effectively contaminate the whole building and expose all occupants (Spengler 1999). Repace (2000) reported that “dilution ventilation, air cleaning or displacement ventilation technology (a new unproven ETS control technology) even under moderate smoking conditions cannot control ETS risk to *de minimis* levels for workers or patrons in hospitality venues without massively impractical increases in ventilation.”

C.7.3 Air filtration

Air cleaning is not an effective method for controlling ETS exposure. Devices, such as smoke-eaters, electronic air cleaners, ozonators and mechanical or chemical filtration, should be dismissed as ineffective for ETS control (American Lung Association and the American Thoracic Society 1997, cited in Samet and Wang 2001).

ETS is a complex mixture of about 4000 compounds distributed among combustion gases, volatiles and particulates. Some of the major toxics include fine respirable particulates, nicotine, carbon monoxide, nitrogen oxides, acrolein, formaldehyde, acetaldehyde and cancer-causing chemicals such as arsenic, vinyl chloride, benzene, nitrosamines and polycyclic aromatic hydrocarbons (PAHs). Filtration of these diverse compounds is extremely complex and a filtration system capable of removing these contaminants does not commercially exist and may not be viable.

One researcher recommended starting with a five-centimetre deep filter with a 30 per cent particulate capture efficiency, a 30-centimetre deep 90 per cent high-efficiency particulate filter, an activated carbon filter for volatiles and a final 10-centimetre deep 30

per cent particulate filter. However, this filter combination does not trap combustion gases or low molecular weight compounds such as formaldehyde and acrolein. Even if a filter existed that was 100 per cent effective, such a filter would not reduce contaminant levels in a restaurant to acceptable levels sufficient to protect human health because general or dilution ventilation ensures that ETS contaminants have a half-life in the indoor space before they are captured by the return air system and brought in contact with filtration beds, thus ensuring that occupants will inhale unacceptable levels of ETS contaminants.

C.8 Smoking legislation

C.8.1 Nationwide smoking ban in Canada

In addition to the federal Tobacco Act, which regulates the manufacture, sale, labelling and promotion of tobacco, each province has its own set of laws that focus on, among other concerns, smoking in public places. Provincial laws that restrict smoking in public places help non-smokers breathe easier, reduce overall smoking behaviour, generate increased public awareness about tobacco concerns, and help to change social norms related to smoking.

Smoking in Canada is banned in indoor public spaces and workplaces, including restaurants, bars, and casinos, by all territories and provinces, and by the federal government. As of 2012, legislation banning smoking within each of these jurisdictions is mostly consistent, despite the separate development of legislation by each jurisdiction. Notable variations between the jurisdictions include whether or not, and in what circumstances ventilated smoking rooms are permitted; whether or not, and up to what distance away from a building smoking will be banned outside of a building; and, whether or not smoking will be banned in private vehicles occupied by children (Health Canada, 2007).

C.8.2 Smoking ban and the Alberta-Tobacco Reduction Act

The Tobacco Reduction Act protects Albertans from the harmful effects of second-hand smoke by removing smoking from public places, workplaces and public vehicles. Smoking is limited to private living accommodations and private vehicles.

On November 14, 2007, Bill 45, the Smoke-Free Places (Tobacco Reduction) Amendment Act, 2007 passed third and final reading.

- The Smoke-Free Places (Tobacco Reduction) Amendment Act, 2007
 - Prohibits smoking in all public places and workplaces
 - Bans tobacco displays, promotions and advertising in retail outlets
 - Removes tobacco sales from pharmacies, health-care facilities and post-secondary campuses
- The act's implementation timeline was spread over more than a year:
 - On January 1, 2008, all Alberta public and work places became smoke-free
 - In July 2008, power walls and other tobacco displays or promotion were covered or removed in retail stores around the province
 - On January 1, 2009, the final decree was enacted removing tobacco from pharmacies, health-care facilities and post secondary institutions
- The legislation also stated that no person shall smoke:
 - Inside a building
 - Within five metres of a doorway, window or air intake

- On a patio related to a business, restaurant, lounge or nightclub
- In a bus, taxi, public transit, bus shelter or phone booth
- In bars, bingo halls and casinos
- In the common areas of a multi-unit residential facility, including patios, pools, other recreation areas and enclosed parking garages

C.8.3 Smoking bans in vehicles

Research and experience on banning smoking in public places has shown that educational campaigns and voluntary smoking bans are not effective on their own. Instead, a smoke-free law paired with an educational campaign, before and after the implementation of the law, is ideal for increasing smoking-ban effectiveness (Saltman *et. al.*, 2009).

Smoking with anyone under the age of 16 present in a vehicle is currently banned in nine provinces across Canada including British Columbia, Newfoundland and Labrador, Manitoba, Ontario, New Brunswick, Prince Edward Island, Saskatchewan and Yukon Territory. The town of Okotoks became the first Alberta community that banned smoking in vehicles carrying children. Table C-4 list jurisdictions in Canada that have legislation in force banning smoking in vehicles carrying children.

Table C-4 Canadian communities, provinces and territories that ban smoking in vehicles carrying children

Jurisdiction	Applicable age (under the age)	Date law in force	Date law adopted
Communities			
Wolfville ,NS	19	June 1, 2008	Nov 19, 2007
Surrey, BC	19	July 31, 2008	July 14, 2008
Okotoks, AB	16	Sept 1, 2008	July 15, 2008
White Rock, BC	16	Nov 1, 2008	Oct 20, 2008
Richmond , BC	19	Nov 30, 2008	April 28, 2008
Leduc, AB	18	July 2, 2011	Dec 13, 2010
Provinces / territories			
British Columbia	16	April 1, 2009	May 29, 2008
Ontario	16	Jan 21, 2009	June 18, 2008
New Brunswick	16	Jan 1, 2010	May 1,2009
Nova Scotia	19	April 1, 2008	Dec 13, 2007
Yukon	18	May 15, 2008	April 22, 2008
PEI	19	Sept 15, 2009	May 15, 2009
Manitoba	16	pending	June 11, 2009

Source: Saltman, *et.al.* 2009; CTVEdmonton, 2010

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Appendix D

Radon

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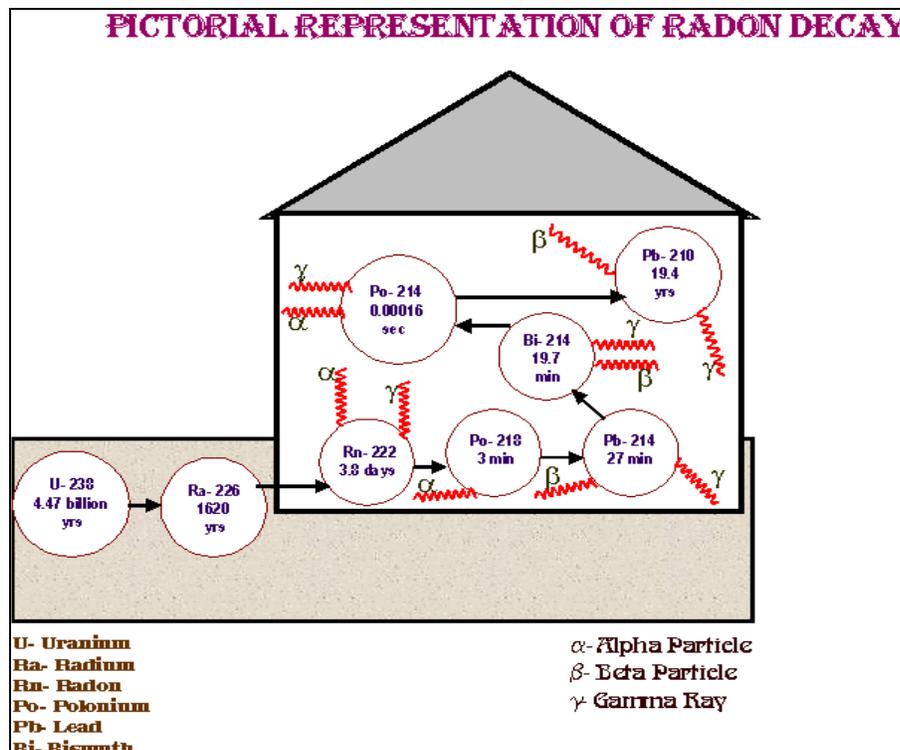
D. Radon

D.1 Introduction

D.1.1 What is radon?

Radon is a ubiquitous, naturally occurring, colourless, odourless and tasteless radioactive gas. Radon, an alpha emitter, is part of the U_{238} decay series (see Figure D-1) produced by the radioactive decay of radium-226 (U_{238}), a naturally occurring mineral found in varying quantities in soil. The radioactive decay of radon results in the production of other radioisotopes referred to as “radon progeny” or “radon daughters”. Examples of radon “daughters” include radon-222, radon-220 and radon-219. Radon-222 has a 3.82-day half-life compared to a 56-second half-life for radon-220 (thoron) and a four-second half-life for radon-219 (thoron).

Figure D-1 Radon’s position in the uranium decay process

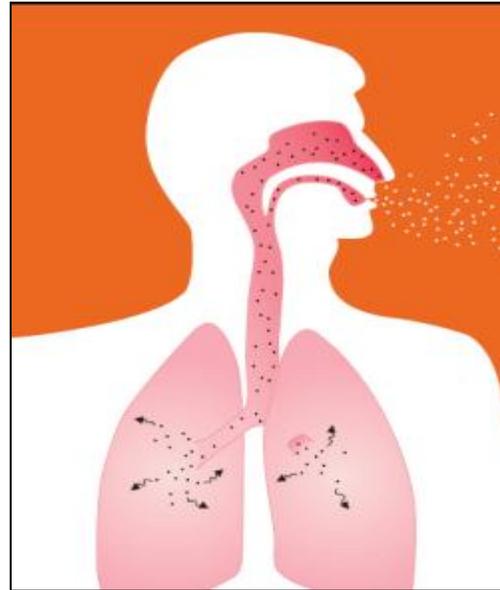


Source: Ohio Radon Information System website. Available at http://www.eng.utoledo.edu/aprg/radon/information/files/r_decay.gif,

D.1.2 What is the risk

Radon gas and radon progeny in the air can be breathed into the lungs where they break down further and emit alpha particles (see Figure D-2). These radon daughters are radioactive, short-lived products that attach almost immediately to aerosol particles in the atmosphere; however, some do remain unattached. Two of these radon daughters, polonium-218 and polonium 214, emit ionizing alpha particles of high mass and energy, which are capable of damaging DNA and lung tissue (Godish 2000). DNA damage can result in abnormal cell growth, with the subsequent possibility of the development of cancer. Cancers caused by radioactivity are started by chance and not everyone exposed to radon will develop lung cancer. The time between exposure and the onset of the disease is usually many years (Health Canada, 2009).

Figure D-2 Radon alpha particles in the lungs



D.1.3 Radon health risk assessment

Current radon risk assessment studies are based on epidemiological studies with respect to radon in indoor air and drinking water (USNRC, 1999). For the purpose of this manual, risk assessments from the Biological Effects of Ionizing Radiation Committee (BEIR) will be discussed.

The BEIR committee developed a radon risk assessment model in 1988 that was based on different radon exposure studies of underground miners. The early risk assessment model for radon was based on risk co-efficients derived from miner studies from Sweden, the United States and Canada. The BEIR model inherently incorporates the effects of other factors, such as cigarette smoking, on lung cancer (Samet 2001, cited in Spengler *et. al.* 2001). Recent epidemiological evidence shows a synergistic relationship between radon and tobacco smoke, as electrically charged radon progeny tend to attach to smoke particles thus increasing the risk of lung cancer to smokers; the extent of this synergistic relationship is uncertain. However, it led researchers to conclude that most radon-induced lung cancer probably occurs among smokers (Samet 1989, 2001, Spengler *et. al.* 2001).

In 1999, BEIR VI report provided risk estimates for different exposure scenarios and made projections of the lung cancer burden in the United States attributed to radon progeny (USNRC 1999). Table D-1 presents estimated attributable risk for lung cancer deaths from exposure to radon. The risk estimates were calculated by using 1985 to 1989 U.S. population mortality rates.

Table D-1 BEIR VI estimated attributable risk for lung cancer death from domestic exposure to radon

Model	Population	Ever-smokers	Never-smokers
Males			
Committee's preferred models			
Exposure-age-concentration model ¹	0.141	0.125	0.258
Exposure-age-duration model ²	0.099	0.087	0.189
Other models			
CRR ³ (< 50 WLM)	0.109	0.096	0.209
BEIR IV	0.082	0.071	0.158
Females			
Committee's preferred model			
Exposure –age-concentration model ¹	0.153	0.137	0.269
Exposure-age-duration model ²	0.108	0.096	0.197
Other models			
CRR ^a (< 50WLM) ³	0.114	0.101	0.209
BEIR IV	0.087	0.077	0.163

¹Exposure age concentration model is a model based on exposure to average radon concentration

²Exposure age duration model is a model based on duration of exposure to radon

³CRR – Constant Relative Risk model is a model which assumes that, after a certain time, the ratio of the risk at a specific dose to the risk in the absence of dose does not change with time. In this case, CRR is based on a submultiplication relationship between tobacco and radon.

Source: USNRC 1999

To characterize risks to the population, BEIR has used the population attributable risk (AR), which shows how much of the lung cancer burden could, in theory, be prevented if all exposures to radon were reduced to the background level of radon in outdoor air. The above risk estimates suggest that radon progeny should be considered as a significant cause of lung cancer. Risk estimates for smokers and never-smokers are based on the assumption of submultiplicative combined effects of smoking and radon progeny. The submultiplicative combined effect can be defined as the effect which is less than the anticipated effect if the joint effect were the product of the risks from the two agents individually, but more than the anticipated effect if the joint effect were the sum of the individual risks. Therefore, on a percentage basis, the attributable risks appear to be higher for never-smokers than smokers. However, the number of attributable cancer deaths is far higher among smokers than among individuals who have never smoked (Samet 2001, cited in Spengler 2001). The reader should refer to *Health Effect of Exposure to Radon*, BEIR VI, 1999 (National Academy Press, a free PDF version is downloadable at http://www.nap.edu/catalog.php?record_id=5499) for a detailed discussion on risk estimates of radon. A summary discussion on BEIR VI report is also available from USEPA website: <http://www.epa.gov/radon/beirvi.html>.

D.2 Toxicology and mechanism of toxicity

The presumed mechanism of carcinogenesis of radon and its progeny is the irradiation of the lining of the airways within the lungs and their subsequent deposition and decay. Alpha particles are emitted by both radon and radon progeny. However, it is the high energy alpha particles from the radon progeny that are responsible for most of the bronchial tissue damage, resulting in DNA mutations and subsequent abnormal cell growth leading to cancer. Lung cancer is the only health effect associated with the exposure to high levels of radon as human skin is thick enough not to be affected by radon and radon daughters. However, bronchial and lung tissue are prone to the harmful effects from exposure to radon and radon daughters (ATSDR 1990).

D.3 Health effects

The only known health effect associated with exposure to radon in indoor air is an increased risk of developing lung cancer. The effects of radon are dependent on the levels of radon in the home or building and how long a person is exposed to these levels. (Health Canada, 2009).

- **Acute effects**

Radon is one of the naturally occurring radionuclides found in the environment. No information is available on the acute short-term non-cancer effects of the radionuclides in humans (USEPA, 2009).

- **Chronic effects**

Radon is considered a significant indoor air contaminant and a major contributor to the incidence of lung cancer. Health Canada (2009) estimates that approximately 10 per cent of lung cancers in Canada are related to radon exposure. Similarly, eight to twenty-five percent of all current lung cancer cases in United States may be because of radon exposure, according to USEPA. In the U.S. alone, radon may be the cause of 15,000 to 22,000 deaths from lung cancer each year (American Lung Association 2002). Next to smoking, radon is considered as the second leading cause of lung cancer in the United States (American Lung Association 2002, Health Canada 2009).

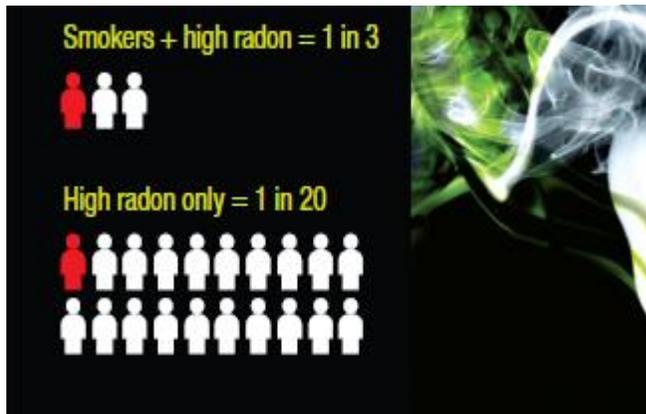
- Sensitive or vulnerable

Children may be more susceptible to the effects of radon and radon daughters than adults (ATSDR 1990). Differences in lung morphometry and breathing rates can result in higher doses of radon intake among children than adults (Samet 1989).

Populations with chronic respiratory diseases, such as asthma, emphysema or fibrosis, may be more susceptible to exposure to radon and radon daughters (ATSDR 1990) because of reduced pulmonary clearance ability. Also, individuals who have existing lung lesions may be more susceptible to the tumour-causing effects of radon (Morken 1973, cited in ATSDR 1990).

- Smoke and radon exposure

For smokers the risk of lung cancer is significant because of the synergistic effects of radon and smoking. The combined effects of radon exposure and tobacco use significantly increase the risk of lung cancer. It is estimated that a non-smoker exposed to elevated levels of radon over a lifetime has a one in 20 chance of developing lung cancer. That estimate increases to a one in three chance if a smoker is also exposed to elevated levels of radon over a lifetime.



Source: Health Canada 2010. Radon-Another Reason to Quit
http://publications.gc.ca/collections/collection_2011/sc-hc/H128-1-11-648-eng.pdf

The lifetime risks listed in Table D-2 shows the risk for smokers and non-smokers of developing lung cancer because of radon exposure.

Table D-2 Risk of developing lung cancer from radon

Risk of developing lung cancer from radon	
Lifetime risk to a smoker exposed to radon	
Lung cancer risk for lifetime exposure to radon at 800 Bq/m ³	30 %
Lung cancer risk for lifetime exposure to radon at 200 Bq/m ³	17 %
Lung cancer risk from smoking only,	12 %
Lifetime risk to a non-smoker exposed to radon	
Lung cancer risk for lifetime exposure to radon at 800 Bq/m ³	5 %
Lung cancer risk for lifetime exposure to radon at 200 Bq/m ³	2 %
Lung cancer risk for exposure to radon at low outdoor levels	1 %

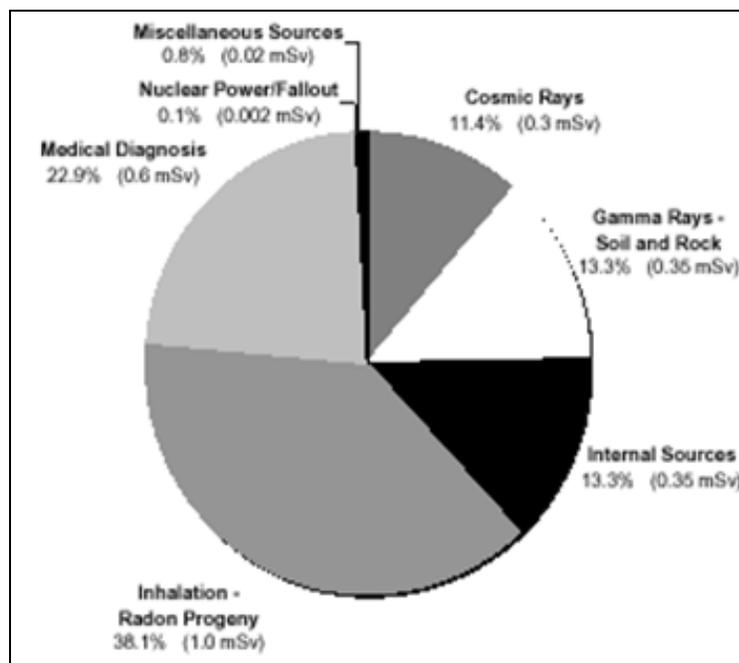
Source: Health Canada 2011. Radon: Is It in Your Home? ISBN 978-1-100-19613-8. Health Canada Publications. C2011

D.4 Sources and pathways

Radon is ubiquitous and naturally occurring radioactive gas. As a result, radon and its parent and daughter compounds can be classified as Naturally Occurring Radioactive Materials (NORM) and can be found naturally in soils beneath buildings, domestic water supplies and building materials, such as granite facings. All of which can contribute to the presence of radon in indoor air. Increased amounts of radon can also be found in soils contaminated with specific types of industrial waste including tailings and other byproducts of uranium and phosphate mining (Health Canada 1999). Compared to other sources, radon entering homes through the soil is usually a much larger risk (USEPA, 2009)

Sources of natural radiation can be classified into three groups: (1) a dose of direct cosmic radiation that arrives at the earth's surface from the sun and outer space; (2) a dose from environmental radiation through natural radioactivity at the earth's surface; and (3) internal radiation (Health Canada, 2008). Figure D-4 shows the annual radiation dose percentages that an average Canadian receives from difference sources. Radon exposure via inhalation pathway accounts for about 38 per cent of the total annual radiation dose.

Figure D-4 Average annual radiation dose to Canadians¹



¹Average total dose of 2.62 mSv per year)

Source: *Canada: Living with Radiation: AECSB, 1995*

Unlike the other decay products in the U_{238} decay series, radon is a gas. The other decay products are all solids. Because it is a gas, radon can pass through anywhere it finds an opening where the house touches the ground. It moves within underlying soils, enters homes through cracks in the foundation, gaps around pipes, sump holes and floor drains. It is drawn inside naturally by differences in pressure between the indoor environment and the outside (Godish 2000; Health Canada 2008). As radon is a noble

gas, it is chemically inert and does not react with other substances (Calgary Health Region 1993).

Sources of radon within buildings can be attributed to different building materials, such as masonry and granite materials, and the infiltration of soil gas via exposed soil in crawl spaces. Additional routes include cracks and openings in slab-on-grade floors and through below-grade walls and floors which generally are the primary route for radon infiltration into homes. Radon may also volatilize from well water when it is heated or agitated (aerated), such as during a shower or when using a clothes washer or dishwasher (USEPA 1998, 1999). Soil-gas intrusion is the major source of radon in homes whereas, in most cases, waterborne radon is a much smaller contributor to indoor air radon levels. Because of this, efforts should be focused on reducing the contribution of soil gas intrusion to indoor radon levels in homes where elevated radon levels exist both in water and air (Barn et al. 2011). Figure D-5 and Table D-3 present major routes of radon infiltration into the indoor air.

Figure D-5 Sources and pathways of radon into a building



Source: Radon: is it in your home? http://www.bc-sc.gc.ca/envh-semt/alt_formats/becsscsc/pdf/pubs/radiation/radon_brochure/radon-brochure-eng.pdf (Accessed on January 9, 2012)

Table D-3 Major routes of radon infiltration into the indoor air

Major routes of radon infiltration into the indoor air	
A.	Cracks in concrete slabs.
B.	Cavities behind brick veneer walls that rest on uncapped hollow-block foundation.
C.	Pores and cracks in concrete blocks.
D.	Concrete floor-wall joint cavities.
E.	Exposed soil, as in a sump.
F.	Weeping (drain) tile, if drained to open sump.
G.	Cracked mortar joints.
H.	Cavities around concrete floor and wall pipe penetrations.
I.	Open tops of concrete block walls.

Source: USEPA. 1987. Radon Reduction in New Construction: An Interim Guide, Office of Radiation Programs, OPA-87-009, Washington, D.C., August 1987

D.4.1 Outdoor and indoor concentrations of radon

Our discussion on outdoor and indoor concentrations of radon is preceded by a discussion on the units of radon measurement and exposure. The following two boxes show that radon levels and radon progeny concentrations are measured in a variety of different units

Units of measurement for radon

Radon:

(Devices that measure concentrations of radon gas)

- The concentration of radon in either indoor or outdoor air is measured by its radioactivity in units of picocuries per litre (pCi/L), (U.S. system of measurement),
- The curie (Ci) is based on the activity of one gram of radium226 and equals 3.7×10^{10} disintegrations per second). One picocurie corresponds to 10^{-12} curies.

- or -

- Becquerels per cubic meter (Bq/m^3) (International system of measurement). 1 Becquerel is equal to 1 disintegration per second.

Radon Progeny

(Devices that measure the radiation emitted from radon progeny):

- The majority of dose received from radon is actually derived from energy emitted by the decay products rather than the gas itself. Because of this, the dose-per-unit radon gas activity is greatly dependent on the state of equilibrium of the decay products. To better describe the hazard associated with radon, worker exposure has historically been expressed in terms of the decay product activity. The unit developed for this is the Working Level (WL) (CDC, 2008).
- A working level is described as the amount of short-lived radon decay products in one litre of air that will ultimately decay with 1.3×10^5 million electron volts per litre (MeV) of alpha energy or 2.08×10^{-5} joules (J) per cubic meter
- The Working Level is a measure of the cumulative exposure to radon progeny in air. To describe exposure, the unit Working Level Month (WLM) is normally used. One WLM is described as the exposure received by an individual inhaling air containing a radon progeny concentration of WL for a period of 170 hours (one working month) (CDC, 2008). Health Canada defines one working level month as equivalent to $3.54 \text{ mJ}\cdot\text{h}\cdot\text{m}^{-3}$.
- The working level is a measure of the cumulative exposure to radon progeny in air. To describe exposure, the unit working level month (WLM) is normally used. One WLM is described as the exposure received by an individual inhaling air containing a radon progeny concentration of WL for a period of 170 hours (one working month) (CDC, 2008). Health Canada defines one working level month as equivalent to $3.54 \text{ mJ}\cdot\text{h}\cdot\text{m}^{-3}$.
- At full equilibrium one WL would be equivalent to 100 pCi/L of Rn-222 or 7.5 pCi/L of Rn-220. While this is a significant difference in the gas concentrations, by definition of the working level, the decay products will ultimately emit the same amount of alpha energy. This, however, does not lead to the same lung dose. This is caused largely by the difference in the half-lives of the decay products. Since Rn-220 products have longer half lives, the body has longer to transport the activity from one compartment to another and thus deliver dose to different areas of the lung (CDC, 2008).

Unit conversion for radon measurement

To make comparisons between data recorded in different units, the conversion examples listed below can be used for interpreting radon level measurements:

$$1 \text{ Bq/m}^3 = 0.027 \text{ pCi/L}$$

$$1 \text{ pCi/L} = 37 \text{ Bq/m}^3$$

(5.4 pCi/L is equal to 200 Bq/m³)

Note: Care must be exercised in converting from units of radon progeny to radon gas as the ratio between the units depends on a number of factors (Health Canada, 2008). There is no mathematical formula that will convert radon concentration to WL (working level) because the equilibrium factor varies in different situations. Equilibrium is extremely rare in real world.

1. If radioactive decay was the only removal method for the short-lived radon progeny, secular equilibrium would exist between the radon and its progeny after a few hours, then:

$$\text{WL} = \text{Rn conc. (pCi}\cdot\text{L}^{-1}) \times 0.01$$

or

$$\text{WL} = \text{Rn conc. (Bq}\cdot\text{m}^{-3}) \times 0.00027$$

2. Removal of the progeny by means other than radioactive decay results in the WL being less than that given in the equations above. This fractional reduction is known as the equilibrium factor (EF) and cannot be calculated by a formula because of the variety and complexity of radon progeny removal mechanisms; therefore, the WL cannot be calculated. Typically, the EF is either assumed (typically 0.4 to 0.5 for residential situations) or determined experimentally by simultaneous measurement of radon concentration and WL (Gesell, 2011).
3. The correspondence between WLs and radon concentration in air in pCi/liter depends on the extent to which radon daughters are in equilibrium with the parent radon. At complete equilibrium, one pCi/liter results in an exposure equal to 0.01 working levels. The assumption is generally made that inside buildings the radon decay product/radon equilibrium is 50 per cent. Thus, inside buildings, 1 pCi/liter = 0.005 WL, or 1 WL = 200 pCi/liter (University of Michigan, 2012).

The concentration of radon in indoor air is dependent upon the following variables:

- The radon concentration in the underlying soil and rock
- The soil porosity and permeability
- The availability of access routes, such as cracks and openings for gas entry into a building or residence
- Negative pressure
 - Radon transport into a home is increased when the premises are under negative pressure. This negative pressure can be created by excessive or prolonged use of home exhaust fans and the operation of fireplaces and wood stoves without combustion air supplies. Also contributing to increases in negative pressure is

heated air rising in homes causing a stack effect, wind blowing past a home which causes a downwind draft or Venturi effect (USEPA 1987), and indoor and outdoor temperature differentials.

- Ventilation rate:
 - Increased air exchange with outdoor air reduces the indoor radon level.
 - How tightly the building is sealed reduces energy costs. Tighter buildings increase indoor radon levels because of the decreased infiltration of outdoor air and exfiltration of indoor air.

Indoors, radon exposure can also occur from drinking water. A study conducted by B.C. Centre of Disease Control (BCCDC 2011) estimated that waterborne radon contributed less than 10 Bq/m³ to indoor radon levels. This is a minor contribution considering the Health Canada guideline for indoor radon concentrations is 200 Bq/m³. Similar results were found using an action level proposed by the USEPA, where radon in water is expected to contribute less than 20 Bq/m³ to indoor air levels. Based on these numbers, it is expected that water contributes minimally to indoor air levels of radon in a home (BCCDC, 2011).

The Canadian drinking water guideline for radium (²²⁶Ra) is 0.5 Bq/L. In comparison, the World Health Organization's guidance level is 1 Bq/L while the USEPA's standard is 5 pCi/L (approximately 0.2 Bq/L).

No drinking water guidelines or standards for radon (²²²Rn) in drinking water have been developed by Health Canada, the World Health Organization (WHO) or the USEPA. While it is not deemed necessary in Canada because of typically low levels, WHO does provide some guidance, suggesting that remediation is necessary at concentrations above 1,000 Bq/L of radon in water. In 1999, the USEPA proposed a Maximum Contaminant Level (MCL) as well as an Alternative MCL (AMCL) of 300 pCi/L (11 Bq/L) and 4,000 pCi/L (148 Bq/L), respectively; however, these values have not yet been completed. The MCL and the AMCL are intended to reflect two approaches to radon risk reduction, one which targets water as an important source and one which takes a multimedia approach, targeting soil gas intrusion. Although no U.S. federal radon standard exists, state drinking-water standards or guidelines have been developed by the states of Connecticut (185 Bq/L), Maine (148 Bq/L) and Massachusetts (370 Bq/L).

Finally, the European Union has provided its member states with some guidance on developing reference levels for radon in water, suggesting that below 100 Bq/L no action needs be taken, but above 1000 Bq/L remediation should take place (BCCDC, 2011)

Health Canada (2009) concludes that the health risk from ingesting radon-contaminated drinking water is negligible because most of the radon escapes at the faucet or water outlet, leaving only minimal amounts in the water itself. However, it should be noted that radon levels in drinking water, if sufficiently elevated, can significantly affect airborne radon concentrations. Where indoor-air radon concentrations exceed 200 Bq/m³ as an annual average concentration in the normal living area, then the source of the radon should be investigated, including monitoring radon concentrations in drinking water. If radon concentrations in drinking water exceed 2,000 Bq/L, it is recommended that actions be taken to reduce the release of radon from the drinking water into indoor air (Health Canada, 2009).

D.5 Exposure

The fate of radon in the body includes the following (USNRC 1999):

- Ingested radon is absorbed from the gut.
- Exhalation is the major route of elimination from the body.
- Ingested radon is largely eliminated within an hour.
- Body adipose tissue is the major site of long-term retention.

Overall, a person's exposure to radon will depend on the specific region in which one lives and their proximity to radon-producing geological formations. Exposure to radon occurs via two major exposure pathways: ingestion and inhalation. Inhalation is the primary route of exposure to radon in indoor air. Risk from ingesting radon-contaminated drinking water is considered negligible but should be mitigated when indoor air radon concentrations exceed 200 Bq/m^3 or radon concentrations in drinking water exceed 2000 Bq/L (Health Canada, 2009).

Exposure to higher levels of radon occurs in indoor air because radon levels are found in higher concentrations indoors than outdoors (CDWG 1995). UNSCEAR (1988) estimated an average population weighted mean indoor radon concentration of 50 Bq/m^3 for temperate regions of the world.

Exposure to radon from indoor and outdoor air far exceeds the exposure to radon from drinking water through both ingestion and inhalation. The global average dose of radon from all sources through inhalation is 1 mSv/year (WHO 1993), which is almost half of the total radiation exposure of 2.4 mSv/year (UNSCEAR 1988). The following box provides detailed information about radiation exposure and dose.

Radiation exposure and dose

Radiation exposure

All exposures to ionizing radiation carry a risk of biological damage although this risk decreases as the exposure decreases. For example, the risk associated with natural background radiation is very small. For workers in certain industries, such as miners and medical radiographers, the risk is slightly higher. Exposure levels from a nuclear or radiological emergency can vary widely depending on the nature of the incident, the type of radiation involved and even weather patterns.

Dose assessment

There are a number of factors to consider in calculating the quantity—or dose—of radiation a person has received, including:

- Nature of the ionizing radiation
- Strength of the source
- Biological sensitivity of the area exposed
- Exposure factors, such as time, distance and shielding from the source

This calculation is referred to as a dose assessment.

Radiation dose terminology

The terminology for specifying radiation dose and its effects on the human body takes into account all factors important in determining radiation's biological effect. The most often used dose measurements include absorbed dose, equivalent dose, effective dose and collective dose.

Absorbed dose

As radiation passes through matter, some of its energy is left behind or "absorbed" by the matter. This absorbed energy is referred to as the absorbed dose and is measured in grays (Gy).

Equivalent dose

Different types of radiation have different effects on tissue. To account for these differences, the absorbed dose is multiplied by a radiation weighting factor. This factor is dependent upon the type and amount of radiation involved. The result is referred to as the equivalent dose and is expressed in sieverts (Sv).

Effective dose

Different tissues and organs are affected differently by radiation. For example, radiation is more likely to affect lung tissue than skin tissue. To account for the differing sensitivities, the equivalent dose is multiplied by a *tissue-weighting factor*. The resulting unit, referred to as the effective dose, is expressed in sieverts (Sv).

Collective dose

The collective dose refers to the amount of radiation received by a group of people. This dose is calculated by multiplying the average effective dose by the number of persons exposed. The collective dose is expressed in person-sieverts (person-Sv).

Radiation exposure limits

The Canadian Nuclear Safety Commission (CNSC), the federal regulator of nuclear facilities and materials in Canada, sets radiation dose limits for workers, such as nuclear power workers and medical personnel who work with sources of ionizing radiation. The CNSC also sets dose limits to protect the general public from overexposure to radiation from licensed nuclear facilities or substances in Canada.

Radiation dose limits

The following table shows the current Canadian dose limits for exposure to licensed sources of radiation.

Population group	Dose limits: over five years	Dose limits: annual
Worker	100 mSv	50 mSv
Public	—————	1 mSv

Source: Health Canada, 2008, add rest from original

Health Canada (2012) recently conducted a cross-Canada survey of radon concentrations in homes. Table D-3 shows the percentage of participants in each province and territory with results below 200 Bq/m³, between 200 and 600 Bq/m³ and above 600 Bq/m³.

Table D-3 Population-weighted percentage of Canadian living in homes with radon concentrations for each province and territory

Province/Territory	Below 200 Bq/m ³	200 to 600 Bq/m ³	Above 600 Bq/m ³
Alberta	94.3 %	5.5 %	0.2 %
British Columbia	96.1 %	3.4 %	0.5 %
Manitoba	80.6 %	18.0 %	1.4 %
New Brunswick	79.4 %	15.2 %	5.4 %
Newfoundland/Labrador	94.9 %	4.4 %	0.7 %
Nova Scotia	89.3 %	8.2 %	2.5 %
North West Territories	94.6 %	4.9 %	0.5 %
Nunavut	100.0 %	0.0 %	0.0 %
Ontario	95.4 %	4.2 %	0.6 %
Prince Edward Island	96.5 %	3.5 %	0.0 %
Quebec	91.8 %	7.5 %	0.7 %
Saskatchewan	84.3 %	14.4 %	1.3 %
Yukon Territory	80.4 %	13.8 %	5.8 %

Source: Health Canada, 2012. *Cross-Canada Survey of Radon Concentrations in Homes. Table 3. Available at <http://www.bc-sc.gc.ca/ewb-semt/radiation/radon/survey-sondage-eng.php> (Accessed on May 28, 2012)*

While the radon levels in the vast majority of Canadian homes are below the current Canadian guideline of 200 Bq/m³, the results show that approximately 6.9 per cent of Canadian homes have elevated radon levels. This survey confirms that radon levels vary significantly across the country and that there are areas where high levels of indoor radon are more prevalent. Manitoba, New Brunswick, Saskatchewan and the Yukon had the highest percentages of participant homes which tested above the radon guideline. Conversely, Nunavut and Prince Edward Island had the lowest percentage. However, the data in Table D-3 should never be used by a homeowner in making a decision whether to test their home for radon. At best, these data are an estimate of the number of homes with levels above the Canadian Radon Guideline in a particular province or territory. The only way to know if a home has an elevated level of radon is to test the home, regardless of location (Health Canada, 2012).

D.6 Guidelines and recommended actions

D.6.1 Health Canada

Although there is no regulation that governs an acceptable level of radon in Canadian homes or public buildings including schools, hospitals, care facilities and detention centres. Health Canada and partners (2007) developed a guideline which recommends the following:

- Remedial measures should be undertaken in a dwelling whenever the average annual radon concentration exceeds 200 Bq/m³ in the normal occupancy area.
- The higher the radon concentration, the sooner remedial measures should be undertaken.
- When remedial action is taken, the radon level should be reduced to a value as low as practicable.
- The construction of new dwellings should employ techniques that will minimize radon entry and will facilitate post-construction radon removal should this subsequently prove necessary.

Health Canada further provides recommendations on the timeline of remediation based on the radon concentration measured in a home.

Health Canada recommended actions for radon remediation

Radon concentration	Recommended action time
< 200 Bq/m ³	No action required
200- 600 Bq/m ³	Remediate within 2 years
> 600 Bq/m ³	Remediate within 1 year

Source: Health Canada. 2010. *Radon: Protect Yourself and Your Family*. Available at <http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/protect-protoger-eng.php> (Accessed on January 11, 2012)

D.6.2 U.S. Environmental Protection Agency (USEPA)

EPA's current action level is 4 pCi/L. EPA recommends homes be fixed if the radon level is 4 pCi/L or more. Because there is no known safe level of exposure to radon, EPA also recommends that Americans consider fixing their home for radon levels between 2 pCi/L and 4 pCi/L. The average radon concentration in the indoor air of America's homes is about 1.3 pCi/L. It is this level that USEPA based its estimate of 20,000 radon-related lung cancers a year.. It is also for this simple reason that USEPA recommends that Americans consider fixing their homes when the radon level is between 2 pCi/L and 4 pCi/L.

The average concentration of radon in outdoor air is 0.4 pCi/L or 1/10th of EPA's 4 pCi/L action level. The U.S. Congress has set a long-term goal that indoor radon levels be no higher than outdoor levels. While this goal is not yet technologically achievable in all cases, the radon level in most homes today can be reduced to 2 pCi/L or below (USEPA, 2009).

USEPA recommended actions for radon remediation

Radon concentration	Recommended action time
≥4 pCi/L (about 150 Bq/m ³)	Remediation of home should be conducted.
2-4 pCi/L (75-150Bq/m ³)	Remediation of home is recommended because the radon concentration is higher than the average indoor radon concentration in the indoor air of America's homes. Most homes today can be reduced to 2 pCi/L or below with the available technologies.

Source: U.S. Environmental Protection Agency, 2009. *A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon*. Available at <http://www.epa.gov/radon/pdfs/citizensguide.pdf> (Accessed on January 12, 2012)

D.6.3 World Health Organization (WHO)

WHO's recent studies have shown that, when exposed to a radon concentration of 100 Bq/m³, a non-smoker's risk of lung cancer by age 75 years increases by 1 in a 1000 compared to non-exposed persons (2005 press release). Therefore, WHO proposes a reference level of 100 Bq/m³ to minimize health hazards because of indoor radon exposure. However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq/m³, which represents approximately 10 mSv per year according to recent calculations by the International Commission on Radiation Protection (WHO, 2009).

D.6.4 The American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASHRAE Standard 62.1 (ASHRAE 2010) specifies minimum ventilation rate and other measures intended to provide acceptable indoor air quality in new or existing buildings. The 2010 revision of ASHRAE 62.1 adopts the EPA's action level as the target indoor concentration for Radon.

ASHRAE's concentration of interest for radon	
4 pCi/L (about 150 Bq/m ³)	Based on lung cancer, average exposure for one year.

Source: © ASHRAE (*Ventilation for Acceptable Indoor Air Quality*), (Standard 62.1-2010), (2010).

CNSC, formerly known as the Atomic Energy Control Board (AECB), Canada sets radiation exposure limits in relationship to nuclear facilities. CNSC sets two types of exposure limits: one for occupationally exposed persons, the other for the general public. The annual occupational exposure limit is 4 WLM. The annual exposure limit for the general public is 70 Bq/m³. In homes and other non-occupational settings, the maximum permissible annual average concentration of radon daughters caused by the operation of a nuclear facility is 0.02 WL (radon level 148 Bq/m³).

CNSC's permissible exposure limits	
70 Bq/m ³	Annual exposure limit for general public

Source: Canadian Centre for Occupational Health and Safety (2009), *Radon in Buildings*, Available at http://www.ccohs.ca/oshanswers/phys_agents/radon.html (Accessed on January 12, 2012)

D.7 Radon testing

Since it is impossible to know which homes will have elevated levels, the only way to determine whether a home has a high radon level is to test for it (Health Canada, 2008). In Canada, the responsibility of radon testing and taking steps to lower radon concentrations when necessary rest with building owners (Canadian Nuclear Association, 2009). However, there is no legal requirement for a landlord to test a rental property, thus tenants will have to test radon themselves unless the landlord agrees to test for radon. If the radon levels are found to be high, the landlord is not required to fix the problem because the Canadian guideline for radon in indoor air is voluntary; there is no legal requirement for the landlord to remediate the situation to lower the radon level (Health Canada, 2011).

Testing is easy and inexpensive and can be completed by the homeowner or a professional. Homeowners are responsible for the cost of radon testing in their own homes. Most homes can be fixed for about the same cost as other common home repairs (Health Canada, 2008).

The following two Health Canada documents provide guidance for radon measurements in various types of buildings:

- Health Canada's document, *A Guide for Radon Measurements in Residential Dwellings (Homes)*, is available for concerned people who require guidance regarding types of measurement devices, device placement, measurement duration and the interpretation of measurement results in residential homes (available at http://publications.gc.ca/collections/collection_2009/sc-hc/H128-1-08-543E.pdf, accessed on February 27, 2012).
- A separate guide, *Guide for Radon Measurements in Public Buildings*, is written for persons and organizations intending to carry out radon measurements in public buildings. These buildings, considered dwellings, have a high occupancy rate or residency period for members of the public. The types of buildings include hospitals, schools, long-term care residences and correctional facilities. (http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/radiation/radon_building-edifices/radon_building-edifices-eng.pdf (accessed on February 27, 2012)).

Buildings where the occupants are employees are considered “work places” and; therefore, exposure to radon is governed by different guidelines and regulations, such as the Canadian Guidelines for Management of Naturally Occurring Radioactive Materials (NORM) and the Canada Labour Code (Health Canada, 2008).

The Health Canada documents provide technical guidance for measuring radon in a building, including testing devices, testing duration and locations. Below is a brief summary of these important technical requirements described in the Health Canada guide documents.

D.7.1 Measurement duration

Since the radon concentration inside a home varies over time, measurements gathered over a longer period of time will give a much better indication of the annual average radon concentration. Health Canada (2008) recommends that homes be tested for a minimum of three months, ideally between October and April.

D.7.2 Measurement location

To provide a realistic estimate of the radon exposure of the occupants, all measurements should be made in the normal occupancy area of the lowest lived-in level of the home. The normal occupancy area is defined as any area occupied by an individual for more than four hours per day.

Potential measurement locations include family rooms, living rooms, dens, playrooms and bedrooms. A lower level bedroom is preferred because people generally spend more time in their bedrooms than in any other room in the house. Similarly, if there are children in the home, lowest level bedrooms or other areas such as a playroom are preferred.

- The preferred device location is by an interior wall at a height of 0.8 m to 2 m (3 ft. to 6.5 ft.) from the floor in the typical breathing zone, however, at least 50 cm (20 in.) from the ceiling and 20 cm (8 in.) from other objects so as to allow normal air flow around the detector. The detector should be placed approximately 40 cm (16 in.) from an interior wall or approximately 50 cm (20 in.) from an exterior wall.
- Measurements should not be made in kitchens or laundry rooms. Kitchen exhaust fan systems and airborne particles caused by cooking may affect some measurement devices.
- Measurements should not be made in bathrooms because relatively little time is spent in a bathroom. Also, high humidity may affect some measurement devices and use of an exhaust fan may temporarily alter radon concentrations.
- Measurements should not be made in closets, cupboards, sumps, crawl spaces or nooks within the foundation. Radon concentrations in these areas are not representative of the concentration in the occupied area of the house.
- The location should not be in air currents caused by heating, ventilating and air conditioning vents, doors, fans and windows. Locations near heat, such as above radiators, near fireplaces or in direct sunlight, should be avoided as some measurement devices may be affected. Similarly devices should not be placed on or near electrically powered equipment or appliances, such as the tops of televisions, stereos or speakers.
- Homeowners should always consider re-testing whenever major renovations are performed that might substantially change the ventilation or air flow in the home or increase use of rooms in the lowest-occupied level. For example, a home basement that undergoes refinishing should be retested, assuming the original test was performed on another level (main floor).

D.7.3 Radon measurement devices

Since the radon concentration inside a house varies over time, measurements gathered over a longer period of time will give a more accurate reading of the radon level in a house. There are several radon measurement devices that may be used to test a home or building for radon. These devices fall into two broad categories: those used for long-term measurements (three to 12 months) or those designed for short-term measurements (less than 3 months and more typically two to seven days). Health Canada recommends that houses be tested for a minimum of three months, ideally between September and April when windows and doors are typically kept closed (Health Canada, 2011). The detection methods listed below are currently recognized by Health Canada as acceptable for measuring radon in homes and public buildings (Health Canada, 2008)

- Devices for long-term measurements (three-12 month in duration)
 - Alpha track detector
 - Electret ion chamber
 - Digital detector
- Devices for short-term measurements (< three months, more typically two to seven days)
 - Activated charcoal adsorption
 - Charcoal liquid scintillation
 - Electret ion chamber
 - Continuous radon monitoring
 - Continuous working level monitoring

The National Collaborating Centre for Environmental Health (NCCEH) at the B.C. Centre for Disease Control (BCCDC) conducted an evaluation on various devices and summarized that (NCCEH, 2009):

- Long-term radon testing over 12 months provides the most accurate estimate of average annual indoor radon levels. Alpha-track or electret ion chamber detectors are recommended for such long-term tests.
- Short-term testing can be used either for preliminary crude screening of the effectiveness of radon remediation and prevention work already undertaken, or of the possible need for remediation of real estate being purchased. Regardless of the results, long-term testing should be subsequently carried out for confirmation.

For detailed comparisons of advantages and disadvantages of various types of detectors, the reader should refer to the NCCEH's publication *Residential Indoor Radon Testing* (available at: http://www.ncceh.ca/sites/default/files/Radon_Testing_May_2009.pdf).

There are two options for testing a house for radon: purchase a do-it-yourself radon test kit or hire a radon-measurement accredited professional. A list of radon detector suppliers may be found in a local community's *Yellow Pages*. Information on radon testing in Canada is available through the Health Canada website (<http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/protect-proteger-eng.php>).

D.8 Radon control and mitigation

D.8.1 Radon control for new constructions

When considering sites for new house construction, various factors should be considered, including (Godish 1989):

- **Soil permeability**

Increased permeability will facilitate the migration of radon within soil. Soil permeability is a site-specific variable determined by consulting "soil maps." For instance, clay soil will retard the movement of radon while sandy or gravelly soil will offer minimal restriction to the upward migration of radon gas.

- **Unstable soils**

Soils predisposed to frost heaving or having high shrink-swell capacities that may be unstable, thus causing the settling and cracking of subsurface structures, such as basements.

- **Site selection**

In areas where radon is a concern, homes should not be constructed on glacially deposited materials such as eskers and kames because of increased soil permeability, or on top of uranium and phosphate tailings as they have the potential for high radon concentrations.

For new homes and buildings, radon prevention strategies can be undertaken during construction to reduce residents' exposure to radon. NCCEH (2009) summarizes approaches that can be used to reduce indoor radon exposure in new buildings based on literature review:

- Reduce radon entry points into the home or building by installing a polyethylene barrier membrane in the foundation and traps in floor drains, and by minimizing cracks in concrete materials
- Construct a block-and-beam-supported concrete floor that allows for passive underfloor ventilation.
- Reducing forces which draw radon-containing air into homes by installing fresh air and combustion air ducts.

-or-

- Provide for an active soil depressurization system through installing a polyvinyl chloride pipe in the floor slab onto which an exhaust pipe can be attached, if needed.

Studies conducted by Woolliscroft *et. al* (1994) and Arvela (2001) demonstrated that in new home construction both barrier membranes and block-and-beam construction were effective in reducing indoor radon levels to below the current Canadian guideline action level of 200 Bq/m³.

- Barrier membranes have been found to reduce indoor radon levels by up to 50 per cent.
- Block-and-beam construction have been found to reduce indoor radon levels by up to 50 per cent.
- Barrier membranes used together with block-and-beam construction combine to substantially reduce indoor radon levels.

The National Research Council Canada (NRCC) launched a new National Model Construction Codes (2010 edition), which provided significant technical changes related to radon control and mitigation for new constructions.

- The new Health Canada guideline of 200 Bq/m³ for indoor radon concentration has been referenced in this appendix.
- Parts 5 and 6 now require that engineers and designers consider radon protection in their designs.
- Air barrier requirements in Part 9 were consolidated and prescriptive measures on providing a rough-in for a future radon mitigation system added.

The national codes must be adopted by provincial and territorial authorities to become law (NRCC, 2011).

D.8.2 Remediation of radon in existing homes

Information for remediation of radon in existing houses and buildings can be found from various jurisdictions. For example:

1. Canada Mortgage and Housing Corporation (CMHC). 2010. *Radon -A Guide for Canadian Homeowners*. Available at : <http://www.cmhc-schl.gc.ca/odpub/pdf/61945.pdf>
2. Health Canada -*Environmental and Workplace Health*. <http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/index-eng.php>
3. Health Canada. 2010. *Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors*. Available at : http://publications.gc.ca/collections/collection_2012/sc-hc/H128-1-11-653-1-eng.pdf
4. U.S. Environmental Protection Agency <http://www.epa.gov/radon>
5. USEPA. 1994. *Radon Prevention in the Design and Construction of Schools and Other Large Buildings* (USEPA/625/R-92/016). Available at : <http://www.epa.gov/nrmrl/pubs/625r92016/625r92016.htm>

NCCEH's literature review (2009) concludes that the following points should be considered for assessing the cost-effectiveness of radon abatement methods for existing homes:

- Of the remediation measures evaluated to reduce indoor radon levels in already built homes, active systems were found to be better than passive ones.
- Depressurization methods were the most effective remediation measures.
- Active ventilation measures were the next most effective, passive ventilation less effective.

- Sealing alone was found to be the least effective method.
- In the case large buildings or of dwellings having high radon levels, combination remediation strategies have been found to be more effective than single measures.

Health Canada (2010) provides a summary of radon reduction systems that professional contractors can use to mitigate radon in existing homes. The mitigation options are listed in Tables D-5 and D-6. For detailed discussion on these mitigation options, readers should refer to *Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors* (Health Canada 2010).

Table D-5 Mitigation options of using masonry and hollow block foundations

Foundation type <i>Foundation floor</i>	Poured concrete		Slab-on-grade	
	<i>Exposed soil/ pavers</i>	<i>Concrete slab</i>	<i>Exposed soil (building extension)</i>	<i>Concrete slab</i>
Mitigation options				
Close large openings to soil in any accessible parts of foundation walls/floor.	☑	☑	☑	☑
Trap floor drains that lead to soil.	☑	☑	☑	☑
Cover soil water drain sump and exhaust it to outside.	☑	☑	☑	☑
Isolate foundation area from living area. Exhaust foundation area air to outside*.	☑	☑	☑	☑
Isolate foundation area from living area. Install heat-recovery ventilator to supply fresh air to living area and exhaust foundation area air to outside*.	☑	☑	☑	☑
Install heat-recovery ventilator to supply fresh air to living area and exhaust from bathroom or furnace area to outside*.	☑		☑	
Cover accessible area of exposed soil/pavers with plastic membrane, exhaust from beneath to outside*.		☑		☑
Exhaust from beneath concrete slab to outside*.			☑	☑

Source: Health Canada. (2010) Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors

Table D-6 Mitigation options of pouring concrete and slab-on-grade foundations

Foundation type	Poured concrete		Slab-on-grade	
	Exposed soil/ pavers	Concrete slab	Exposed soil (building extension)	Concrete slab
Mitigation options				
Close large openings to soil in any accessible parts of foundation walls/floor.	☑	☑		☑
Trap floor drains that lead to soil.	☑	☑		☑
Cover soil water drain sump and exhaust it to outside.	☑	☑		☑
Isolate foundation area from living area. Exhaust foundation area air to outside.*	☑	☑	☑	
Isolate foundation area from living area. Install heat-recovery ventilator to supply fresh air to living area and exhaust foundation area air to outside*.	☑	☑	☑	
Install heat-recovery ventilator to supply fresh air to living area and exhaust from bathroom or furnace area to outside*.				☑
Cover accessible area of exposed soil/pavers with plastic membrane, exhaust from beneath to outside*.	☑		☑	
Exhaust from beneath concrete slab to outside*.		☑		☑

* CAUTION: Back-drafting of combustion appliances is possible; for example, from a wood stove, oil or gas furnace, and oil or gas water heater.

Source: Health Canada. (2010) *Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors*

D.8.3 Removal of radon from household water

Radon can be removed from water by using one of two methods (CDC, 2010):

- **Aeration treatment**

This treatment sprays water or mixes with air, and then vents the air from the water before use. However, home aeration devices have not undergone broad testing or evaluation to determine their efficiency in removing radon from water sources.

- **Granular-activated carbon (GAC) treatment**

GAC treatment filters water through granular activated carbon. Radon attaches to the carbon leaving the water free of radon. Disposing of the carbon may require special handling if the carbon is used at a high radon level or if the carbon has been used for a long time.

A GAC tank, which is similar in appearance to a water softener tank, provides high collection efficiency for radon (up to 99 per cent) (USEPA 1987). Small carbon water filters, such as those normally attached to kitchen faucets or placed under the sink, are not of sufficient size to be effective in lowering of radon levels in water.

As mentioned previously, the various control measures outlined above are not presented in great detail, nor do they represent the only control options available. It is also important to note that no two structures are alike with regard to radon infiltration, building design, air exchange rates and atmospheric conditions. Consequently, even homes located in close proximity to one another and similar in structure, will have unique conditions that can lead to different radon levels. Therefore, site-specific control measures are recommended.

For further information on radon, consult the following sources::

- *What You Need To Know About Radon* (by Health Canada)
http://www.edmonton.ca/environmental/documents/Radon_-_What_You_Need_To_Know.pdf
- The Lung Association. *The Lung Association's Radon Awareness Campaign* (2011/2012). <http://www.ab.lung.ca/~ablung/site/radon>
- Alberta Health Services. Lung Cancer <http://www.albertahealthservices.ca/2270.asp>
- Alberta Health Link at 1-866-408-5465 (LINK)

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E. Biological factors

E.1 Introduction

Indoor environments contain a complex mixture of live (viable) and dead (nonviable) micro-organisms, toxins, allergens, volatile microbial organic compounds and other chemicals. Biological contaminants include bacteria, moulds, mildew, amoeba viruses, animal dander and cat saliva, house dust mites, cockroaches and pollen (USEPA, 2010; Macher, 1999). These biological contaminants originate from a variety of indoor and outdoor sources. The indoor concentrations of some of these organisms and agents are known or suspected to be elevated in damp indoor environments and may affect the health of people living or working there. In particular, it has been suggested that dust mites and fungi, both of which favour damp environments, play a major role. For example, several fungi produce allergens known to be associated with allergies and asthma. Many fungi also produce toxins and irritants with suspected effects on respiratory health. Dampness may also promote bacterial growth and the survival of viruses (WHO, 2009).

Based on the nature and properties of micro-organisms, biological agents can act as allergens, infectious agents, toxicants that cause various health conditions. There is strong evidence regarding the hazards posed by several biological agents that pollute indoor air; however, WHO (2009) concluded that the individual species of microbes and other biological agents that are responsible for health effects cannot be identified for several reasons. First, people are often exposed to multiple agents simultaneously. Second, accurately estimating exposure can be complex. Third, exposure to biological agents can create many symptoms and health outcomes. The exceptions include some common allergies, which can be attributed to specific agents, such as house-dust mites and pets.

This chapter provides general information on the characteristics, ecology, reservoirs, sources and health effects of the biological agents most commonly encountered in indoor environments. These include: (a) living infectious micro-organisms including bacteria, fungi, amoeba, and viruses, (b) allergens from plants, micro-organisms, arthropods, birds, and mammal, (c) endotoxins, (d) mycotoxins from fungi, and (e) microbial volatile organic compounds(MVOCs).

E.1.1 Types of biological agents

In this section, the following biological agents are briefly introduced. For detailed information, see this chapter's sections *E.2 Moulds* through *E.7 Pollen*):

- Fungi (moulds)
- Mycotoxins
- Dust mites
- Bacteria
- Endotoxins
- Exotoxin
- MVOCs
- Viruses
- Animal allergens
- Pollens

E.1.1.1 Fungi (moulds)

Fungi are ubiquitous eukaryotic organisms, comprising an abundance of species. They may be transported into buildings on the surface of new materials or on clothing. They may also penetrate buildings through active or passive ventilation. Fungi are found in the dust and surfaces of every house, including those with no problems with moisture. Once fungi are indoors, fungal growth can occur only in the presence of moisture. Many fungi grow readily on any surface that becomes wet or moistened. Virtually all fungi readily germinate and grow on substrates in equilibrium with a relative humidity below saturation or 100 per cent.

“Mould” is a layman’s term for fungi that can grow on building materials in homes or other buildings (Health Canada, 2007). More specifically, it refers to all species of microscopic fungi that grow in the form of multicellular filaments, called hyphae which are the macroscopic structure. In contrast, microscopic fungi that grow as single cells are called yeasts, a connected network of tubular branching hyphae has multiple, genetically identical nuclei and is considered a single organism, referred to as a colony (Madigan and Martinko, 2005 as cited in WHO, 2009).

Mould growth can influence air quality because both spores and mycelial fragments are dispersed into the air and can be inhaled. Their penetration into the bronchial tree depends on their size. The smaller particles penetrate deeper into the lungs.

Three features of mould biochemistry that are of special interest in terms of human health include the following (Health Canada, 2007):

- Mould cell walls contain (1->3)- β -D-glucan, a compound with inflammatory properties.
- Mould spores and mycelial fragments contain allergens.
- The spores of some species contain low molecular weight chemicals that are cytotoxic or have other toxic properties (e.g. satratoxins and atranones produced by *Stachybotrys chartarum*).

E.1.1.2 Mycotoxins

Mycotoxins, or fungal toxins, are low-relative-molecular-mass biomolecules produced by fungi, some of which are toxic to animals and human beings (WHO, 2009). Mycotoxins are known to interfere with RNA synthesis and may cause DNA damage. Some fungal

species may produce various mycotoxins, depending on the substrate. In the case of *Penicillium*, one such compound is penicillin, a strong antibiotic (WHO, 2009). Several mycotoxins, such as aflatoxin from *Aspergillus flavus* and *Aspergillus parasiticus*, are potent carcinogens. Many mycotoxins are immunotoxic, but the trichothecene mycotoxins are immunostimulating at low doses (Eduard, 2006). Numerous mycotoxins have been classified by their distinct chemical structures and reactive functional groups, including primary and secondary amines, hydroxyl or phenolic groups, lactams, carboxylic acids, and amides.

Mycotoxins can be found in spores as well as in and on hyphal fragments, on surfaces and in the matrix on which toxin producing moulds are growing, and in dust from these environments (AIHA, 2008). Mycotoxin exposure is ubiquitous in human populations, primarily including ingestion and inhalation. Ingestion of mycotoxins in large doses (generally a milligram or more per kilogram of body weight) from spoiled or contaminated foods can cause severe human illness. Mycotoxins are regularly found in grains, cereals, nuts and animal products including meat, eggs and milk. Mycotoxins found in foods include trichothecenes, fumonisins, ochratoxin A, aflatoxins and zearalones (Bush *et. al*, 2006). Toxicity from ingested mycotoxins is out of scope of this manual and will not be discussed further.

In the non-occupational setting the potential route of exposure is through inhalation. Mycotoxins are not volatile and, if found in the respirable air, are associated with mould spores or particulates. They are not cumulative toxins, having half-lives ranging from hours to days depending on the specific mycotoxin. Calculations for both acute and subacute exposures on the basis of the maximum amount of mycotoxins found per mould spore for various mycotoxins and the levels at which adverse health effects are observed make it highly improbable that home or office mycotoxin exposures would lead to a toxic adverse health effects (Bush et al, 2006).

E.1.1.1 Dust Mites

House dust mites are arachnids, and many different species have been identified; however, only a few are of concern with respect to damp indoor environments. The natural food source of house-dust mites includes skin scales, although many other sources may be used. Therefore, in most houses, nutrition is abundantly available, particularly in mattresses and carpets or rugs. Laboratory studies have shown that most dust mites require a relative humidity in excess of 45% to 50% for survival and development, but they feed and multiply more rapidly at higher relative humidity. Indoor humidity is therefore the main influence on the presence and propagation of house dust mites. Damp houses therefore significantly increase exposure to dust-mite allergens, at least in populations living in mild and temperate climates (WHO, 2009).

E.1.1.3 Bacteria

Bacteria are ubiquitous prokaryotic single-cell organisms, comprising an abundance of components. They can be found in the dust and on the surfaces of every house, including those with no damp problems. Health -significant bacteria in indoor environments can be attributed to any of the following three types of sources:

- Aerosols from humans and animals
- Aerosols from water sources including humidifiers, showers and faucets
- Aerosols from the disturbance of bacteria growing on damp organic matter, similar to fungi

Generally, coughing, sneezing and speaking generate the majority of human aerosols. The following two bacteria are important because of their infectious and debilitating potential: *Legionella pneumophila* and *Pseudomonas aeruginosa*.

Additionally, human aerosolized bacteria that can be transmitted indoors include anthrax, brucellosis and tuberculosis. In certain circumstances, common waterborne bacteria from the genera *Acinobacter* can also cause life-threatening diseases. Significant exposure to bacteria in residential buildings can occur as a result of direct aerosolization from indoor water sources, such as humidifiers, and water damaged building materials and furnishings. Exposure to specific dust-borne bacteria can occur in dusty indoor environments (Godish 1989; Godish, 2000).

As described for fungi, water is a critical requirement for bacterial growth. In fact, bacteria require higher water activities than most fungi. The temperature and nutrient demands are generally met in most indoor environments. Surprisingly, few studies have been conducted on bacterial growth in damp houses. Those that have suggest that bacteria grow in the same areas as fungi. In particular, *Streptomyces*, a gram-positive spore-forming bacteria that are not normal indoor flora in urban environments, may grow on damp or wet building materials (Hyvarinen et al., 2002). Therefore, this bacteria's presence in indoor air may suggest that a building has a moisture problem (Samson et al., 1994). Although no clear association with dampness has been found, it has been suggested that endotoxins from gram-negative bacteria occur at increased levels in damp buildings (Bischof et al., 2002; Solomon et al., 2006).

E.1.1.4 Endotoxins

Endotoxins are integral components of the outer membrane of Gram-negative bacteria and are composed of proteins, lipids and lipopolysaccharides (LPS). The term *endotoxin* refers to a toxin on the bacterial cell wall, which is often liberated as a result of cell lysis. In the environment, airborne endotoxins are usually associated with dust particles or aqueous aerosols. They have a broad size distribution but the levels may be higher in the coarse fraction (Schwarze et al., 2007). Heavy exposure to endotoxins can cause respiratory symptoms including non-allergic asthma but moderate-to-low exposure may protect against allergies and asthma (Douwes, Pearce, and Heederik, 2002). It has been hypothesized that endotoxins play a role in the pathogenesis of rheumatic diseases in damp buildings (Lorenz et al., 2006).

LPS are a class of pure lipid carbohydrate molecules (free of protein and other cell-wall components) and are responsible for most of the immunological properties of bacterial endotoxins. LPS are stable, water-soluble, non-allergenic molecules composed of a lipid and a polysaccharide and have not been found in the cell walls of Gram-positive bacteria, mycobacteria or fungi (Morrison and Ryan, 1979; Rietschel et al., 1985). The lipid moiety of LPS, called *lipid A*, is responsible for their toxic properties. Although the terms *endotoxins* and *lipopolysaccharides* technically have different meanings, they are often used interchangeably in the scientific literature.

The concentrations of endotoxins in the indoor environment range from a few to several thousand endotoxin units. (See the following box for a definition of endotoxin unit per milligram of house dust (Douwes, Pearce and Heederik, 2002). When the concentration is expressed per square metre, it varies even more. The endotoxin levels in different studies vary only moderately regardless of the geographical area, which is remarkable, as the analytical methods used were not standardized. Few studies have focused on airborne concentrations in the indoor environment. Park et al. (2000) reported a mean airborne endotoxin level of 0.64 units/m³ in 15 houses in Boston, United States, and mean levels of endotoxins in dust of 44 units/mg to 105 units/mg. The mean inhalable level of endotoxins measured in nine houses in Belgium was similar; that is, 0.24 units/m³ (Bouillard, Devleeschouwer, and Michel, 2006). Indoor concentrations may be higher in damp houses, but a study conducted in areas of Louisiana affected by hurricane Katrina and the subsequent flooding did not confirm this (Solomon et al., 2006). Other studies also found no evidence for a relationship between endotoxins in house dust and observed dampness or mould.

Definition of an endotoxin unit

The potency of endotoxin is measured by comparing the biological activity of the sample to a reference standard. The most common biological assay is the Limulus ameobocyte lysate (LAL) assay, which utilizes the ameobocyte cells of the Limulus polyphemus (horseshoe crab). The U.S. reference standard is a LPS purified from E. coli O113:H10:K. The current preparation (1986) is known as EC6.

Because endotoxin molecular weight varies, a very broad range (from 10,000 to 1,000,000 Dalton), endotoxin levels are measured in "endotoxin units" (EU) with reference to EC6 reference standard endotoxin (U.S. Pharmacopoeia, Inc.; 1 EU = 0.1 ng EC6).

It must be emphasized that endotoxin measurements are based on a biological assay for biological activity or potency and do not represent a measure of the concentration of a single chemical substance (U.S. Pharmacopoeia, 1995 as cited in Maytt & Milton, 2001)

Source: Poole, S., D. Dawson, and R. E. Gaines Das. 1997. Second international standard for endotoxin: calibration in an international collaborative study. J. Endotoxin Res. 4:221–231.

Maytt T.A. & Milton D.K., 2001. Chapter 42, Endotoxins in Indoor Air Quality Handbook, Spengler, JD, Samet JM and McCarthy JF (Eds.). McGraw Hill Publications, 2001 ISBN 0-07-445549-4.

E.1.1.5 Exotoxins

Exotoxins are typically proteins, often enzymes that are produced and excreted by bacteria. They have the potential to cause damage after their release from the cell. An example of a well-known exotoxin is botulism toxin, which is produced by *Clostridium botulinum* (Godish, 2000).

E.1.1.6 Microbial volatile organic compounds (MVOCs)

Different types of microbial volatile organic compounds (MVOCs) are produced from bacteria. MVOCs are produced from wash waters, septic sewage, human wastes, animal wastes and decaying materials of plant and animal origin. The human body also produces MVOCs that result in typical body odour. *Geosmin* is an MVOC produced by some fungi

and has a characteristic earthy odour of soil. Bacteria can also produce inorganic gaseous emission such as hydrogen sulphide and ammonia from anaerobic decomposition (Godish, 2000).

E.1.1.7 Viruses

The presence and survival of airborne viruses within indoor environments is not generally associated with moisture sources within buildings, but is more a function of air turnover and circulation, temperature, relative humidity and the presence of other pollutants. Even though hundreds of human viruses exist and are capable of causing disease, viruses cannot replicate outside their human host. The amplification and dissemination of viruses depends primarily upon human activity and only slightly upon indoor air parameters (Calgary Health Region 1993). However, the energy efficiency or air-tightness of a home can increase exposure to viruses and increase the risk of illness. Viruses are common and ubiquitous contaminant especially in the winter or flu-season of the year (Calgary Health Region, 1993). Building ventilation systems can lessen airborne concentrations of viruses by a variety of mechanisms.

It has been hypothesized that damp indoor environments with sufficiently high air humidity prolong the survival of respiratory viruses, so that the occupants are at greater risk of respiratory infection and, possibly, the onset of allergic disease (Hersoug, 2005). Although some experimental evidence shows significantly better survival times for several common cold-causing viruses, no clinical or epidemiological data are available. It is therefore unclear whether exposure to viruses should be considered as a risk associated with damp indoor spaces (WHO, 2009).

Viruses contribute to some common illnesses that occur within the general human population. The common cold viruses including rhinoviruses and coronaviruses cause common symptoms such as fatigue, headache, nausea and myalgia. These symptoms are also associated with a wide variety of other environmental stressors (Burge, 1985, cited in Calgary Health Region, 1993). Apart from sneezing and coughing, flushing of toilets is another daily household activity that has the potential to aerosolize human enteric pathogenic viruses in homes and public facilities (Sattar and Ijaz, 1987). In rare cases, viruses can also be shed in animal dropping or urine debris, such as Hantavirus. The virus can infect people when they inhale dirt and dust contaminated with mouse urine or droppings, such as when people stir up dust while working in, or cleaning out, storage units and sheds (Macher, 1999).

E.1.1.8 Animal and insect allergens

In homes, pet animals have the potential to contaminate indoor air and affect the health of occupants with high concentrations of allergens. These allergens can be transferred to clothing during interaction with animals and pets. In this process, allergens can also be transported into homes where there are no pets (Woodcock and Custovic, 1998). Allergens from cats, dogs and rodents, such as rats, can elicit an allergic response and sensitization reaction in humans (Spengler et al., 2001).

Rat, mice, rabbits, gerbils and guinea pigs have proteinuria. Urinary proteins from those animals can become potent allergens to human beings. High concentrations of urinary proteins, such as Rat n 1, are found in male rats and are accumulated in and around rat cages. After the urine dries, it becomes airborne with particle sizes of approximately 7 µm (Spengler et al., 2001).

Insects can be sources of allergens in indoor environments. Cockroaches can cause allergic reactions in humans. In badly cockroach-infected homes, cockroach allergens have been measured in high concentrations in house dusts (Spengler et al., 2001).

E.1.1.9 Pollens

Pollen grains and plant allergens cause allergic discomfort and other reactions in human beings. Temperature and moisture availability are two important factors responsible for the distribution of plant pollens. The primary source of indoor pollens is outdoor air. The transport of pollens from outdoors to indoors depends on the presence of open windows, doors, ceilings, cracks, gaps in the outer walls and air intakes. Significant health effects, such as hay fever, asthma and allergic dermatitis, can be attributed to pollen exposures (Spengler et al., 2001).

E.1.2 Sources of biological agents

Biological agents are present both indoors and outdoors. The presence of many biological agents in the indoor environment is because of high humidity and inadequate ventilation. Excess moisture on almost all indoor materials leads to growth of microbes, such as mould and bacteria, which subsequently emit spores, cells, fragments and volatile organic compounds into indoor air. Moreover, high humidity promotes the chemical or biological degradation of materials, which also pollute indoor air. Dampness has therefore been suggested to be a strong, consistent indicator of risk for asthma and respiratory symptoms, such as cough and wheeze. The health risks of biological contaminants of indoor air could thus be addressed by considering dampness as the risk indicator (Institute of Medicine, 2004).

Table E-1 lists the various indoor and outdoor sources where biological agents can be present and the factors responsible for their growth in different microenvironments.

Table E-1 Potential sources of biological agents entry routes into buildings and factors related to microbial growth

Sources/route	Factors responsible for growth
<i>Outdoors</i>	
Outdoor air	<ul style="list-style-type: none"> • Crop planting and harvesting – exposed soil, soil turning, disturbance of plant materials • Excavation or construction operations • Wastewater treatment or irrigation • Textile mills, slaughter houses or rendering plants • Composting operations
Building exterior	<ul style="list-style-type: none"> • Poor grading or water drainage • Water intrusion • Blocked rain gutters • Penetrations in siding and veneer • Damage to building envelope • Wood rot in structural timbers • Animal infestation near building or crawl space beneath the building
<i>HVAC Systems</i>	
Outdoor air intakes (OIA's)	<ul style="list-style-type: none"> • Bioaerosol sources near OIA's • These sources may include plant debris, bird droppings, insect or rodent infestations • Other factors such as proximity of other systems such as sanitary air vents, cooling

Sources/route	Factors responsible for growth
	towers and evaporative condensers near Outdoor air intake
Filters	<ul style="list-style-type: none"> • Dampness • Microbial growth on filters • Gaps between filters and housings • Low efficiency filters
Heat exchangers	<ul style="list-style-type: none"> • Dirty heating or cooling coils • Excessive water in condensate pans • Inadequate drainage from collection pans • Blow-through of water droplets onto surfaces downstream of coils • Dampness and microbial growth on acoustical lining • Poorly maintained air washers or humidifiers • Stagnant water in air washers or humidifiers
Supply air plenums and ductwork	<ul style="list-style-type: none"> • Excessive surface deposits • Dampness and surface microbial growth • Inaccessible humidifiers
Supply air diffusers	<ul style="list-style-type: none"> • Surface deposits, rust or microbial growth on louvers • Soiling of adjacent ceilings and walls • Poor air mixing
<i>Indoor occupied space</i>	
Water damage	<ul style="list-style-type: none"> • Evidence of roof or plumbing leaks, water intrusion or spills • High indoor humidity (> 70%) • Inadequate drying of carpets and other building materials • Musty or mouldy odours
Condensation on windows, perimeter walls or other cool surfaces	<ul style="list-style-type: none"> • Inadequate insulation or intrusion of outdoor air
Air conditioners on window Evaporative air coolers	<ul style="list-style-type: none"> • Inconvenient location for maintenance • Dirty grilles • Standing water in condensate pans or sumps • Dampness and surface microbial growth in or near units
Fan coil and induction units	<ul style="list-style-type: none"> • Dirty heating or cooling coils and filters • Excessive water in condensate pans • Inadequate drainage from collection pans • Dampness and surface microbial growth near units
Potted plants	<ul style="list-style-type: none"> • Microbial growth on leaves and soil • Excess moisture from overwatering
Carpet	<ul style="list-style-type: none"> • Poorly maintained or water damaged carpets serve as a source for dirt accumulation and microbial growth
Fabric office partitions, wall coverings, drapes & upholstered furniture	<ul style="list-style-type: none"> • Poorly maintained or water damaged fabric covered and upholstered items serve as sources for dirt accumulation and microbial growth
Portable humidifiers	<ul style="list-style-type: none"> • Microbial growth may occur in the water reservoirs • Spray or mist units
Return air plenum	<ul style="list-style-type: none"> • Excessive surface deposits • Dampness and surface microbial growth

Source: *Bioaerosols: Assessment and Control*, Macher et al., 1999; *American Conference of Governmental Industrial Hygienist*

E.1.3 Health conditions related to exposure to biological agents

Table E-2 lists those bioaerosol-related health conditions and the known or suspected causative agents that can be allergenic, infectious or toxic.

Table E-2 Alphabetical listing of conditions related to exposure to biological agents

Condition	Description	Known or suspected causative agents
Allergic bronchopulmonary mycosis (ABPM)	A condition seen in asthmatics resulting from immunological reactivity to colonization of the airways with a fungus (mould)	Fungi (e.g. <i>Penicillium</i> spp.)
Allergic bronchopulmonary aspergillosis (ABPA)	The most common form of allergic bronchopulmonary mycosis in which the colonizing fungus is an <i>Aspergillus</i> sp	<i>Aspergillus flavus</i> <i>Aspergillus fumigates</i> <i>Aspergillus terreus</i>
Hypersensitivity disease (allergy)	Disease for which a subsequent exposure to an antigen produces a greater effect than that produced on initial exposure	Bacterial antigens Fungal Amebic Arthropodal Bird, Pollen Mammalian
Asthma	A chronic inflammatory condition of the airways; usually characterized by intermittent episodes of wheezing, coughing and difficulty breathing	Bacterial antigens Fungal Ameba Anthropodal Bird Pollen Mammalian Endotoxin
Common cold	Head cold, acute viral rhinitis, acute coryza; characterized by rhinitis, sneezing, lacrimation (tearing), irritated nasopharynx, chills, and malaise	Rhinoviruses or coronaviruses
Cryptococcosis	Systemic fungal infection usually presenting as a respiratory infection and occasionally as meningitis (e.g. in HIV-infected persons)	<i>Cryptococcus neoformans</i>
Hantavirus pulmonary syndrome (HPS)	Often fatal acute respiratory infection preceded by a flu-like illness	Dust containing rat or deer mice dropping or urine
Histoplasmosis	Systemic fungal infection of varying severity, with the primary lesion usually in the lungs	<i>Histoplasma capsulatum</i>
Influenza	Acute infectious disease of the respiratory tract, characterized by fever, headache, myalgia, prostration	Influenza virus
Inhalation fever	Bebrile, flu-like illness following heavy exposure to certain biological or chemical agents from environmental sources	Bacteria, <i>Legionellae</i> Fungi Amebae Endotoxin
Legionnaires' disease	Bacterial pneumonia; preceded by anorexia, malaise, myalgia and headache; accompanied by fever, chills and cough.	<i>Legionella pneumophila</i>
Pontiac fever	A form of inhalation fever; characterized by fever, chills, headache and myalgia	<i>Legionella</i> spp.
Primary amebic meningoencephalitis (PAM)	Rare inflammation of the brain and its lining because of infection with <i>Neogleria fowleri</i>	<i>Neogleria fowleri</i>
Tuberculosis (TB)	Bacterial infection that may affect many organs but most commonly the lungs	<i>Mycobacterium tuberculosis</i>

Adapted from: Bioaerosols: Assessment and Control, Macher et al., 1999; American Conference of Governmental Industrial Hygienist

E.2 Moulds

E.2.1 Sources

Moulds are fungi that can be found both indoors and outdoors. It is currently unknown how many species of fungi exist but estimates range from tens of thousands to perhaps three hundred thousand or more. Moulds grow best in warm, damp and humid conditions, and spread and reproduce by making spores. Mould spores can survive harsh environmental conditions, such as dry conditions that do not support normal mould growth.

Moulds are found in virtually every environment and can be detected, both indoors and outdoors, year round. Mould growth is encouraged by warm and humid conditions. Outdoors they can be found in shady, damp areas or places where leaves or other vegetation is decomposing. Indoors they can be found where humidity levels are high, such as basements or showers.

The species that grow on a given substrate depends largely on the water activity of the substrate. Water activity is a measure of water availability and is defined as the ratio of the vapour pressure above a substrate relative to that above pure water measured at the same temperature and pressure. The minimum water activity required for fungal growth on building surfaces varies from less than 0.80 to greater than 0.98 (Grant et al., 1989). On the basis of their water requirements, indoor fungi can be divided into three categories: (1) primary colonizers, which can grow at a water activity less than or equal to 0.80; (2) secondary colonizers, which grow at a water activity level of 0.80 to 0.90; and (3) tertiary colonizers, which require a water activity greater than 0.90 to germinate, and start mycelial growth (Grant et al., 1989).

Although high levels of humidity and some surface and interstitial condensation may be sufficient for most primary and secondary colonizers, tertiary colonizers generally require serious condensation problems. These problems may be because of construction faults, including inadequate insulation, in combination with poor ventilation, or water damage from leaks, flooding and groundwater intrusion. Fungi also need nutrients, which may include carbohydrates, proteins and lipids. The sources are diverse and plentiful, ranging from plant or animal matter in house dust to surface and construction materials, such as wallpaper and textiles, condensation or deposition of cooking oils, paint and glue, wood, stored products, such as food, books and other paper products. Therefore, nutrients are generally not a limiting factor for indoor fungal growth. In fact, fungi are known to grow even on inert materials such as ceramic tiles and can obtain sufficient nutrients from dust particles and soluble components of water. Water is the most critical factor in indoor fungal growth, as also shown in field studies, which show elevated numbers of fungi and fungal spores in damp houses (WHO, 2009).

Some of the common indoor moulds include the following (CDC, 2010):

- Cladosporium
- Penicillium
- Alternaria
- Aspergillus

E.2.2 Health effects

When moisture problems occur and mould growth results, building occupants may begin to report odours and a variety of health problems, such as headaches, breathing difficulties, skin irritation, allergic reactions and aggravation of asthma symptoms. All of these symptoms could potentially be associated with mould exposure.

All moulds have the potential to cause health effects. Moulds produce allergens, irritants, and in some cases, toxins that may cause reactions in humans. The types and severity of symptoms depend, in part, on the types of mould present, the extent of an individual's exposure, the ages of the individuals and their existing sensitivities or allergies. Five well defined pathophysiological mechanisms have been linked to adverse health outcomes caused or exacerbated by moulds: (1) immunologic reactions including allergic reactions such as rhinitis, dermatitis or skin rash; asthma, hypersensitivity pneumonitis (HP); (2) toxicity, (3) infection, (4) irritation, and (5) opportunistic infection (EPA, 2008).

Specific reactions to mould growth can include the following (USEPA, 2008):

- **Allergic reactions**

Inhaling or touching mould or mould spores may cause allergic reactions in sensitive individuals. Allergic reactions to mould, which are common, can be immediate or delayed. Allergic responses include hay fever-type symptoms, such as sneezing, runny nose, red eyes and skin rash or dermatitis. Mould spores and fragments can produce allergic reactions in sensitive individuals regardless of whether the mould is dead or alive. Repeated or single exposure to mould or mould spores may cause previously non-sensitive individuals to become sensitive. Repeated exposure has the potential to increase sensitivity.

- **Asthma**

Moulds can trigger asthma attacks in persons who are allergic or sensitized to moulds. The irritants produced by moulds may also worsen asthma in non-allergic or non-sensitized people.

- **Hypersensitivity pneumonitis**

Hypersensitivity pneumonitis may develop following either short-term (acute) or long-term (chronic) exposure to moulds. The disease resembles bacterial pneumonia and is uncommon.

- **Irritant effects**

Mould exposure can cause irritation of the eyes, skin, nose, throat and lungs, and sometimes can create a burning sensation in these areas.

- **Opportunistic infections**

People with weakened immune systems, such as immunocompromised or immunosuppressed individuals, may be more vulnerable to infections by moulds as well as more vulnerable than healthy persons to mould toxins. *Aspergillus fumigatus*, for example, has been known to infect the lungs of immunocompromised individuals. These individuals inhale the mould spores which then start growing in their lungs. *Trichoderma* has also been known to infect immunocompromised children. Immunocompromised persons and persons with chronic lung diseases like

COPD are at increased risk for opportunistic infections and may develop fungal infections in their lungs (CDC, 2010).

Healthy individuals are usually not vulnerable to opportunistic infections from airborne mould exposure. However, moulds can cause common skin diseases, such as athlete's foot, as well as other infections, such as yeast infections.

E.2.2.1 Health effects associated with exposure to mould metabolites

Different fungal metabolites, such as MVOCs, mycotoxins and glucans, can cause non-allergenic or toxigenic illnesses in exposed individuals.

- **MVOCs**

Moulds produce a variety of volatile organic compounds (IOM, 2004), the most common being ethanol (Schleibinger et. al., 2005) which are responsible for the unpleasant musty odours associated with fungal growth. Exposure to MVOCs from moulds has been linked to symptoms such as headaches, nasal irritation and other upper or lower respiratory tract symptoms, dizziness, fatigue and nausea (IOM, 2004; USEPA, 2008). Research on MVOCs is still in the early phase at the time.

- **Mycotoxins**

Moulds can produce toxic substances called mycotoxins. Some mycotoxins cling to the surface of mould spores; others are found within spores. More than 200 mycotoxins have been identified from common moulds, and many more remain to be identified. Some of the moulds that are known to produce mycotoxins are commonly found in moisture-damaged buildings. Exposure pathways for mycotoxins can include inhalation, ingestion, or skin contact. Although some mycotoxins are well known to affect humans and have been shown to be responsible for human health effects, for many mycotoxins, little information is available. Much of the information on the human health effects of inhalation exposure to mycotoxins comes from studies done in the workplace and some case studies or case reports (USEPA, 2008).

Some moulds can produce several toxins, and some moulds produce mycotoxins only under certain environmental conditions. The presence of mould in a building does not necessarily mean that mycotoxins are present or that they are present in large quantities. Aflatoxin B₁ is perhaps the most well known and studied mycotoxin. It can be produced by the moulds *Aspergillus flavus* and *Aspergillus parasiticus* and is one of the most potent carcinogens known. Ingestion of aflatoxin B₁ can cause liver cancer. There is also some evidence that inhalation of aflatoxin B₁ can cause lung cancer. Aflatoxin B₁ has been found on contaminated grains, peanuts, and other human and animal foodstuffs. However, *Aspergillus flavus* and *Aspergillus parasiticus* are *not* commonly found on building materials or in indoor environments.

Many symptoms and human health effects attributed to inhalation of mycotoxins have been reported including mucous membrane irritation, skin rash, nausea, immune system suppression, acute or chronic liver damage, acute or chronic central nervous system damage, endocrine effects and cancer. More studies are needed to understand the health effects related to most mycotoxins. However, it is clearly prudent to avoid exposure to moulds and mycotoxins (USEPA, 2008).

Some moulds, such as *Aspergillus versicolor* and *Stachybotrys atra* (*chartarum*), are known to produce potent toxins under certain circumstances. Although some mycotoxins are well known to affect humans and have been shown to be responsible for human health effects, for many mycotoxins little information is available, and in some cases, research is ongoing. For example, some strains of *Stachybotrys atra* can produce one or more potent toxins. In addition, preliminary reports from an investigation of an outbreak of pulmonary hemorrhage in infants suggested an association between pulmonary hemorrhage and exposure to *Stachybotrys chartarum*.

The occurrence of mould-related toxicity (mycotoxicosis) from exposure to inhaled mycotoxins in non-occupational settings is not supported by the current data, and its occurrence is improbable (IOM, 2004; Robins, 2004; Robert, 2006). CDC (2009) concluded that the causative association between the levels of airborne mycotoxins in damp buildings and adverse health effects has not been sufficiently demonstrated. In addition, CDC (2009) concludes that a possible association between acute idiopathic pulmonary hemorrhage among infants and *Stachybotrys chartarum* (*Stachybotrys atra*) has not been scientifically established either. Further studies are needed to determine what causes acute idiopathic hemorrhage.

- **Glucans or fungal cell wall**

Glucans are small pieces of the cell walls of moulds which may cause inflammatory lung and airway reactions. These glucans can affect the immune system when inhaled. Exposure to very high levels of glucans or dust mixtures including glucans may cause a flu-like illness known as Organic Dust Toxic Syndrome (ODTS). This illness has been primarily noted in agricultural and manufacturing settings (USEPA, 2008).

The Institute of Medicine report, *Damp indoor spaces and health*, concluded that there was insufficient evidence for a causal association between mould exposure and health effects but sufficient evidence of an association of indoor exposure to mould with upper respiratory tract symptoms, cough and wheeze in otherwise healthy people; with asthma symptoms in people with asthma; and with hypersensitivity pneumonitis in individuals susceptible to that immune-mediated condition (IOM, 2004).

Health Canada (2007) has also carried out two reviews of the scientific literature pertaining to the health effects of indoor moulds (Health Canada 1995; 2004). The Institut national de santé publique du Québec also published a review on this subject (d'Halewyn et al., 2003). The following conclusions were drawn by Health Canada (2007) The conclusions do not apply to persons with compromised immune systems, who are at risk for fungal colonization and opportunistic infection (IOM, 2004).

- Exposure to indoor mould is associated with an increased asthma-related symptoms, such as chronic wheezing, irritation symptoms and non-specific symptoms.
- In laboratory animal studies, instillation of fungal antigens (*Penicillium* sp. and *Aspergillus* sp.) and fungal cell components [(1->3)-β-D-glucan] resulted in an inflammatory response in the lungs of rodents, while instillation of *Stachybotrys chartarum* spores resulted in severe histological and biochemical changes.

E.2.2.2 Concerns about insufficient evidences of mould-induced effects

The IOM (2004) found sufficient evidence and limited or suggestive evidence linking indoor mould exposure and respiratory illness. Recent reviews of the literature support IOM's conclusion that insufficient valid scientific data exist to epidemiologically establish a causal relationship between inhaled mould exposure and human illness in indoor environments, although associational relationships exist for some adverse health outcomes (Bush et. al., 2006; Seltzer and Fedoruk, 2007). Excessive moisture facilitates the growth or accumulation of various non-fungal microbial agents, insects and rodents, all of which can result in adverse health effects similar to those from mould. The literature supporting other mould-related components, such as MVOCs and (1->3)- β -D-glucan, as capable of producing adverse health effects is presently insufficient for the assignation of cause or even association (Seltzer and Fedoruk, 2007).

The IOM's findings are also supported by the World Health Organization (WHO) *Guidelines for Indoor Air Quality: Dampness and Mould* (2009). WHO guidelines states that:

Microbial growth may result in greater numbers of spores, cell fragments, allergens, mycotoxins, endotoxins, β -glucans and volatile organic compounds in indoor air. The causative agents of adverse health effects have not been identified conclusively, but an excess level of any of these agents in the indoor environment is a potential health hazard.

Persistent dampness and microbial growth on interior surfaces and in building structures should be avoided or minimized, as they may lead to adverse health effects. Indicators of dampness and microbial growth include the presence of condensation on surfaces or in structures, visible mould, perceived mouldy odour and a history of water damage, leakage or penetration. Thorough inspection and, if necessary, appropriate measurements can be used to confirm indoor moisture and microbial growth.

As the relations between dampness, microbial exposure and health effects cannot be quantified precisely, no quantitative health-based guideline values or thresholds can be recommended for acceptable levels of contamination with micro-organisms. Instead, it is recommended that dampness and mould-related problems be prevented. When they occur, they should be remediated because they increase the risk of hazardous exposure to microbes and chemicals.

The following box presents a summary of findings regarding the association between health outcomes and the presence of mould or other agents in damp indoor environments.

Summary of findings regarding health outcomes and the presence of mould or other agents in damp indoor environments

Sufficient evidence of a causal relationship

(No outcomes met this definition)

Sufficient evidence of an association

- Upper respiratory tract (nasal and throat) symptoms
- Asthma symptoms in sensitized asthmatic persons
- Hypersensitivity pneumonitis in susceptible persons²
- Wheeze
- Cough

Limited or suggestive evidence of an association

- Lower respiratory illness in otherwise-healthy children

Inadequate or insufficient evidence to determine whether an association exists

- Dyspnea (shortness of breath)
- Airflow obstruction (in otherwise-healthy persons)
- Mucous membrane irritation syndrome
- Chronic obstructive pulmonary disease
- Inhalation fevers (nonoccupational exposures)
- Lower respiratory illness in otherwise-healthy adults
- Rheumatologic and other immune diseases
- Acute idiopathic pulmonary hemorrhage in infants
- Skin symptoms
- Asthma development
- Gastrointestinal tract problems
- Fatigue
- Neuropsychiatric symptoms
- Cancer
- Reproductive effects

¹ These conclusions are not applicable to immunocompromised persons, who are at increased risk for fungal colonization or opportunistic infections.

² For mould or bacteria in damp indoor environments. Data from The Institute of Medicine of the National Academies. *Damp indoor spaces and health*. Washington, DC: The National Academies Press; 2004, p. 10.

Source: *The Institute of Medicine of the National Academies. 2004. Damp indoor spaces and health. Washington, DC: The National Academies Press.*

E.2.3 Exposure

Indoor exposure to fungal aerosols, such as spore and hyphae and mycelium fragments, and their metabolic byproducts can occur from a variety of sources and pathways:

- Infiltration of outdoor fungal aerosols to the indoors through exposure via inhalation and dermal pathways
- Aerosolization of spores and hyphae/mycelia fragments and VOCS from different indoor sources (both inhalation and dermal pathways are relevant, ingestion is possible)

E.2.4 Exposure limits and guidelines

Because of variances in personal sensitivities and the presence of diverse groups of moulds, it has been impossible to set different exposure limits for moulds that can be applied to protect human health. In spite of these limitations, a few studies are available regarding exposure limits and the effect of inhaled moulds on human health (Davis, 2001). However, these studies have been limited by the absence of definitive biomarkers specific to moulds. At the present time, there are no established biomarkers that can prove that an individual has been exposed to moulds although research is progressing in this area. As a result of this limitation, a definitive correlation between mould exposure and incidence of specific health effects is not possible. *The New York City Department of Health Guidelines* (2008) states that susceptibility among humans varies with the genetic predisposition, age, state of health and concurrent exposures. Based on large information gaps in this dataset, it is not possible to determine safe or unsafe levels of exposure to moulds for the general population.

It is not possible to determine safe or unsafe levels of exposure for the general public because of variation of individual susceptibility, lack of standardized and validated environmental exposure sampling methods and lack of reliable biological markers (Douwes et. al., 2003).

At the time of the writing of this manual, no work had established the specific adverse effect that occurs at the lowest level of exposure nor had a true LOAEL or NOAEL been established, or chronic respiratory exposures in animals had not been gauged. More importantly, studies have focused on spores or on individual pure mycotoxins, neither of which characterizes what people breathe in indoor spaces. Indoor exposures are a complex mixture of moulds, bacteria, fragments of both types of organisms, their multiple toxic products and biologically derived small particles, gases and other air pollutants. Effects, depending on the susceptibility of the exposed occupants and their degree of exposure, can be combinations of allergic response, inflammation and its consequences, and other toxic responses.

E.2.4.1 Health Canada

Health Canada's *Residential Indoor Air Quality Guideline – Mould* (2007) reviewed the scientific literature on moulds and health effects and found:

- Exposure to indoor mould was associated with an increased prevalence of asthma-related symptoms, such as chronic wheezing, irritation symptoms, and non-specific symptoms.
- Instillation of fungal antigens in laboratory animal studies (*Penicillium* sp. and *Aspergillus* sp.) and fungal cell components [(1->3)- β -D-glucan] resulted in an inflammatory response in the lungs of rodents, while instillation of *Stachybotrys chartarum* spores resulted in severe histological and biochemical changes.

Health Canada concluded that mould growth in residential buildings may pose a health hazard. Health risks depend on exposure and, for asthma symptoms, on allergic sensitization. However, the large number of mould species and strains growing in buildings and the large inter-individual variability in human response to mould exposure precludes the derivation of exposure limits. Therefore, Health Canada recommends: (1) to control humidity and diligently repair any water damage in residences to prevent

mould growth; and (2) to clean thoroughly any visible or concealed mould growing in residential buildings. These recommendations apply regardless of the mould species found growing in the building. Further, in the absence of exposure limits, results from tests for the presence of fungi in air cannot be used to assess risks to the health of building occupants.

E.2.4.2 U.S. Environmental Protection Agency (USEPA)

In the absence of threshold limits, in most cases if visible mould growth is present, sampling is unnecessary. In specific instances, such as cases where litigation is involved, the sources of the mould contamination is unclear, or health concerns are a problem, sampling may be considered as part of the site evaluation (USEPA, 2010).

E.2.4.3 World Health Organization (WHO)

As the relations between dampness, microbial exposure and health effects cannot be quantified precisely, no quantitative health-based guideline values or thresholds can be recommended for acceptable levels of contamination with micro-organisms. Instead, it is recommended that dampness and mould-related problems be prevented. When they occur, they should be remediated because they increase the risk of hazardous exposure to microbes and chemicals.

E.2.4.4 New York City

New York City (2008) *Guidelines on Assessment and Remediation of Fungi in Indoor Environments*, also recommends indoor air monitoring for bioaerosols and bulk sampling not be a routine component of a building investigation. Air monitoring should be limited to a number of specific goals or reasons:

- Air monitoring is required to identify and quantify fungi for medical reasons.
- Air monitoring is conducted to help localize a fungal amplifier that is eluding discovery by following a concentration gradient.
- Air monitoring may be necessary to determine if fungal contamination has spread to other areas via an HVAC system.
- Bulk or surface sampling is not recommended as a routine investigation activity. Bulk sampling and analysis may be required as part of a medical evaluation or to complete an equivocal visual inspection, e.g., sample suspect discolouration or staining.
- In addition to the above conditions, air or bulk sampling may also be performed for legal purposes.

New York City (2008) recommends that buildings with visible mould growth (alive or dead), evidence of water damage or musty odours be addressed immediately. Releases of water or other moisture control problems in the building must be stopped, water damaged areas identified and promptly dried. Mould damaged materials should be delineated and remediated following recommended procedures, described later in this chapter. Environmental sampling is **not** usually necessary to proceed with remediation of visually identified mould growth or water-damaged materials. Decisions about appropriate remediation strategies can generally be made on the basis of a thorough visual inspection. Environmental sampling may be helpful in some cases, such as to confirm the presence of visually identified

E.2.5 Control measures

In general, control measures for indoor environments are directed at source control and prevention, and universally involve moisture control. These practices include controlling humidity, ventilation and other factors related to building materials and building structures.

In all situations, the underlying moisture problem must be corrected to prevent recurring mould growth. Indoor moisture can result from numerous causes, such as façade and roof leaks, plumbing leaks, floods, condensation and high relative humidity. An appropriate building expert may be needed to identify and repair building problems. An immediate response and thorough cleaning, drying or removal of water-damaged materials will prevent or limit microbial growth.

Relative humidity should generally be maintained at levels below 65 per cent to inhibit mould growth. Short-term periods of higher humidity would not be expected to result in mould growth. However, condensation on cold surfaces could result in water accumulation at much lower relative humidity levels. Relative humidity should be kept low enough to prevent condensation on windows and other surfaces.

Emphasis should be placed on ensuring proper repairs of the building infrastructure so that water intrusion and moisture accumulation is stopped and does not recur. Practical measures to avoid basement flooding and buildup of humidity are listed below. (CMHC, 2011, Avoiding Basement Flooding.)

E.2.5.1 Practical measures to avoid basement flooding and humidity build-up

- **Drainage around buildings**

Proper drainage helps to:

- Prevent wet basements, frost heaving problems and the build-up of hydrostatic pressure on basement floors, banks and retaining walls. A well-designed land drainage system can convert useless, poorly drained land to valuable building sites or permit construction to be carried on during extended periods of wet weather.
- Reduce the amount of water flowing into a house's sewer system and to the main sewer system to lessen the risk of sewer backup.
- Reduce water seepage into a home through basement windows and cracks in your basement walls.
- Keep the moisture content of the soil around and under a house stable to reduce the chances of cracking and shifting. If water collects next to a basement, it can make its way to the footings that support the basement walls. The increased moisture may cause the footings to heave or settle.
- Extend the life of a sump pump by reducing the amount of work it has to do.

Be sure that any drainage improvements made do not cause water to flow onto the neighbour's property.

- **Eavestroughs and downspouts**

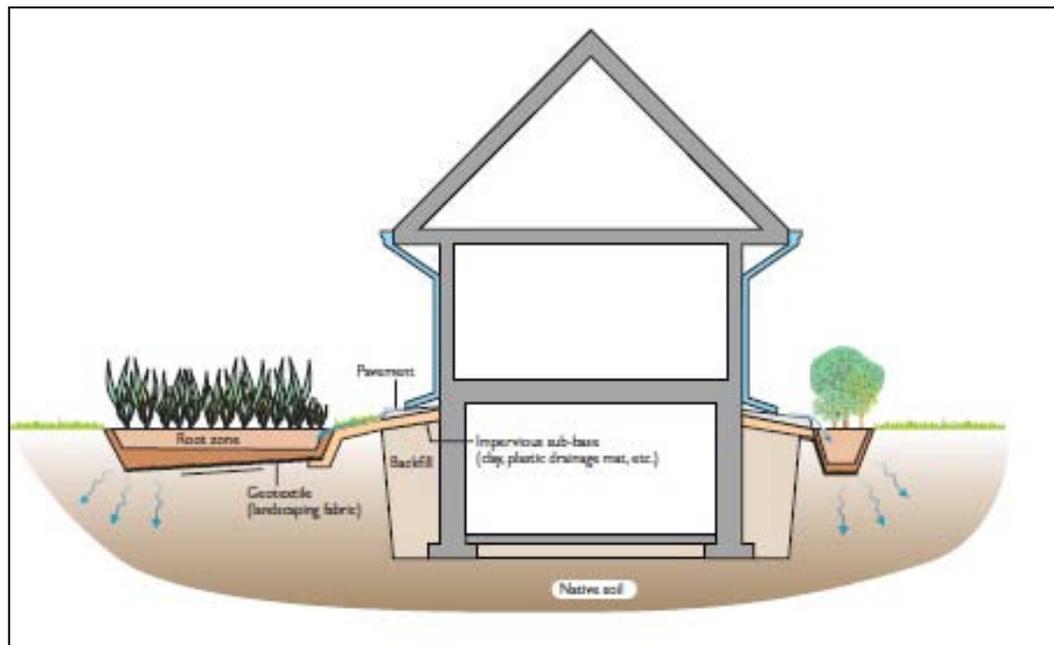
- Water pours out of your eavestroughs into downspouts. If the downspouts are dumping the water right beside your foundation, it drains directly to the weeping tile and can easily overload your home's drainage. Make sure downspouts extend at least 1.8 m (6 ft.) from your basement wall. Also, be sure the water does not drain toward the neighbour's basement walls. It should drain away from a house toward the street, rear yard, or back lane. If the downspouts are connected to a home's sewer system or weeping tile, disconnect them.
- Clean debris from eavestroughs regularly. If they overflow even when clean, replace them with larger size eavestroughs and downspouts.
- Extend downspouts so that water flows away from a house and does not collect next to the basement walls and windows.

- **Lot grading**

If the land around your home slopes in toward the foundation, rainwater heads right for the weeping tile around the basement and can overload the foundation drainage system. The land around many homes settles over time, and then slopes in toward the foundation. If the lot slopes inward, fill in and grade the lot so that, for at least 1.8 m (6 ft.) out from around the foundation, the land slopes away from the house.

Build up the ground around a house so that water drains away from basement walls. Also, examine sidewalks, patios, decks and driveways. These can settle over time and cause water to drain back towards the basement walls (Figure E-1).

Figure E-1 Grading and planting around a house



Source: Canada Mortgage and Housing Corporation (CMHC). Avoiding Basement Flooding, 2011. All rights reserved. Reproduced with the consent of CMHC. All other uses and reproductions of this material are expressly prohibited.

Note: Gardens and plants may be accommodated within properly graded sites by ensuring that a continuous flow of surface water away from the building is maintained. The backfilled area immediately surrounding foundations (1.8 m or 6 ft.) should not be planted. Instead, this perimeter should be made impervious to water penetration and sloped away. Planting adjacent to this perimeter zone should have a sloped base below the root zone lined with a geo-textile that will convey excess water away from the building and the plants. This approach reduces: 1) the need for plant watering, 2) the amount of water conveyed to the foundation drains; and 3) the cost of any future foundation maintenance or repair, as the plants do not have to be moved to access the below grade foundations.

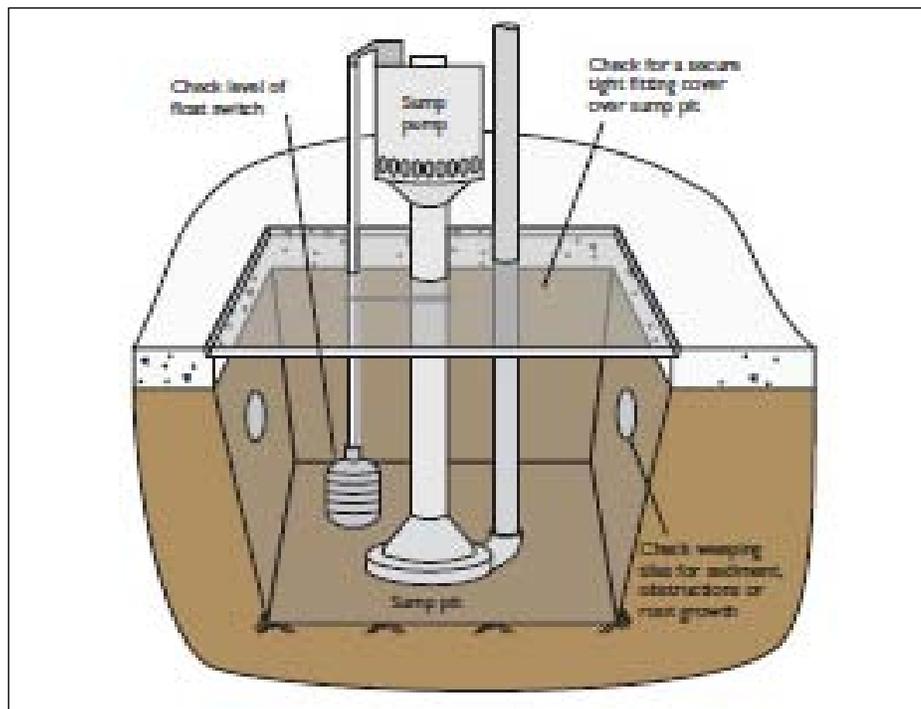
- **Flood-proofing devices**

If a home-drainage system or the neighbourhood's drainage system overloads, it is still possible to prevent rain water and sewage from backing up into the basement by installing one or more flood-proofing devices, such as sump pumps or back flow valves. Each installation is unique and some devices, such as back flow valves, may require a plumbing permit. Check with the local municipal office or a qualified plumber before proceeding with any installation.

- **Sump pit drainage system**

A sump pit drainage system includes a sump pit, a sump pump and a discharge pipe. The sump pit, set into the basement floor, collects water from the weeping tiles around a basement. The pump pushes the water outside a house through the discharge pipe (Figure E-2).

Figure E-2 Typical sump pump installation



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Note: In some cases, basement flooding is caused by an inadequate foundation drainage system. If the weeping tile is clogged, it should be properly replaced, but often the problem is a sump pump with insufficient capacity, or a sump pit that is not deep enough to lower the water table below the foundation. Consult with the local municipal office or a qualified plumbing contractor to ensure that your sump pit and sump pump are correctly sized.

Place a sump pump discharge pipe properly so that it:

- ◇ Drains somewhere onto your property where water can be absorbed, such as your lawn or flower beds
- ◇ Do not direct water onto neighbouring properties, lanes, sidewalks or streets

▶ Sump pit

- ◇ Clean the pit each year after freeze-up. Weeping tile drainage may carry small amounts of soil, sand and debris into the pit from around your basement foundation.
- ◇ Some water may remain in the pit and cause a musty smell if it sits for a long time. If so, flush the pit by adding fresh water until the pump removes the stale water.

▶ Sump pump

- ◇ Check and test the sump pump each spring before the rainy season begins, and before leaving a house for a long time. Pour water into the pit to trigger the pump to operate.
- ◇ Remove and thoroughly clean the pump at least once a year. Disconnect the pump from the power source before you handle or clean it.
- ◇ Check the pit every so often to ensure it is free of debris. Most pumps have a screen that covers the water intake. The screen should be kept clean at all times.

▶ Sump pump discharge pipe

- ◇ Place a sump pump discharge pipe properly so that it drains somewhere onto your property where water can be absorbed, such as your lawn or flower bed. Also be careful the water does not drain onto neighbouring properties, lanes, sidewalks or streets.
- ◇ Check the place where the discharge pipe leaves the house. If the pipe is discharging right against the basement wall, the water will drain down into the weeping tiles and continue to recycle through the system.
- ◇ Check the discharge point regularly to make sure that nothing is blocking the flow.
- ◇ If a pump runs often in the winter and the resulting ice is causing hazardous conditions on the lawn and sidewalks, call local municipal office for assistance.

○ **Backwater valve**

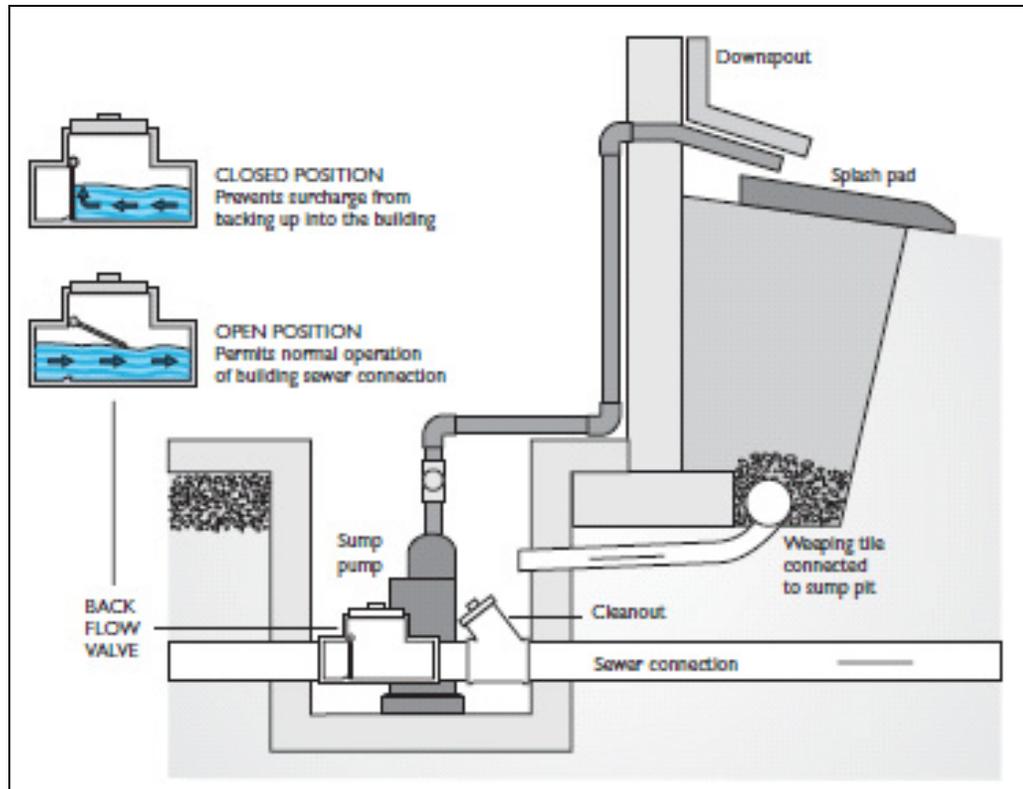
A backwater valve is a device that prevents sewage in an overloaded main sewer line from backing up into your basement. The valve automatically closes if sewage backs up from the main sewer (Figure E-3). A properly installed backwater valve must be placed so that sewage backup will be stopped and not come out through other outlets in a basement, such as sinks, toilets, showers and laundry tubs.

- ▶ Make sure that the valve is accessible at all times.

- ▶ Check the valve regularly and remove any material that may prevent the valve from operating properly.

A homeowner will normally require a permit and inspection to install a back flow valve and sump pit. Since part of the basement floor will be dug up and since proper placement of these items is important, a qualified plumbing contractor is recommended for the procedures.

Figure E-3 Back flow valves and sump pumps are effective means of avoiding basement flooding



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In existing homes experiencing basement flooding because of sewer backup, an effective prevention strategy is to install a sump pump and a backflow valve. This type of installation must normally be approved by the municipality and it is recommended to have the work performed by a qualified plumbing contractor.

- **Additional protection measures**

There are also several additional flood protection measures that may be considered.

- Plumbing fixture maintenance

Have a qualified plumber regularly inspect all flood-proofing devices and plumbing fixtures, such as sump pumps, backwater valves and floor drains to ensure proper operation. Check the operating instructions for more detailed

information and safety guidelines, or ask a qualified plumber to explain the details of the system.

- Backup sump pump

Severe storms are often accompanied by power blackouts. A battery powered backup sump pump may be a prudent investment. Most pumps are made to fit in beside the main sump pump and also have an audible alarm that warns the main pump has failed so that a home owner can attend to its repair or replacement. There are also water powered backup sump pumps available that run by water flowing through the pump impeller.

- Basement finishes and furnishings

If a risk of basement flooding is still possible, it is advisable to install impermeable floor and wall finishes, such as ceramic tile, to lessen damage and make cleanup easier. Make sure basement furniture has legs that keep the furniture fabrics above any accumulated flood water. Area rugs are a good alternative to full broadloom as these can be removed and properly cleaned in the event of flood damage.

E.2.5.2 Preventative and remedial measures recommended by Health Canada

Health Canada has published several documents related to fungal contamination. In particular, the reader is advised to refer to *Fungal Contamination in Public Buildings: A Guide to Recognition and Management*. This publication primarily focuses on how to investigate and mitigate fungal contamination. The guide was developed to assist health professionals and IAQ experts to recognize and manage fungal contamination problems in public buildings. Health Canada (2004) has recommended that the guide should be followed during indoor air investigation of all public buildings except hospitals and buildings in industrial settings. The guide presents a step-by-step protocol to analyze and investigate fungal contamination.

- Phase I Assessing the magnitude of the health problem
- Phase II Identifying problems in the building environment
- Phase III Sampling & Identification of indoor fungal amplifiers
- Phase IV Risk communication
- Phase V Destructive sampling, if required
- Phase VI Taking remedial actions based on findings

The reader is advised to refer to the original publication for an extensive discussion on the various phases of investigation and remediation. The guide is available at (http://www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/fungal.pdf).

Another publication by Health Canada, entitled *Indoor Air Quality in Office Buildings: A Technical Guide*, is also available. This publication primarily focuses on office buildings and provides recommendations, including an investigation protocol. The report recommends several strategies for microbial remediation in buildings (Health Canada, 1995).

- Remove water sources that encourage fungal growth. Prevent the accumulation of standing water in and around HVAC system. Maintain a relative humidity at less than 60 per cent.
- Remove fungus-contaminated substrates, such as mouldy ceiling tiles and carpets.. Wash all smooth surfaces with diluted five per cent bleach (250 mL/4 litre of water).
- In HVAC systems, use direct steam injection instead of recirculated water for humidification. If spray systems are used, a preventive maintenance program should also be set up as these systems could be contaminated. Humidifiers should be drained and cleaned with chlorine bleach at intervals of two to four months. Rust and scale deposits should be cleaned and removed at least once or twice a year.
- Dirty contaminated insulation should be quickly removed.
- Personal portable humidifiers should not be allowed in offices.
- Use prefilters and extended face-type secondary filters with dust sport efficiency > 85 per cent. Replace prefilters four to six times a year and secondary filters once a year.

E.2.5.3 Remediation of mould affected areas (New York City Department of Health and Alberta Health Services)

New York Department of Health (NYDH, 2008) has five levels of remediation strategies determined by the extent of mould contamination, starting with Small Isolated Areas (< 10 ft² /< 1 m²). The goal of remediation is the controlled removal and cleaning of mould-contaminated materials and surfaces to prevent mould aerosols from contaminating adjacent areas. Another aim of fungal remediation is to protect the health of workers performing the abatement work (NYDH, 2008). However, for very small mould contaminated area, the remediation requirements can be less stringent. Alberta Health Services Environmental Public Health (AHS EPH) has developed a protocol for the routine removal of mould contamination that is less than 1 ft² or 0.1 m² in size (AHS EPH, 2011).

- **Very small and localized areas** (<1 ft² or 0.1 m²)
 - Building owners or regular maintenance staff can easily remediate these areas using standard cleaning techniques, such as scrubbing surfaces using a cleaning agent and water. The use of personal protective equipment (PPE) is discretionary but recommended. At a minimum, wash hands immediately after the work.
- **Small isolated areas** (<10 ft² or 1 m²) (e.g., ceiling tiles, small areas on walls)
 - Have building staff who have received training in proper cleaning methods, personal protection and potential health hazards associated with mould exposure. Clean the area. Individuals associated with cleanup projects should be free from ailments such as asthma, allergy and immune disorders. Workers should wear gloves, eye protection and approved disposable respirators (N95).
 - The work area should be unoccupied.
 - Cover the work area floor, egress pathways and difficult-to-clean surfaces and items, such as carpeting, electronic equipment and belongings, with plastic

sheeting sealed with tape. As an alternative, remove carpets, electronic equipment or belongings before remediation. Efforts should be made to reduce dust generation. Dust suppression methods particularly during any cutting or resurfacing of materials are highly recommended. Methods to consider include cleaning or gently misting surfaces with a diluted water and soap solution before removal; using high-efficiency particulate Air (HEPA) vacuum-shrouded tools; or using a vacuum equipped with a HEPA filter. Also, work practices that create excessive dust should be avoided.

- Clean mouldy materials using a soap and water. Contaminated materials that can't be cleaned should be removed from the building in sealed plastic bags. There are no special requirements for the disposal of mouldy materials.
 - HEPA-vacuum the work area used for egress or clean the area using a damp cloth or mop and a water and soap solution.
 - All areas should be left dry and visibly free from mould, dust and debris.
- **Medium-sized isolated areas** (10ft² to 100 ft² or 1 m² to 9 m²)

Follow all the recommendations provided in level 1 plus the following.

- Cover the floor, egress pathways and items left in the work area with plastic sheeting and seal with tape before remediation.
 - Seal ventilation duct and grilles and other openings in the work area with plastic sheeting. The HVAC system servicing this area may need to be shut down to properly seal vents.
 - Erect a polyethylene sheet containment barrier around the work area.
 - After contaminated materials are removed, HEPA-vacuumed the area and clean it with a damp cloth or mop using a detergent solution.
- **Large areas** (> 100 ft² /or 9 m² of contiguous mould) (e.g., a 100 ft² or 9 m² mould-contaminated wall)

Personnel should be trained in the handling of mould-damaged materials and be supplied with the following equipment:

- A minimum of half-face elastomeric respirators with P-100 filters used in accordance with the OSHA respiratory protection standard (29 CFR 1910.134)
- Full-body coveralls with head and foot coverings
- Gloves and eye protection

For the containment of the affected area, take the following steps.

- Shut down the HVAC system servicing this area during remediation.
- Isolate the work area using plastic sheeting sealed with duct tape. Remove furnishings from the area and use plastic sheeting to cover ventilation ducts See the plastic sheeting with duct tape.
- Consider using an exhaust fan equipped with a HEPA filter to generate negative pressurization.

- Consider using airlocks and a clean changing room. Cover egress pathways if a clean changing room is not used.
- Before leaving isolated areas, workers should remove disposable clothing to prevent the tracking of mould-containing dusts outside of the work area.

- **Remediation of HVAC systems**

Mould growth in heating, ventilation and air-conditioning (HVAC) systems can pose building-wide problems. Obtaining professional help should always be considered in addressing even small amounts of mould growth or moisture problems within an HVAC system. Recurring problems, regardless of size, may suggest a systemic problem and appropriate professional help should be sought. The use of disinfectant inside air handling and duct systems is not permitted in Canada. HC does not provide a DIN for disinfectant use inside HVAC systems. Please check and confirm.

- **Small isolated area of mould growth in the HVAC system** (<10 ft², such as box filter or a small area on insulation)

Follow all the recommendations provided for small isolated area remediation plus the following:

- ▶ This work can be performed by trained regular building staff.
- ▶ Shut down the HVAC system.
- ▶ Erect containment and use wet suppression.
- ▶ HEPA vacuum the work area and immediate surroundings, and then clean it with a damp cloth or mop and a detergent solution.

- **Large area of mould growth in the HVAC system** (>10 ft²)

Follow all the recommendations provided above plus the following:

- ▶ Work should be performed by professionals.
- ▶ Isolate the work area from the other areas of the HVAC system by using plastic sheeting sealed with duct tape.
- ▶ Use an exhaust fan equipped with a HEPA filter to generate negative pressurization should be considered.
- ▶ Consider using airlocks and a clean changing room. Perform air clearance before re-occupancy with the HVAC operating.
- ▶ Cover egress pathways if a clean changing room is not used.

More information can be found from the following sources:

1. *Mould Guidelines for the Canadian Construction Industry* (Canadian Construction Association, 2004) www.cca-acc.com/mould
2. *Guidelines on assessment and remediation of fungi in indoor environments* (New York City Department of Health and Mental Hygiene, 2008) www.nyc.gov/html/doh/html/epi/mouldrpt1.shtml
3. *Fungal contamination in public buildings: Health effects and investigation methods* (Health Canada, 2004) www.hc-sc.gc.ca

4. *Flood Cleanup: Avoiding Indoor Air Quality Problems Fact Sheet* (USEPA, 2003).
<http://www.epa.gov/iaq/pdfs/floods.pdf>
5. *A Brief Guide to Mould, Moisture and Your Home* (USEPA, 2010).
<http://www.epa.gov/mould/pdfs/mouldguide.pdf>
6. *Mould Prevention Strategies and Possible Health Effects in the Aftermath of Hurricanes and Major Floods* (Centers for Disease Control and Prevention, 2006)
<http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5508a1.htm>.
7. *Best Practices for Mould at the Worksite* (Government of Alberta – Employment and Immigration, Occupational Health & Safety)

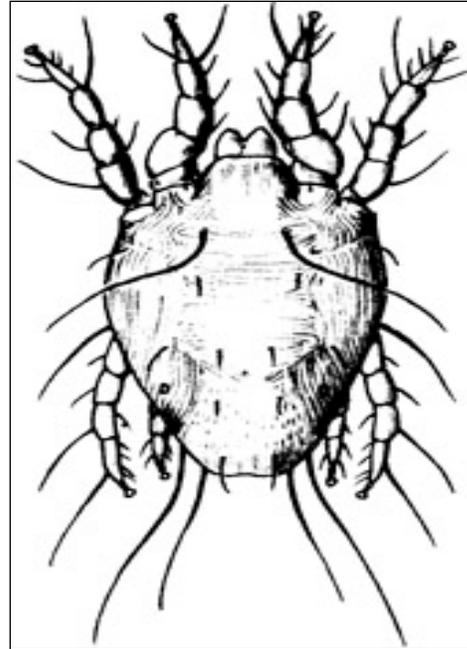
E.3 Dust mites

House dust mites are classed with spiders, ticks and scorpions. House dust mites belong to the phylum *Arthropoda*, class *Arachnida*. Dust mites can be found in carpets, house dust, mattresses, pillows, upholstered furniture, bedcovers, clothes, stuffed toys and other fabric covered items (USEPA, 2001; NIEHS, 2001). Dust mites are not visible to the naked eye. An adult female of *D. farinae* measures approximately 0.36 mm long and 0.43 mm wide. The female lays one egg each day. When dust mites die, their bodies disintegrate into microscopic fragments that become airborne and, in turn are inhaled by humans (USEPA, 2001).

A dust mite has a three-stage life cycle: egg, larva (nymph) and adult. There is no distinct pupa stage in the life cycle of a dust mite. Therefore, the metamorphosis is said to be incomplete. The larval stage is protracted. The nymph develops and grows and sheds its skin three times before it becomes a fully formed, sexually mature adult. Nymphs of dust mites closely resemble a smaller version of the adult form with two notable exceptions. They are mostly colourless and have only three pairs of legs. The hind (fourth) pair of legs doesn't develop until the adult mite emerges from the final ecdysis. The entire cycle from egg to adult spans two to three weeks. The adult dust mite *D. pteronyssinus* live for about a month (Syred, 2000). However, the lifetime of *D. farinae* female spans up to 75 days. The following dust mite species, typically found in house dust samples, are variously distributed around the world. Some species of house dust mites, belonging to the genus *Dermatophagoides*, are commonly found in North America (Godish, 2000).

- *Dermatophagoides pteronyssinus* (European house dust mites)
- *Dermatophagoides farinae* (American house dust mites)
- *Dermatophagoides microcera* (first found and studied in Scandinavian countries)
- *Euroglyphus maynei* (commonly found in tropical and sub tropical areas)
- *Blomia tropicalis* (commonly found in tropical and sub tropical areas)

Figure E-4 Typical house dust mite



Source: <http://ohioline.osu.edu/hyg-fact/2000/2157.html>, accessed February, 01, 2002.)

E.3.1 Sources

In addition to various sources, in this subsection different factors responsible for dust mite survival indoors are briefly discussed.

Dust mites usually feed on human skin scales, pollen, fungi, bacteria, moth and butterfly scales, animal dander and skin scales of birds. It has been shown in laboratory experiments that human, cat, dog and horse dander acts as a growth medium. Dust mites can absorb water from the air (Ogg, 2001). Dust mites are commensal with humans, depending on them for food supply.

Dust mites live on pillows, mattresses, bedding, stuffed toys, upholstered furniture, fabrics and carpets. They feed on skin flakes from people and thrive in humid environments. Dust mites are more abundant in residences with wall-to-wall carpeting than bare floors or area rugs. Carpet is a suitable medium for dust mites to grow and feed upon shed human skin (Godish, 2000). Long, loose-pile carpets are especially prone to the accumulation of dust mites and food sources. Dust mites can burrow deep into the fibres of these carpets, protecting themselves from removal by vacuum cleaners.

The life span of dust mites can vary depending on the indoor temperature and relative humidity (RH). House dust mites have the potential to tolerate a wide temperature range from 0°C to 30°C with an average optimum temperature of 20°C to 25°C for breeding.

Unlike their potential to withstand a wide temperature range, dust mites have less tolerance to variations in RH (Syred, 2000). It has been shown that mites gradually dehydrate and die when held in RH below 50% for more than 11 days. Favourable temperature and relative humidity (>50%) can be responsible for dust mite growth in indoor environments. Microclimates can occur in home where RH levels would not be supportive of dust mites. For instance, in a basement, cooler temperatures at the interface of the basement floor slab and carpet may elevate RH to support dust mites. Other microclimates such as may occur inside a bed would also be very supportive. Dust mites grow best at RH of 70% to 80% and temperatures of 20°C to 25°C. However, even in very dry conditions, it may take months for dust mites in sofas, carpets or mattresses to die and allergen levels to fall (Arlan et al., 1982, Platt-Mills et al., 1987, cited in Pope et al., 1993). The life cycle of house dust mites consists of egg, larva, protonymph, tritonymph and adult stages. Each stage consists of an active feeding and a short non-feeding, quiescent period. From these life stages, the protonymphal stage is resistant to desiccation which allows them to survive long dry periods, such as the winter heating season (cited in ACGIH 1999). Under unfavourable climatic conditions, the protonymphal stage may survive for up to several months.

Seasonal variations in mite populations, both live and dead populations, have also been reported. Mite population exhibited the highest density in the humid months from June to October and the lowest density during the dryer and low heating months from January to April (Arlan et al., 1982). In this study conducted by Arlian et al (1982), dead mite populations showed less seasonal fluctuations than the live population. Dead mites were higher in number than live mites during the heating season when mite population declined significantly. Temporal mite density fluctuated synchronously with indoor RH (Arlan et al. 1982). In other field observations, higher numbers of dust mites were recorded in residential (> 100 mites/gram of dust) versus institutional buildings (> 20 to 40 mites / gram of dust) such as schools, nursing homes and office buildings (Godish,

2000) because of more favourable conditions in the residential buildings than in the institutional buildings.

E.3.2 Health effects

Dust mites can trigger asthma symptoms and can cause asthma in children with no previous asthma symptoms (United States Environmental Protection Agency, 2008).

Dust mites produce allergenic proteins that are attached to sensitized cells in the air passages and cause hay fever and asthma when inhaled. These proteins come from the digestive tract of mites and are found at high levels in mite feces. Mite (fecal pellets) are usually 10 to 20 µm in diameter (Tovey et al., 1981; De Blay et al., 1992, cited in Platts-Mills, 2001).

Several acute and chronic health effects have been reported among individuals exposed to dust mites. The following box shows different acute and chronic effects from exposure to dust mites (Godish, 2000; Spengler et al., 2001).

Health effects caused by exposure to dust mite allergens	
Acute effects	Chronic effects
<ul style="list-style-type: none">• Acute asthmatic attacks• Mucous membrane irritation• Cold allergy• Nasal passage obstruction and nasal irritation	<ul style="list-style-type: none">• Chronic allergic rhinitis• Chronic asthma• Atopic dermatitis• Difficulty in concentrating

House dust mites significantly affect allergic adults and children by inducing asthmatic symptoms (Meijer et al., 1995). In addition to genetic susceptibility, individuals who are exposed to house dust mites in their childhood were found to be more susceptible to develop asthma (Sporik et al., 1990). House dust mites also aggravate atopic dermatitis in individuals suffering from asthma can be considered he to dust mite exposure.

A comparison of the prevalence rate of mite sensitization among asthmatics and non-asthmatics emergency-room patients in the USA showed that asthmatic individuals have a higher prevalence of mite allergen sensitization (production of IgE antibodies) than non asthmatics (Godish, 2000).

E.3.3 Exposure

The primary route of exposure to dust mites is inhalation and dermal contact. However, dust mites and dust mite allergens don't become airborne unless they are disturbed or stirred-up. Airborne dust mite levels and exposures increase significantly during indoor activities such as organizing beds, pillows and mattresses and during cleaning rooms and carpets (Godish, 2000; Spengler et al., 2001). Different studies are available on dust mite concentrations in different indoor fabric materials such as pillows and mattresses.

Pillows (7.2 µg/g of dust) were found to contain a higher number of mite allergens than mattresses (6.8 µg/g of dust) (Baena-Cagnani et al., 1999).

E.3.4 Control measures

CMHC (2008) recommends the following strategies to control dust mites¹.

- Reduce the relative humidity (RH) in your house to reduce dust mites and mould.
Dust mites need RH above 55 per cent to grow. The most effective way to prevent the growth of dust mites is to reduce the RH of your house in the winter. The Canadian asthma consensus report (1999) recommends humidity levels below 50 per cent.
- Vacuum thoroughly and often since dust mites are a component of household dust. Use a vacuum cleaner with a HEPA filter or a central vacuum that exhausts to the outside.
- Wear a N95 respirator while vacuuming. Sensitive individuals and children should keep away from the immediate area. This will help reduce exposure to dust mites that become airborne with fine dust.
- Maintain and change furnace filters, per O&M schedule.
Properly maintained filters can reduce fine particles in your air distribution system that can be a home for dust mites (see CMHC's About Your House fact sheet Your Furnace Filter). To further reduce the amount of dust circulated by your air distribution system, regularly vacuum as far as you can reach into air registers and return ducts. If you find that the return air ducts are dirty, or if the ducts have not been cleaned since the house was built or you moved in, have your ducts cleaned. Ensure that the contractor does not spray chemicals, such as fungicides, disinfectants or essential oils into the ducts.
- Reduce the amount of particulates you bring into the house by taking off your shoes upon entry and using washable doormats.
- Remove surface dust with a HEPA vacuum or a damp cloth instead of dry dusting to help control dust (Canadian Partnership for Children's Health & Environment, 2005).
- Reduce the number of upholstered furnishings and fabric coverings in your bedroom that can provide a home for dust mites.
- Wear a N95 respirator while HEPA vacuuming upholstered furnishings.
- Avoid carpets because they are good dust collectors that can hold dust mites.

¹ CMHC recommendations available at http://publications.gc.ca/collections/collection_2011/schl-cmhc/nh18-24/NH18-24-46-2009-eng.pdf:

Sleeping area strategies include the following:

- Change bedding often.
- Wash bedding in warm water. Contrary to popular belief that hot water is needed to kill dust mites, a warm-water wash with pre-soaking is effective at controlling dust mites (Vyszynski-Moher, Arlian & Neal, 2002).
- Use washable linens, such as cotton with small enough pore size, such as 200 thread count. Washing bedding often is more important than encasing a mattress with a cover that cannot be removed easily for cleaning.
- Vacuum mattresses with a HEPA vacuum periodically.
- Replace pillows at least once a year.
- Avoid the use of “acaricides” (pesticides that kill dust mites).
- Allow bedding to dry by keeping beds uncovered when you get out of bed.

E.4 Cockroaches

Although all insects have the potential to elicit an allergic response in humans, cockroaches have been studied extensively because of their common presence indoors and ability to induce respiratory diseases in humans (Godish, 2000). Figure E-5 presents cockroaches commonly found in North America and other countries. German and American cockroaches are commonly found in North America. The following species of cockroaches produce respiratory allergens.

- American cockroach – *Periplaneta americana*
- Asian cockroach – *Blattella orientalis*
- German cockroach – *Blattella germanica*

German cockroaches are very common in densely populated areas of Canada and the United States.

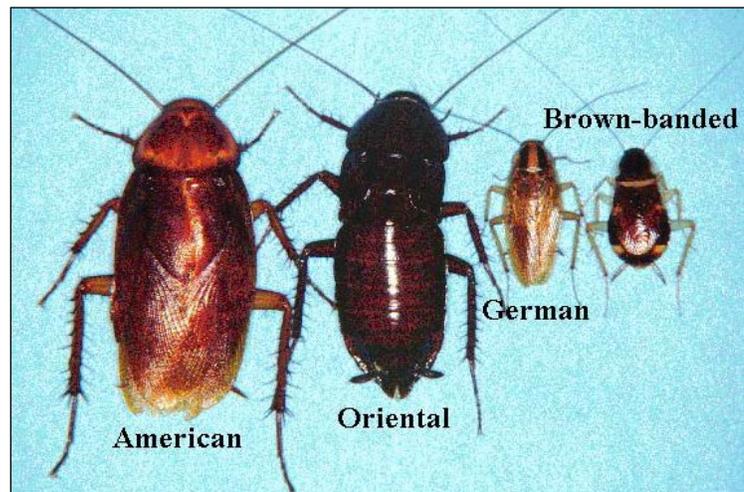
They are also found in other parts of the world. An adult German cockroach is 10 mm to 15 mm long and is commonly found in close proximity to areas where there are human beings. On

average, a female German cockroach can live up to 200 days. The male life span is shorter than a female. Females can produce four to six egg cases during their lifetime. Each egg case can contain 30 to 40 eggs. German cockroaches can be found in the thousands in highly infested buildings. They are never found outdoors. The only limiting factor that affects German cockroach survival is cold temperatures. Studies have shown that they were unable to colonize in cold temperature and couldn't survive in homes in northern climates without central heating systems. Other factors such as water, food and harborage also control the survival and growth of German cockroaches (Valles, 1996).

- **American cockroach**

American cockroaches can be found in moist shady outdoor areas such as yards, hollow trees, woodpiles and mulch. They can also be found under roof shingles and in attics. They dwell outside but go indoors for food and water during extreme weather conditions (Hagenbuch et al., 1988, cited in Barbara, 2000). During the day time, the American cockroach rests in harborages close to water pipes, sinks, bathrooms and toilets, where a favourable microclimate is present (Bell and Adiyodi, 1981, cited in Barbara, 2000). American cockroaches are larger than German cockroaches. They are approximately 38 mm long and have reddish brown wings. Adult female American cockroach can live up to 440 days (Godish, 2000). The female on average produces an egg case once a month for 10 months. Each egg case can

Figure E-5 Common cockroaches



Source: University of Nebraska website: <http://pested.unl.edu/comprao.jpg>; accessed: Feb. 01, 2002

contain up to 16 eggs. A typical egg case is 8 mm long and 5 mm high. Male cockroaches have a shorter life span than females (Godish, 2000; Barbara, 2000).

Environmental factors such as temperature and humidity can increase or decrease the developmental time of the American cockroach (Barbara, 2000). Under ordinary room temperature, the developmental time (egg to adult) averages about 600 days during which they molt at least 10 to 13 times. In one experiment, adult females lived up to 440 days at ordinary room conditions, but at 29°C, their life span was decreased to 225 days and adult males, on average, lived about 200 days. American cockroaches can also thrive in moderate winter temperatures. They are omnivorous and opportunistic feeders. In addition to decaying organic matter, they can consume a variety of things such as paper, boots, hair, bread, fruit, cloth and dead insects (Barbara, 2000).

E.4.1 Cockroach allergens

Cockroach allergens consist of fecal material, saliva and different body parts. Two major allergens that have been identified from German cockroaches are Bla g I and Bla g II (Godish, 2000). These cockroach allergens are homologous with proteins derived from other species and many of those proteins are enzymes. Bla g I and Bla g II have molecular weights of 25 KDa (Kilodalton) and 36 KDa, respectively. Cockroach allergens can be found in floor dust samples. Very limited information is available on the aerodynamic behaviour of particles that contain cockroach allergens. The aerodynamic properties of cockroach allergens are unknown although they are believed to be >10 µm. It is highly unlikely that these allergens will become airborne on their own. Vacuuming and other indoor activities will readily aerosolize cockroach allergens (Godish, 2000; Spengler et al., 2001).

Cockroach allergen concentrations were analyzed using monoclonal antibody assays. The measured concentrations were reported in units per gram (U/g). U.S. studies found more than 2 U/g Bla g II in floor dust in 25% to 75% of low-income houses. In highly infested houses, cockroach allergens as high as 1,000 U/g were recorded in the kitchens (Godish, 2000).

E.4.2 Health effects and sensitive or vulnerable

A comparison of the prevalence rate of cockroach sensitization among asthmatics and non-asthmatics emergency room patients in the USA showed that asthmatic individuals have a higher prevalence of cockroach allergen sensitization (production of IgE antibodies) than non asthmatics (Godish, 2000).

Exposure to German cockroach (*Blattella germanica*) allergens has been reported to cause chronic respiratory diseases such as asthma (Pomes et al., 2002; Godish, 2000). Information on the allergenicity of the American cockroach is limited.

E.4.3 Control measures

The following control measures are recommended to reduce exposure and eliminate cockroach allergens (Platt-Mills, 2001, cited in Spengler et al., 2001; Barbara, 2000) from indoors:

- Remove food sources.
- Bait trap stations or use boric acid where cockroach debris are found.
- Eliminate sites where cockroach can breed.
- Periodically inspect hard-to-reach places.
- Remove rotting leaves.
- Get rid of moist areas in and around a structure.
- Apply approved insecticides to basement walls, wood scraps and other locations.

Specific control measures vary by species, but the most successful and effective method for the control or elimination of an infestation is to set up an integrated pest management (IPM) program that includes identification, sanitation, exclusion, trapping, physical removal and chemical treatment. A detailed discussion of each of these steps is beyond the scope of this manual. The reader should refer to the *Public Health Pest Control Manual* for additional information. The manual is available at <http://vector.ifas.ufl.edu/manual.htm>.

E.5 Animal allergens

Of residences in the United States, 30% to 50% have mammalian pets that are housed indoors (Godish, 2000). According to *No Puppy Mills Canada* (<http://www.nopuppymillscanada.ca>), an estimated 1.45 million pups are produced each year in Canada excluding backyard breeding. Based on U.S. data provided above, it can be assumed that almost 10 million pets may be living with or in close proximity to Canadians.

Allergens from these mammals, along with birds, can cause immunological sensitization and symptoms of chronic allergic rhinitis and asthma in humans. Because of regular interaction with pets such as cats and dogs, sensitization to their allergens is commonly observed. According to Godish (2000), sensitization to cat dander among asthmatics in the United States can vary from 9% to 41%. The highest level of sensitization has been observed in suburban dwellers, whereas, the lowest level has been observed in low-income urban areas. It has been estimated that six to 10 million individuals in the United States are allergic to cat allergen. The following animals, which cause immunological sensitization and other respiratory ailments in humans, are briefly described below (Godish, 2000).

- Dog allergens
- Cat allergens
- Rodent allergens, such as rats, mice and guinea pigs

E.5.1 Dog allergens

Can f 1 and albumin are major dog allergens. Although predominantly occurring in dog saliva and hair, they are also found in very low concentrations in the urine and feces (Godish, 2000). Arlian et al. (2001) reported that dog allergens are ubiquitously found in residences, buildings and schools, day-care centres and workplaces where there are no dogs. In that study, Arlian et al. (2001) measured dog allergens on walls, smooth floors, carpets and finished furniture in homes with or without the presence of dogs. Carpet was reported to be the major reservoir for dog and other pet allergens. The mean levels of Can f 1 per square meter of carpet surface area in homes with dogs were 12, 24 and 47 times higher than for smooth floors, finished furniture and walls, respectively. The amount of allergen collected in homes with dogs was significantly higher than that collected in the homes without dogs (Table E-3).

Table E-3 Mean quantity of dog allergen ($\mu\text{g Can f 1/m}^2$)

Location of homes	Homes with dogs	Homes without dogs
Furniture	15.35 ± 5.43	4.95 ± 3.65
Walls	7.96 ± 3.42	3.64 ± 2.15
Smooth floors	32.10 ± 7.02	12.01 ± 6.18
Carpets	373.34 ± 61.09	3.50 ± 1.87

The passive transport, such as transport via contaminated clothing of dog allergens is an important mechanism for the widespread distribution of dog allergens in indoor and outdoor environments (Godish, 2000). For example, individuals can be exposed to dog allergens from the clothing of other people who have contacted dogs and carried that

contamination to other locations. In some residential buildings, dog allergens in floor dust samples have been found as low as 0.3 µg/g in the absence of a dog and as high as 10,000 µg/g in the presence of a dog (Godish, 2000).

According to Godish (2000), 2.3 per cent of the U.S. population is sensitive to dog allergens. It is believed that several micrograms of dog allergens can affect both adults and children and can provoke asthmatic symptoms. The presence of several types of indoor allergens can affect children and other vulnerable individuals. Sarpong and Karrison (1998) reported that children with combined sensitivity to cat, dog, dust mite and cockroach allergens can be at increased risk of severe asthma.

E.5.2 Cat allergens

There are two types of cat allergens: Fel d 1 and Fel d 2. The size of the particle that contains these allergens can vary from < 2.5 µm to 10 µm. Because of their small size, they can become easily airborne even in undisturbed indoor environments) and, they can remain airborne for extended periods of time (even hours (Godish, 2000). Particles that carry cat allergens appear to be very sticky. Therefore, cat allergens tend to stick to clothing during handling and grooming activities.

A single cat has the potential to release 3 µg to 7 µg of allergen per day. Fel d 1 (*Felis domesticus 1*) is the major cat allergen found in indoor air. It is an acidic glycoprotein and can be found in cat hair, skin, saliva, sebaceous glands secretions and urine. It is easily dispersed into the air during owner handling and grooming and by a cat's self-grooming licking behaviour.

Carpets act as reservoirs for cat allergens. In a school environment, students who own cats can bring allergens to schools. Even if a cat is gone from a home, a past history of a cat's presence can also lead to health problems among humans. A higher concentration of airborne cat allergens can be associated with factors, such as a high number of cats and a building with a low air exchange rate.

Godish (2000) has reported an association between different cat allergen concentrations and risk of sensitization (Table E-4).

Table E-4 Risk of sensitization to cat allergens in dust samples

Concentration of cat allergens in dust samples		
< 1 µg/g	1 to 8 µg/g	> 8 µg/g
Low sensitization risk	Major sensitization risk	Major risk of causing acute asthmatic symptoms

Source: Godish (2000), In Indoor Environmental Quality, Lewis Publishers, 2001

Allergic individuals can show acute symptoms of rhinitis, conjunctivitis or wheezing within 20 minutes of exposure to cat allergen, such as after entering a cat-inhabited house (Platt-Mills, 2001, cited in Spengler et al., 2001).

E.5.3 Control measures

The following general control measures or avoidance measures can be carried out to reduce exposure to dog and cat allergens.

- If possible, keep animals outside. Removal of a dog in one study improved asthma symptoms (IOM, 2000).
- More frequent indoor vacuuming and wet mopping may help reduce indoor levels of allergens. It is recommended that HEPA vacuums or vacuflows are exhausted to the outdoors.
- Use effective air filtration.
- Wash animals regularly (twice a week) to reduce indoor allergen levels (IOM, 2000).

E.5.4 Hanta virus

E.5.4.1 Background

Various hantaviruses are found in the droppings, urine and saliva of infected rodents. Humans can contract the virus by breathing in airborne particles or by being bitten by an infected animal. In Canada, a hantavirus called the *Sin Nombre* virus, which been identified in deer mice, is capable of infecting humans.

Hantaviruses are part of a group of viruses called the *Bunyaviridae*. Exposure to hantaviruses can cause a rare, but often fatal, disease called Hantavirus pulmonary syndrome (HPS).

E.5.4.2 Risk factors of hantaviruses

Hantavirus is typically transmitted by breathing in airborne particles of the droppings, urine and saliva of infected rodents. However, there have been a small number of reported cases of HPS believed to have been contracted through rodent bites. Most cases occur in the spring during cleaning when people may breathe in airborne particles.

Rodents neither get sick from the infection nor pass it along to other animals. Transmission of the virus from person-to-person has not been reported in North America.

The earliest documented case of HPS in Canada was contracted in Alberta in 1989. Since then, there have been more than 70 confirmed cases. Most of the cases occurred in western Canada (Manitoba, Saskatchewan, Alberta and British Columbia), except for one case in Quebec. Hantavirus infections contracted by Canadians outside the country have also been recognized, including two fatal cases from South America.

- Even where its incidence among mice is highest, hantavirus infects only a tiny proportion of people who come in contact with it. However, in the few people who develop hantavirus infection, it can be fatal in one-third of the cases if left untreated.
- There is no vaccine, treatment or cure for HPS. However, early detection and medical care is extremely important and reduces the risk of death. Those who are infected may be given medication for fever and pain as well as oxygen therapy.
- The virus has existed in North America for many years but only was recognized for the first time in May 1993 in New Mexico.
- Deer mice surveys for hantavirus were done in Alberta around a decade ago. Between four and 23 per cent of mice were positive. There was no correlation between the number of mice and the number of human cases.

E.5.4.3 Health effects and symptoms

Early symptoms are similar to the flu, but can quickly develop into severe breathing problems and in some cases hantavirus infection can be fatal.

The following flu-like symptoms can result from Hantavirus pulmonary syndrome (HPS) at early infection:

- Fever
- Chills
- Muscle aches
- Headaches
- Nausea
- Vomiting

Symptoms can appear within three to 60 days after exposure. However, the average time it takes for symptoms to appear is 14 to 30 days after exposure. HPS is extremely serious since approximately 30% to 40% of cases result in death, usually within a few days of the initial symptoms appearing. Those who recover do so rapidly and regain full functioning of their lungs, but long term-effects, such as fatigue are common.

HPS can progress rapidly into serious lung complications and include the following symptoms:

- Abnormal fall in blood pressure
- Lungs fill with fluid
- Severe respiratory failure

In Canada, although the risk of exposure is low, the disease can be very severe.

The incidence of the hantavirus and the risk it poses to the public is low. However, particularly in the spring, when the weather improves and people spend more time outdoors and doing spring cleaning, remember to keep any risk to a minimum and *take precautions to avoid hantavirus infection.*

Strategies for minimizing risk of hantavirus

The only confirmed carrier of the hantavirus in Alberta is the deer mouse (reddish-brown or in some cases grey, but always with white fur on the underside of the neck, belly, feet and tail). However, it is possible that other rodents may carry the virus and it is not always easy to determine what kind of mouse one is exposed to, particularly when

the only evidence is droppings. The virus does not appear to have any effect on virus-carrying mice or cause any illness in pets.. Even if dogs and cats they are exposed to the virus, they do not pass the infection onto their owners. The main risk of infection comes from being exposed to accumulations of mouse droppings in enclosed areas; for example, cleaning a garage or shed that mice had been living in during the winter. Hantavirus is passed to humans when they breathe in airborne particles released from the droppings, fresh urine and nesting material of infected rodents.

- All rodents should be treated as potential carriers.
- All rodent droppings should be treated as potentially harmful.
- The primary strategy for minimizing risk of being exposed to hantavirus is to ensure rodent control with the following strategies:
 - Keep mice out of homes and work areas and immediately trap any mice that get in. Block openings that might allow rodents from entering.
 - Store human and animal food, water and garbage in containers with tightly fitted lids.
 - Keep yards clean and store woodpiles above the ground and away from the home.

E.5.5 Rodent allergens

Rat and mouse urine contains high amounts of proteins that are potent allergens (Spengler et al., 2001; Platt-Mills, 2001). Mouse hair also contains allergens. Both types of allergens can be found in any home or building infested by rats or mice (Godish, 2000, Spengler et al., 2001). The following allergens are found in rats and mice.

- Rats - Rat n IA, Rat n IB
- Mouse – Mus m I, Mus m II

Rats and mice can be found in residences, old buildings and schools. Rodents are commonly used as laboratory animals in educational institutions. There is sufficient evidence of an association between exposure to rodents in laboratories and exacerbation of symptoms of lung function in rodent-sensitized asthmatics. In spite of those studies, no definitive studies on rodent allergen exposure and asthma development are found in the literature. Further research is warranted at this time (IOM, 2000).

No studies were found on the influence of rodent eradication on levels of rodent allergens. However, as a general precaution, the following measures can be done:

- Keep a clean indoor environment.
- Prevent exposure to rodents.
- Mouse- and rat-proof buildings to prevent entry from the outdoors.
- Properly clean and sanitize infested area.

E.5.5.1 Cleaning up after rodents infestation (CDC, 2010)

• Urine and droppings

Take precautions before and during clean up of rodent-infested areas. Before cleaning, trap any rodents and seal up any entry ways to ensure that no more rodents can get in. Continue trapping for a week. If no rodents are captured, the active infestation has been eliminated and enough time has passed so that any infectious virus in the rodent's urine and droppings or nesting material is no longer infectious.

Before starting clean up of the space, ventilate the space by opening the doors and windows for at least 30 minutes to allow fresh air to enter the area. Use cross-ventilation and leave the area during the airing-out period.

1. Clean up any urine and droppings.
 - ▶ Prepare a bleach solution of one part bleach to nine parts water.
 - ▶ When you begin cleaning, *do not* stir up dust by sweeping or vacuuming up droppings, urine, or nesting materials.
 - ▶ Wear rubber, latex, or vinyl gloves when cleaning urine and droppings.
 - ▶ Spray the urine and droppings with a disinfectant or a mixture of bleach and water and let soak 5 minutes. The recommended concentration of bleach solution is one part bleach to nine parts water. When using a commercial disinfectant, following the manufacturer's instructions on the label for dilution and disinfection time.
 - ▶ Use a paper towel to pick up the urine and droppings and dispose of the waste in the garbage.
 - ▶ After the rodent droppings and urine have been removed, disinfect items that might have been contaminated by rodents or their urine and droppings.
2. Clean and disinfect the whole area.
 - ▶ Mop floors and clean countertops with disinfectant or bleach solution.
 - ▶ Steam-clean or shampoo upholstered furniture and carpets with evidence of rodent exposure.
 - ▶ Wash any bedding and clothing with laundry detergent in hot water if exposed to rodent urine or droppings.
 - ▶ Remove gloves and thoroughly wash hands with soap and water or use a waterless alcohol-based hand rub when soap is not available and hands are not visibly soiled.

- **Dead rodents or nests**

- Wear rubber, latex or vinyl gloves when cleaning up dead rodents or nests.
- Spray the dead rodent or nest and the surrounding area with a disinfectant or a mixture of bleach and water.
- Soak rodent, nesting materials or droppings in solution for five minutes before wiping up with a paper towel or rag.
- Place the dead rodent or nesting materials in a plastic bag and seal tightly. Place the full bag in a second plastic bag and seal.
- Throw the bag into a covered trash can that is regularly emptied.
- Remove gloves and thoroughly wash hands with soap and water (or use a waterless alcohol-based hand rub when soap is not available and hands are not visibly soiled).

- **Cabins, sheds, barns, or other outbuildings**

- Before attempting to clean cabins, sheds, barns, or other outbuildings, open all doors and windows for 30 minutes. This will allow fresh air to enter the work area.
- Wear rubber, latex, or vinyl gloves and clean up all rodent urine, droppings, nests and dead rodents using disinfectant or mixture of bleach and water.
- Mop floors or spray dirt floors with a disinfectant or mixture of bleach and water.
- Clean countertops, cabinets and drawers with a disinfectant or a mixture of bleach and water.

- **Attics, basements crawlspaces and other storage areas**

Before cleaning attics, basements, crawlspaces and other storage areas, remove the existing rodent infestation by trapping. Even when there is no evidence of infestation, wait about five days before beginning to clean these areas. Just before cleaning the space, open the doors and windows for at least 30 minutes to ventilate the area. Use cross-ventilation and leave the area during the airing-out period.

When cleaning attics, basements, crawlspaces and other storage areas:

- Wear rubber, latex, or vinyl gloves when cleaning up urine, droppings, or nesting materials. Note that a dust mask may provide some protection against dust, molds and insulation fibres, but a dust mask does not protect against viruses.
- Spray any urine, droppings and nesting materials with either a bleach and water solution (one parts bleach to nine parts water) or a household disinfectant prepared according to the label instructions for dilution and disinfection time. Soak well. This will inactivate any virus. Use a paper towel or rag to pick up the materials and dispose of them.

- Mop floors after spraying them using bleach and water solution or a disinfectant. Dirt floors can be sprayed with either bleach and water solution or a disinfectant.
- If exposed insulation has become contaminated with urine and droppings, it should be placed into plastic bags for removal.
- **Items in storage boxes**
 - Move the storage boxes outside and place them in an area that is well-ventilated and exposed to direct sunlight. The outside of the storage boxes can be disinfected using bleach and water solution or disinfectant solution.
 - Remove the potentially contaminated materials while in the sunlit, ventilated area. Remain upwind so that any dust or debris is not blown toward your face. Some contaminated stored materials, such as clothing and books, can be decontaminated by following the recommended methods of disinfection provided in the Table E-5.
 - Dispose of any cardboard boxes contaminated with urine or droppings. Plastic, glass or metal containers can be disinfected by spraying with the bleach and water solution or disinfectant. Then, using a rag or paper towel, wipe up the urine or droppings and dispose of the waste.
 - Clean countertops, cabinets and drawers with disinfectant or bleach and water solution.
 - Decontaminate gloves with disinfectant or bleach and water solution. Wash hands well with soap and warm water.

Table E-5 Recommended methods of textile decontamination (CDC, 2010)

Clothing, bedding, stuffed animals	Carpets/furniture	Books, papers and other non-washable items
<p>Laundry potentially contaminated bedding, clothing, or stuffed animals with hot water and detergent. Use rubber, latex, vinyl, or nitrile gloves when handling contaminated laundry. Machine-dry laundry on a high setting or hang it to air dry in the sun.</p> <p>Laundry detergent breaks down the virus's lipid envelope, rendering it harmless. Additionally, heat generated by the clothes dryer will also ensure that the virus is noninfectious. However, the use of a clothes dryer alone is not recommended as the sole treatment because not all dryers reach the necessary temperature. A temperature of 45 degrees Celsius, or about 115 degrees Fahrenheit, is required to inactivate hantaviruses.</p>	<p>Shampoo rugs and upholstered furniture with a commercial disinfectant or with a commercial-grade steam cleaner or shampoo.</p>	<p>You may leave books, papers and other items that cannot be cleaned with a liquid disinfectant or thrown away, outdoors in the sunlight for several hours, or in an indoor area free of rodents for approximately 1 week before cleanup. After that time, the virus should no longer be infectious. Wear rubber, latex, vinyl, or nitrile gloves and wipe the items with a cloth moistened with disinfectant.</p> <p>Once excreted into the environment by the rodent, hantaviruses can survive in the environment and remain infectious for a period of two or three days. Ultraviolet rays in sunlight inactivate hantaviruses.</p>

• **Heavy rodent infestation**

Special precautions should be used for cleaning homes or buildings with heavy rodent infestation. The special precautions may also apply to vacant dwellings that have

attracted large numbers of rodents and to dwellings and other structures where hantavirus has been confirmed in the rodent population.

Workers who are either hired specifically to perform a clean-up or are asked to do so as part of their work activities should contact their local or provincial health department, local or provincial occupational health and safety authority (OSHA) or CDC for information about preventing rodent-borne diseases.

Persons involved in the clean-up of heavy rodent infestations should wear the protective equipment listed here:

- Coveralls (disposable, if possible)
- Rubber boots or disposable shoe covers
- Rubber, latex, or vinyl gloves
- Protective goggles
- Appropriate respiratory protection device, such as a half-mask air-purifying, a negative-pressure respirator with a high-efficiency particulate air (HEPA) filter or a powered air-purifying respirator (PAPR) with HEPA filters
- Follow local and provincial requirements regarding pulmonary function and fit-testing before beginning any work requiring the use of a respirator.

Personal protective gear should be decontaminated upon removal at the end of the day. All potentially infected waste material including respirator filters from clean-up operations that cannot be burned or deep-buried on site should be double-bagged in appropriate plastic bags. The bagged material should then be labeled as infectious (if it is to be transported) and disposed of in accordance with local requirements for infectious waste.

- **Air ducts (heating and cooling ventilation systems)**

When there is evidence that rodents have access to heating and cooling ventilation systems, it is best to contact a professional rodent exterminating service to remove them. Companies specializing in duct cleaning are familiar with the particular problems and risks associated with rodent infestation in ventilation systems.

Hantavirus is not a new risk to public health, and there is no evidence that it is increasing or spreading. All that is new is our ability to recognize it and deal with it more effectively through early diagnosis and treatment.

For more information on hanta virus, refer to the following resources

- Alberta Health and Wellness Public Health Management Guidelines: Hantavirus. Available at <http://www.health.alberta.ca/documents/ND-Hantavirus.pdf> (Accessed Feb 6, 2012)
- Alberta Health and Wellness Disease and Conditions: Hantavirus. Available at <http://www.health.alberta.ca/health-info/hantavirus.html> (Accessed Feb 6, 2012).
- Health Canada Hantavirus (2009). Available at http://www.hc-sc.gc.ca/hl-vs/alt_formats/pdf/iyh-vsv/diseases-maladies/hantavirus-eng.pdf (Accessed Feb 6, 2012)

E.6 Bacteria

Bacteria are single-celled prokaryote organisms. They lack a true nucleus unlike eukaryote organisms. Once suspended in the air, bacteria can remain in the air for prolonged periods because of their small size. Table E-6 presents the shape and sizes of several bacteria.

Table E-6 Shape and sizes of several bacteria

Bacterial groups	Shapes	Sizes
Coccus	Spherical	0.4 µm – 2 µm
Bacillus	Rod-shaped	Smallest bacilli – length 0.5 µm; diameter 0.2 µm Pathogenic bacilli – diameter 1 to 3 µm Non-pathogenic bacilli – diameter 4 to 20 µm
Spirillum, spirochete and vibrio	Spiral/curved	Spirillum – diameter <1µm; length 1 to 14 µm

Actinomycetes, once classified as a fungus, are now known to be included as a class of bacteria. However, unlike bacteria, Actinomycetes form filamentous structures like fungi. Bacteria can be gram positive or gram negative. Gram-positive bacteria produce and secrete specific disease-causing exotoxins (tetanus, botulinum and *B. cereus* toxins) (Inglis, 2001). In contrast, gram-negative bacteria produce both endotoxins and exotoxins (ACGHI, 1999). In gram-negative bacteria, endotoxins are the lipopolysaccharides that form part of the cell wall (ACGHI, 1999). Although exposure to low concentrations of endotoxins are believe to be required for normal development and maintenance of the immune system, exposure to higher levels can be irritating or toxic, eliciting flu-like symptoms and breathing difficulty.

The predominance of gram-negative bacteria, over gram-positive bacteria, suggests the presence in a building of unusual sources, poor cleanliness or poor ventilation. For example, the presence of oxidase-negative, glucose-fermenting gram-negative bacteria are indicative of fecal contamination, such as from leaked plumbing, improperly vented bathroom exhaust stacks or the presence of standing water. Oxidase-negative, glucose-fermenting gram negative bacteria belong to the *Pseudomonas* genus.

Gram negative exotoxins include verotoxin of *E. coli* and *Shigella* strains and cholera toxin of *Vibrio cholerae*) (Inglis 2001). Legionella is a gram-negative bacteria, it can cause several diseases. Legionnaires' disease is discussed in some detail in the following subsection. A list of common bacteria associated with disease and illness are presented in Table E-7.

Table E-7 Pathological diseases and their causative agents

Disease	Causative agent
Legionnaires' disease	<i>Legionella pneumophila</i>
Pneumonia	<i>Mycoplasma pneumoniae</i>
Respiratory infections	<i>Pseudomonas aeruginosa</i>
Tuberculosis	<i>Mycobacterium tuberculosis</i>
Diphtheria	<i>Corynebacterium diphtheriae</i>
Anthrax	<i>Bacillus anthracis</i>
<i>Meningococcal meningitis</i>	<i>Neisseria meningitides</i>
Wound infections	<i>Staphylococcus aureus</i>

Source: Modified from Godish (2000), *In Indoor Environmental Quality*, Lewis Publishers, 2001

Most naturally occurring bacteria are not considered harmful; many are commensal and are essential for human health. Risk of illness from airborne exposure to bacteria generally arises if bacterial concentrations and exposures are increased, such as may occur from growth amplification indoors or increased indoor sources (ACGIH, 1999). Personal susceptibility and bacterial pathogenicity are also important determinants of health risk.

In non-manufacturing environments, the major environmental and airborne sources of bacteria are the human skin and the respiratory tract including skin shedding, talking, coughing and sneezing (ACGIH, 1999). Other sources included contaminated humidifiers, damp or wet surfaces, standing water, floods and sewer backups.

Indoor air is generally contains higher levels of bacteria than outdoor air, with indoor levels demonstrating wide variability and influence by the number of persons present, their activities, type of clothing and ventilation rate (ACGIH, 1999). Normal airborne bacterial levels can range from $<100/\text{m}^3$ under low occupancy to $>5000/\text{m}^3$ in a schoolroom with actively playing, lightly clad children. High bacterial levels coupled with evidence of low ventilation, such as elevated CO_2 monitoring, suggest poor building maintenance and cleanliness, overcrowding or a lack of ventilation.

E.6.1 Legionella bacteria

Legionnaires' disease is caused by Legionella species. Legionella bacteria live as facultative intracellular parasites in various aquatic micro-organisms. They are gram negative, aerobic and rod-shaped bacteria. The sizes range from 1.5 to 5 μm in length and 0.3 μm to 0.9 μm in diameter. *Legionella pneumophila* is commonly found in all potable water systems (Spengler et al., 2001; Godish, 2000).

In 1977, Centre for Disease Control (CDC) identified *Legionella pneumophila* as the causative agent for a disease outbreak at an American Legion Convention in Philadelphia. The outbreak resulted in 29 deaths attributed to a pneumonia-like illness (Barry, 2001, cited in Spengler, 2001).

E.6.1.1 Sources

Legionella species can be found in outdoor water bodies, such as rivers, streams and ponds, and in indoor water distribution systems. The source of Legionella outbreaks has been attributed to the aerosolization of domestic water from different sources including HVAC systems. Air conditioning equipment, such as cooling towers and evaporative condensers, provides favourable conditions (warm temperature and nutrient medium) for the growth of Legionella (Freije, 1996, cited in Barry, 2001). The following box lists examples of indoor sources of Legionella associated with aerosolization.

Source: Barry, 2001; Spengler et al., 2001; Godish, 2000; ASHRAE, 2000)

Examples of indoor sources of Legionella associated with aerosolization

- Indoor fountains
- Hot-and-cold water taps
- Hot water tanks
- Nebulizers
- Spas and whirlpools
- Cooling towers
- Evaporative condensers
- Humidifiers
- Reservoir misters in supermarkets
- Potable water
- Faucets and showerheads

E.6.1.1.1 Sensitive or vulnerable individuals

Legionnaires' disease is an opportunistic infection. The following risk factors have been identified for Legionnaire's disease (Godish, 2000; Barry, 2001; Spengler et al., 2001; CDC, 1994b; ASHARE, 1998):

- Smoking
- Alcohol consumption
- Middle-aged population groups
- Male gender
- Pre-existing lung diseases
- Diabetes
- AIDS
- Immunosuppressive therapy (i.e., chemotherapy)

According to ASHRAE (1998), the preceding factors can play a major role in the susceptibility of individuals to Legionnaires disease.

E.6.1.2 Health effects

Both acute and chronic health effects can be seen in affected individuals exposed to Legionella.

In addition to Legionnaires' disease, *Legionella pneumophila* also causes flu-like Pontiac fever and infections such as wound inflammation, pericarditis and endocarditis (OSHA Technical Manual, 2000). A non-pneumonia form of Legionnaire is also called Potomac fever. Based on CDC's estimates, 10,000 to 15,000 cases of Legionnaires' disease occur every year in the United States (Barry, 2001; Spengler et al., 2001). The death rate among Legionnaires' exposed individuals has been estimated between 10% to 15%. However, the fatality rate for nosocomial infections in patients can be as high as 30% to 50% (Barry et al., 2001; Spengler et al., 2001; ASTM, 1997).

• **Acute effects**

Generally, Legionnaires' disease is characterized by symptoms of fever, cough and shortness of breath and chest pain, headache, myalgia, diarrhea and confusion (Godish 2000).

• **Chronic effects**

The following long-term health effects can occur after exposure to Legionella (Broward County Extension Education Division, Florida, USA, <http://www.co.broward.fl.us/agriculture/english/consfarm/he348.htm>):

- Immune system damage in older populations and smokers
- Neurological effects such as disorientation, depression, hallucinations, delirium and retrograde amnesia
- Long-term weakness, persistent headaches, chills and chronic coughing

E.6.2 Exposure

Inhalation is the primary route of exposure to Legionella aerosols generated from contaminated water, such as residential and hotel showers and HVAC/humidifier systems (Godish 2000). Although showering is a suspect activity, there is no data that supports exposure to Legionella and disease from showering (Barry, 2001; Spengler et al., 2001; Godish, 2000).

E.6.3 Guidelines

No numerical exposure or health effects guidelines were located for Legionella at the time of the writing of this manual.

E.6.4 Control measures

Several regulatory agencies such as CDC and ASHRAE have provided guidelines and recommendations to control or remediate Legionella bacteria contamination of indoor sources.

Legionella are ubiquitous in the environment. Therefore, a complete eradication of those organisms from indoor sources may not be possible (Barry, 2001, cited in Spengler et al., 2001). Periodic checking and maintenance of indoor sources is essential to minimize contamination (Barry, 2001; Spengler et al., 2001). Detection of a low level of Legionella bacteria ranging from 50 CFU/mL to 100 CFU/mL will require the setting up of an effective maintenance protocol to avoid a Legionella outbreak. CDC has developed several disinfection procedures for potable water systems and cooling towers that are contaminated with Legionella (CDC, 1994b).

E.6.4.1 Disinfection procedures for potable water systems and cooling towers

• Potable water systems

Maintenance of potable water systems from Legionella contamination involves a one-time thermal disinfection process, which can be accomplished by:

- Raising the temperature of water to 65°C (150°F) in the hot water tank
- Flushing each water outlet for five minutes
- Eliminating dead lines.

- **Cooling towers**

CDC has recommended a four stage process of disinfection of cooling towers (Barry, 2001, cited in Spengler et al., 2001) which involves following steps.

1. Preparation

Inspect the cooling tower by wearing PPE (personal protective equipment). Shut down the cooling system unit.

2. Chemical disinfection

Use a chlorine-based disinfectant, such as sodium hypochlorite or calcium hypochlorite, to obtain free residual chlorine (FRC) of 50 ppm. Additional chlorine use is needed to maintain a chlorine concentration of 10 ppm for 24 hours. Adjust the pH to 7.5 or 8.0. Add detergents to remove built up materials including scale, slim and sludge in the piping. Monitor free residual chlorine and pH levels often (15 minutes intervals in first two hours and at two-hour interval within next 24-hour disinfection cycle).

3. Mechanical cleaning

After chemical disinfection, shut down the cooling tower and evaporative condenser. Inspect all water contact areas for sediments and sludge. If sediments and sludge are present, remove them with the help of a brush or a low-pressure water hose. Thoroughly clean all water contact areas including basin, sump, fill, spray nozzles and fittings. Replace old components with new ones.

4. Restart of the cooling tower

After completion of the mechanical cleaning, follow procedures provided below in a stepwise manner.

- ▶ Fill the system with water. Add chlorine to achieve FRC level of 10 mg/l.
- ▶ Let the water circulate for one hour
- ▶ Open blowdown valve to flush the system until the water is free of any turbidity and then drain the system.
- ▶ Open any air intake vents that were closed before cleaning
- ▶ Fill the system with water
- ▶ Restart the cooling tower and evaporative condenser by starting an effective water treatment program.

A detailed cleaning procedure protocol including mechanical cleaning and restart procedure can be obtained by referring to CDC's publication entitled, *Guidelines for Prevention of Nonsocomial Pneumonia*, Respiratory Care 39: 1202-1205. The guideline document can also be obtained from CDC's website <http://www.cdc.gov>).

Comprehensive cleaning of cooling tower systems should be done at least once or twice a year. Before full start up, cleaning of the system is recommended in the spring season. Another cleaning can be done during summer and fall when outbreaks are more likely to occur. The following remedial actions are suggested based on detection of Legionella bacteria in water samples from different sources (Barry 2001, cited in Spengler et al. 2001) (Table E-8).

Explanation for remedial action levels

Remedial action level 1

- Review routine maintenance program recommended by the manufacturer of the equipment to ensure that the recommended program is being followed.
- The presence of barely detectable numbers of *Legionellae* represents a low level of concern.

Remedial action level 2

- Implement action 1.
- Conduct the follow-up analysis after a few weeks for evidence of further *Legionella* amplification.
- Level 2 *Legionellae* represents little concern, but the number of organisms detected indicates that the system is a potential amplifier for *Legionellae*.

Remedial action level 3

- Implement action 2.
- Conduct review of premises for direct and indirect bioaerosol contact with occupants and health risk status of people who may come in contact with the bioaerosol.
- Depending on the results of the review of the premises, action related to cleaning or biocide treatment of the equipment may be indicated.
- Level 3 *Legionellae* represents a low but increased level of concentration.

Remedial action level 4

- Implement action 3
- Cleaning or biocide treatment of the equipment is indicated.
- Level 4 *Legionellae* represents a moderately high level of concern because this level are may cause an outbreak.
- It is uncommon for samples to contain numbers of *Legionellae* that are in this category.

Remedial action level 5

- Immediate cleaning or biocide treatment of the equipment is definitely indicated.
- Conduct post treatment analysis to ensure effectiveness of the corrective action.
- Level 5 *Legionellae* represents a high level of concern because of the potential of an outbreak.
- It is very uncommon for samples to contain numbers of *Legionellae* that fall in this category.

Table E-8 Recommended remedial action for Legionella

<i>Legionella</i> - (CFU/mL) of sample	Recommended remedial action	
	<i>Cooling Tower</i>	<i>Potable Water Sources</i>
Detectable but < 1	1	2
1-9	2	3
10-99	3	4
100-999	4	5
> 1000	5	5

Source: Spengler et al. (2001), In *Indoor Air Quality Handbook, Chapter 48, Legionella*, McGraw Hill publications, 2001.

E.7 Pollen

Pollen is an essential component in the life cycle of flowering plants. It is a capsule, which protects the male gametophyte as it is transferred from anther to a receptive stigma. Pollen grains are transported by two transport mechanisms (Muilenberg, 2001):

- Active transport by insects, birds, bats and other animals
- Passive transport by wind and air currents

Pollens have the potential to come into contact with humans because of their aerial transport.

Under favourable climatic conditions, temperature and moisture, pollens are distributed over a wide distance from one location to another. There are many different types of pollens, ranging up to more than 15 µm in diameter. A few examples are presented below (Spengler et al. 2001, NEIHS 2001):

- Grass pollen, such as Bermuda grass, Johnson grass, Kentucky bluegrass, Orchard grass, Sweet vernal grass and Timothy grass
- Ragweed pollen and other weeds, such as curly dock, lambs quarters, pigweed, plantain, sheep sorrel and sagebrush
- Tree pollen, such as ash, box elder, cottonwood, elm, hickory, maple, olive, pecan, poplar, sycamore, walnut, willow, birch, red oak and the evergreen family of trees including pine fir and spruce. Note: less than 100 species of trees have been shown to cause allergies.

E.7.1 Sources

Outdoor air is the major source for the infiltration of pollen into indoor environments (Muilenberg, 2001). Open windows, cracks and gaps can facilitate pollen entry in to buildings. Modern buildings are less prone to pollen infiltration because of their air tight characteristics. However, human beings and pets can carry pollen from outside and ventilation systems can actively transfer outdoor pollens to the indoors (Muilenberg, 2001). Indoor flowering plants in residential buildings and offices can also contribute to indoor pollen levels.

E.7.2 Indoor and outdoor air dynamics

Most researchers agree that there is a close relationship between outdoor and indoor pollen, although there are some discrepancies (Stock and Morandi, 1988; Cariñanos, 2004). Differences between indoor and outdoor pollen levels can be attributed to multiple factors including seasonality and spatiality of pollens production, different home ventilation strategies, or patterns of occupant movement (Muilenberg, 2001).

- Increased indoor pollen levels have been reported during the spring season, which is the peak pollen production time (Yankova, 1991, as cited in Mulengerg, 2001). Tormo-Molina *et. al.* (2009) found a strong seasonal pattern of pollen levels, with the highest levels in spring and winter, and the indoor concentrations were correlated with the outdoor one. They also found the presence of ornamental vegetation in the

area surrounding the building affected the indoor counts directly as sources of the pollen.

- There are various possible routes by which pollen may enter the indoor airborne environment, such as through the ventilation system (Comtois and Marcoux, 1999) but there is a trend of thought that humans themselves are the vector, either transporting these bioaerosols (Muilenberg, 2001) adhered to their clothing (Takahashi et. al., 2009) or stirring them up from the floor where they are abundant, as people walk about inside a building (O'Rourke and Lebowitz, 1984; Ishibashi et. al, 2006; Hiromi & Susumu, 2001; Vural, 2008). Factors such as indoor ventilation and occupant movements can affect the indoor distribution of pollens (Muilenberg, 2001).
- Pollens can also be found in house dusts. Dusts collected from naturally ventilated homes in Tuscon, Arizona reported a minimum concentration of 178 grains (gr) per gram of dust. The maximum concentration reported in that study was 5.5×10^6 gr (O'Rourke and Lebowitz, 1984, cited in Muilenberg, 2001).
- Pollen grains and pollen allergens should be treated differently. Pollen allergen level is a better indicator of exposure than pollen grain level because grains can be devoid of allergenic activity. A Finish study found birch pollen allergen levels in outdoor dusts to be 10 times higher than indoor residential dusts. It was also reported that urban homes might contain higher dustborne allergen levels than rural homes. In the same study, the passive transport via shoes and clothing was identified as a major factor for pollen transport to the indoors (Yli-Panula and Rantio-Lehtimaki, 1995, cited in Muilenberg, 2001).

E.7.3 Toxicology, health effects and exposure

Pollen grains come into contact with mucosal linings of the nose, eyes and oral cavity. The water soluble allergens react with mast cells resulting in the release of histamine, leukotrienes and cytokines. As a result, hypersensitivity reactions in humans are observed (USEPA, 2000).

The following acute health symptoms are some of the general symptoms observed among individuals exposed to both indoor and outdoor pollen allergens (Muilenberg, 2001).

- Nasal congestion or nasal discharge
- Itching and burning sensation in the eyes, nose and throat
- Swelling of the mucous membranes

The following chronic hypersensitivity diseases have been reported among individuals exposed to pollens (Muilenberg, 2001).

- Hay fever or rhino conjunctivitis (the most common form of pollen-induced disease)
- Asthma
- Allergic dermatitis (rarely seen)

In one study, symptoms of allergic rhinitis were elicited in patients when pollen levels reached 50 gr of pollen/m³ of air (Davies and Smith 1973, cited in Muilenberg 2001).

Cookingham and Solomon (1995) reported that allergen levels required to cause health symptoms vary greatly among individuals, being influenced by recent exposures (cited in Muilenberg 2001). Several laboratory allergy sensitivity studies have shown differences in sensitization rates in different population groups exposed to different pollen agents (Table E-8).

Table E-8 Pollen sensitization rates among population groups

Pollen agent	Population	Percentage of positive skin-prick test reaction	
		Total cohort ¹ (%)	Atopics ² (%)
Olive pollen	Italians	17	23
Rye grass pollen	New Zealand children	32	72
Pecan pollen	Israelis	12	25
Pellitory pollen	Florida allergy patients	Not available	20
Hemp pollen	Nebraska allergy patients	Not available	61

1. Total cohort shows a population not selected on the basis of allergy status

2. Atopics shows those individuals having hypersensitivity diseases with a familial tendency

Source: Muilenberg, M.L. (2001), *Pollen in indoor air: sources, exposure and health effects, Chapter 44, in Indoor Air Quality Handbook, Spengler et al (2001), McGraw-Hill publications, 2001.*

E.7.4 Guidelines

No numerical guidelines for pollen were available at the time of writing of this manual.

E.7.5 Control measures

Different proposals have been made to reduce or eliminate indoor bioaerosols, with efficiencies close to 100 per cent, basically by filtering the air with electrostatically charged activated carbon (Holmquist and Vesterberg, 1999; Kettrup and Schmidt, 1987) or using HEPA (high efficiency particulate air) filters (Billings, 1982; Cheng et. al., 1998). Nevertheless, air conditioning has been suggested as an effective means for reducing the penetration of outdoor bioaerosols into interiors (Enomoto et. al., 2004).

The National Institute of Environmental Health Sciences (NEIHS) has recommended several prevention strategies for different types of pollens including grass, ragweed and tree pollen. The following recommendations are some of the general control measures one can carry out to avoid or prevent pollen exposure (NEIHS), <http://www.niehs.nih.gov/health/topics/conditions/asthma/allergens/pollen/>.

- Wear a mask during lawn mowing. Avoid mowing if allergic to grass pollen.
- Choose, plant alternatives to grasses such as groundcover vegetation or landscaping that do not requiring mowing including xeriscaping, *Cornus canadensis* (bunchberry), creeping tyme, kinnickick and creeping willow.
- If possible, avoid outdoor exposure between 05:00 a.m. to 10:00 a.m. because during those hours, pollen dispersal is high—at least on dry, hot and windy days. In winter, pollen dispersal is low or nonexistent, depending on the climate zone.
- Keep the windows closed to minimize pollen infiltration.
- Install indoor central air conditioners or effective filtration, either central or portable.
- When buying trees for the yard, select trees that have a low allergenic potential, such as dogwood, fig, fir, palm, pear, plum and redwood trees.

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Appendix F

Consumer products

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F. Consumer products

F.1 Introduction

Consumer products are diverse. They include all consumer products primarily designed to be used inside or outside living quarters or residences and in the immediate surroundings which are occupied or intended for occupation by individuals (Environment Canada 1999). They are classified under five broad categories:

- Personal care products or fragrance products
- Cleaning products
- Office equipment
- Ritual products
- Hobbies
- Discussion in this section will be arranged and presented based on the above categories. Depending on availability of information and applicability, the discussion under each category will include one or more of the following topics:
 - Description of product category
 - Guidelines, policies and limitations
 - Exposure
 - Health effects
 - Control measures

The US Environmental Protection Agency (USEPA) has noted that “Over the past several decades, our exposure to indoor air pollutants is believed to have increased because of a variety of factors, including the construction of more tightly sealed buildings, reduced ventilation rates to save energy, the use of synthetic building materials and furnishings, the use of chemically formulated personal care products, pesticides, and household cleaners” (USEPA 2002). By definition, these products are intended for and are commonly found in households. However, many contain potentially harmful substances which can significantly contribute to indoor air pollution. They can potentially affect health negatively and inhalation exposure to these substances has raised concerns (Wolkoff et al. 1998, Nazaroff and Weschler 2004).

Some household products are hazardous substances (US Federal Hazardous Substances Act 1960), if they are:

- Ignitable – capable of burning or causing a fire
- Corrosive – capable of eating away materials and destroying living tissue on contact
- Explosive or reactive – can cause an explosion or release poisonous fumes when exposed to air, water or other chemicals
- Toxic – poisonous, either immediately (acute toxicity) or long-term (chronic toxicity)
- Radioactive – radioactive emissions that can cause cellular and genetic damage, such as cancer, mutations and fetal harm

Consumer products can potentially release chemical vapours or aerosols into the air when used or stored (USEPA 1995). Paint, cosmetics and cleaning products alone account for 18 per cent of volatile organic compounds (VOCs) in the environment (Government of Canada 2006). Organic and inorganic chemicals are extensively used as ingredients in a variety of household products such as cleaning agents and personal care products including fragrances, shampoos and lotions. Office equipment, such as printers, copiers and fax machines, release volatile organic compounds (Godish 2000), and equipment using high voltage electricity has the potential to generate ozone. Although only ethanol and 2-butoxyethanol were listed on labels, Steinemann and colleagues detected 133 different VOC's in the tested products. Each product emitted one to eight toxic or hazardous chemicals, and 44 per cent of the products generated at least one carcinogenic hazardous air pollutant (Steinemann et al. 2010).

VOC concentrations in the indoor environment are influenced mainly by indoor sources rather than by outdoor ones. Common organic pollutants are two to five times higher inside homes than outside, irrespective of whether the homes were located in rural or highly industrial areas (USEPA 2002), suggesting major indoor VOC sources. Following the use of a consumer product, VOC levels can rise sharply immediately, sometimes up to 1,000 times higher than levels before use.

Evidence has also demonstrated that chemical reactions can occur between VOCs and other indoor contaminants. For example, aldehydes can be produced when ozone (O_3) reacts with unsaturated hydrocarbons, such as d-limonene, α -pinene, α -terpene, styrene and isoprene. Terpene hydrocarbons, terpene alcohols and related unsaturated compounds are commonly used as scenting agents in consumer and cleaning products. Terpene hydrocarbons also react rapidly with ozone, producing upper respiratory tract and eye irritants including formaldehyde (Fan et al. 2003), hydrogen peroxide (Li et al. 2002), hydroxyl radical (Weschler and Shields 1997) and secondary organic aerosol (Weschler and Shields 1999, Wainman et al. 2000, Liu et al. 2004, Sarwar et al. 2004).

VOCs are also capable of adsorbing onto different materials such as carpets, furniture and other common household items. Once sorbed, they can be re-emitted or desorbed from those surfaces later. The reader is encouraged to refer to the *Chapter IV Chemical factors: vapours* and *Appendix G Outdoor air factors* for additional information on this indoor air characteristic of VOCs and the correlation between personal exposure and VOCs concentration in indoor and outdoor air.

F.1.1 General health concerns

The diversity of household products makes it challenging to categorically describe the health effects of household products. The health concerns of each product are unique and are determined by its chemical, physical and toxicological properties. In this subsection, the general concerns are described; specific concerns to each category of household products are described in respective sub-sections.

Many scented products contain irritants. Active chemical ingredients in tested fragrances include limonene, anethole, 4-hydroxy-3-methoxy benzaldehyde, linalool, terpinolene, benzene dicarboxylic acid, linalyl acetate and citronellol (Anderson and Anderson 1998). Limonene is a known contact and ingestion irritant to eyes, skin, mouth, stomach and lungs (Wilson 1993).

In one study, Anderson and Anderson (1998) exposed via inhalation male Swiss-Webster mice for one hour to unusually high emissions from five different colognes with a dose range from 0.05 gm to 3.0 gm. Emissions from those colognes were estimated based on the size of the experimental chambers, exposure duration and dilution factors. Emissions caused sensory irritation, pulmonary irritation and neurotoxicity in those mice. Neurotoxicity was severely pronounced after repeated exposures. This experiment confirmed that exposure to very high concentrations of VOCs in fragrance products, far above exposures that would normally be experienced by people causing a variety of acute toxicities in mice.

Some fragrance ingredients can affect the central nervous system (CNS) resulting in dizziness, incoordination, convulsions, and death. Similar acute toxicity data have been reported for other chemical ingredients present in fragrance products. The reader should note that these exposure concentrations are many times higher than levels anyone or any animal including mice would be normally exposed to in day to day activities.

Chemicals associated with various household products can cause chronic health risks including long-term neurotoxic, reproductive, depigmentation and carcinogenic effects (IFRA 1998). Dibutyl phthalate (DBP), an endocrine disrupter, is used as a plasticizer in nail polish and hair products. Exposure to DBP has been confirmed to cause abortions, birth defects, skeletal malformations, reduced sperm count and testicular atrophy in laboratory animals. However, no such health effects have been observed in humans using DBP containing cosmetic products (Health Canada 2001).

Other chemicals used in fragrance products also have induced neurological effects in laboratory animals. Musk ambrette (2,6-dinitro-3-methoxy-4-tert-butyltoluene), which is widely used as a fixative in fragrance formulations, produced hind limb weakness in rats exposed for 12 weeks to high concentrations via ingestion and dermal contact. Degeneration of the central and peripheral nervous system was also observed in test animals (Spencer et al. 1984).

Fabric softeners are another common household item used extensively in clothing dryers to treat fabrics. Fabric softeners contain chemicals, such as alpha terpenol, benzyl acetate, benzyl alcohol, camphor, chloroform, ethyl acetate, limonene, linalool and pentane (USEPA 1991) as well as known irritants, such as isopropylbenzene, styrene, trimethylbenzene, phenol, and thymol (Anderson and Anderson 2000) which can cause serious health effects, such as CNS related effects in human.. In one study, mice exposed to the emissions of five commercial fabric softener products for 90 minutes showed mild

inflammation of interalveolar septae of the lungs. This finding provided an explanation to some of the reported adverse human reactions to fabric softeners (Anderson and Anderson 2000).

Tetrachloroethylene (otherwise known as perchloroethylene or PERC) is used in the dry-cleaning process. It has been shown to cause cancer in laboratory animals. It affects the CNS of humans and animals via inhalation exposure. Both inhalation and ingestion have been shown to affect liver and kidney functions. The greatest exposures to PERC occur in individuals who live in buildings with dry-cleaning facilities.

F.1.2 Sensitization and susceptible groups

Susceptible individuals have shown sensitivity reactions to chemical ingredients in fragrance products. There is a possibility that some ingredients which are organic or biological in origin may elicit allergic responses. Products with scents have been recognized as sources for allergens and irritants of the skin. A study by Madsen (1996) shows a direct correlation between the use of scented products and skin allergy. Scented products can also act as photosensitizers and phototoxins affecting the skin. General sensitivity reactions include systemic contact dermatitis because of balsam of Peru, benzyl alcohol and menthol, and pigmented eruptions because of phototoxic or photoallergic agents in incense and perfumes. Dermatitis reactions have been recorded in some individuals when using toothpaste, perfumes, sanitary napkins and detergents (Larsen 1989). During the 1970s, hair spray was found to have triggered respiratory problems in susceptible populations (Bridges 2002).

Fragrance products can also affect the respiratory system. People with asthma, allergies, sinus problems and rhinitis are more susceptible, often at levels many times lower than those of the general population. Anderson and Anderson (1998) have observed that some susceptible humans exposed to fragrance products might experience some combination of eye, nose or throat irritation, respiratory difficulties, and CNS effects including dizziness, fatigue and lack of coordination.

Young children are more sensitive than adults. The prevalence of asthma symptoms in children has been increasing in the UK (Ninan and Russell 1992, Anderson et al. 1994, Lewis et al. 1996) as well as in other developed countries in recent years (Murphy 1998, Sly 1999, Gerstman et al. 1993). One plausible cause is the common use of cleaning sprays that contain sensitizers such as disinfectants, amines, pinene, or limonene (Wolkoff et al. 1998, Nazaroff and Weschler 2004). A study by Sherriff et al. (2005) has investigated the dose-dependent relationship in prenatal exposure and concluded that mothers who often use chemical-based domestic products during pregnancy are more likely to have offspring with persistent wheezing throughout early childhood.

F.1.3 Exposure

Chemicals and materials from household products can enter the human body via one or more of three exposure routes:

- Ingestion via eating or drinking hazardous substances or contaminated food-and water
- Dermal absorption through the skin, an important pathway for exposure to fragrance products
- Inhalation of gases, vapours and aerosols from different household products, such as cleaning and personal-care products

Inhalation is undoubtedly the most significant exposure pathway. Aerosolized household products are becoming trendy and researchers have suggested that the application of household cleaning products through spraying likely facilitates further respiratory exposure (Zock et al. 2007). This suggestion is based on the observation that while the active ingredients in sprays remain generally unchanged as in the more conventional liquid cleaners; exposure has been mostly associated with sprays rather than liquid cleaners. The same research group has also suggested that one in seven adult asthma cases could have been attributed to the use of sprays.

F.1.4 General measures for reducing exposure to household chemicals

Several precautionary measures can be taken to reduce chemical exposure to various household products (USEPA 1995).

- **Carefully follow label instructions**

Hazardous products usually carry warning labels that give directions for product use and handling as well as explain how to reduce any risks associated with product use and storage. If a warning label recommends that the product should be used in a well-ventilated area or with local exhaust ventilation, then the direction should be followed.

- **Safely dispose of unused chemical containers and cleaning agent bottles**

Gases and vapours can leak from closed containers. Proper disposal of any unused or unneeded chemical containers will help reduce personal exposure to potentially toxic chemicals. Because consumer products, such as paints, stains and solvents including varsol, can leak, they should be kept in a well-ventilated area, such as exhaust-ventilated storage cabinets, and also out of the reach of children. Care should be taken not to dispose of these containers in the regular garbage. Instead use eco-stations and or depots set up during spring clean-up times. The local waste collection agency or fire department could be contacted for information on proper disposal.

- **Minimize exposure to dry cleaned clothing**

Perchloroethylene (PERC or tetrachloroethylene) is used in the dry-cleaning process. PERC has been shown to cause cancer in laboratory animals. USEPA has classified PERC as intermediate between a probable and possible human carcinogen (Group B/C) in 1992 and again revised in 2000 (USEPA 2007). People bringing home dry-

cleaned clothing directly from a dry-cleaning facility can be exposed to elevated levels of PERC via the offgasing process. Although some dry-cleaners are more effective than others at extracting PERC during the drying phase of the dry-cleaning process, it is prudent to take steps to minimize exposure to PERC from dry-cleaned clothing. If dry cleaned garments have a strong odour, ask the dry-cleaner to get rid of the odour by properly drying them. PERC has a relatively high odour threshold (1 ppm) in the air; therefore, dry-cleaned clothing should be kept outside, such as on a porch or in a mudroom, for sometime to ensure complete offgasing before bringing clothing materials inside.

- **Avoid exposure to methylene chloride**

Consumer products, such as adhesives and paint removers, may contain methylene chloride (dichloromethane). Methylene chloride has been shown to cause cancer in laboratory animals and is classified as a probable human carcinogen by USEPA. Once absorbed, methylene chloride is converted to carbon monoxide in the body. If methylene chloride is listed on the product label, handle the product carefully. Avoid skin contact and use only in a well-ventilated area. If possible, select other products that do not contain methylene chloride.

F.2 Personal care products

Personal care products include, but are not limited to, the following products:

Examples of fragrance-related products containing volatile organic compounds (VOCs)

- After shave lotion
- Deodorant stick
- Hairspray
- Hand lotion
- Nail colour
- Contact lens solution
- Perfume
- Nail polish remover
- Shampoo
- Shaving cream
- Soap

*not included in the fragrance products category

Twenty common volatile organic compounds found in fragrance products including perfumes, soaps, hand lotion, solid deodorant, after shave lotion, nail enamel remover nail polish are listed in the following box. These chemicals can also be found in household cleaning products, such as floor cleaners and laundry detergent. (Wallace 1991). A discussion on cleaning products is provided in a separate section.

Common volatile organic compounds (VOCs) found in fragrances-related products

- 1,8-cineole
- Acetone
- A-pinene
- A-terpineol
- a-terpinolene
- B-citronellol
- Benzaldehyde
- Benzyl acetate
- Benzyl alcohol
- B-myrcene
- B-phenethyl alcohol
- Camphor
- Ethyl acetate
- Limonene
- Linalool
- Methylene chloride
- Nerol
- Ocimene
- Y-terpinolene

Source: Identification of Polar Volatile Organic Compounds in Consumer Products and Common Microenvironments, Wallace (1991), USEPA, Paper Submitted for presentation at the 1991 Annual Meeting of the AWMA.

The International Fragrance Association (IFRA) defines a fragrance ingredient as any basic substance used in the manufacture of fragrance materials for its odorous, odour enhancing or blending properties. These fragrance ingredients are obtained by extraction and chemical synthesis from natural occurring and synthetic materials. They contain aromatic chemicals, essential oils, natural extracts, distillates, isolates and oleoresins (SCCPNFP 1999).

Allergic reactions are manifested in some individuals when they are exposed to fragrance products via the dermal pathway. When applied to the skin, these products can cause contact allergy. There are different types of immunological reactions (Type I, II, III and IV). Contact allergy is a type IV (delayed hypersensitivity) immunological reaction caused by low-molecular-weight substances.

Eczema, a clinical symptom of contact allergy, is an inflammatory skin disease that is characterized by erythema, induration and in some instances vesicles. At a later stage of exposure, scaling and fissures can develop in sensitive individuals (SCCPNFP 1999). The ability of fragrance products to elicit allergic responses attests to their biological origin of botanical extracts. The following box describes the various immunological reactions.

Five immunological reactions common to humans and animals

Immunological reactions or immunotoxic effects can be described by various responses in the animal or human body. These different immunological reactions include:

- Hypersensitivity
- Chronic inflammation
- Immunosuppression
- Immunostimulation
- Autoimmunity

Hypersensitivity or allergy can be defined as increased reactivity to an antigen; in this case, a fragrance ingredient which a human or an animal have been previously exposed to. Different antibodies mediate different types of allergic reactions. The common type I (anaphylactic) reactions are mediated by IgE antibodies. Type II and III reactions that involve IgG and IgM antibodies are relatively rare and less likely to occur. Type IV reactions or delayed hypersensitivity is a common reaction mediated by T lymphocytes.

Table F-1 lists common allergens in fragrance products.

Table F-1 Most often reported contact allergens in consumer fragrance products

Common name	Comments
Amyl cinnamal	Amyl cinnamal is a well known fragrance allergen It has been identified as a cause of allergic reactions in persons with eczema from cosmetic products.
Amyl cinnamyl alcohol	Five single cases of contact allergy to amyl cinnamyl alcohol by patch testing were found in 4 % (7 out of 179 cases) to 10% (2 out of 20 cases) of patients with contact eczema from cosmetics. Amyl cinnamyl alcohol probably cross reacts with amyl cinnamal.
Benzyl alcohol	Benzyl alcohol was found in several studies to cause allergic reactions in 1.2-15% (2-4 cases) of patients with eczema from cosmetic products.
Benzyl salicylate	Benzyl salicylate was a cause of allergic reactions in 0.2-10% of patients with eczema from cosmetic products and in one study accounted for 75% of reactions to commercial perfumes.
Cinnamyl alcohol	Cinnamyl alcohol is a well-known allergen. It accounts for 5-14% of allergic reactions to fragrance products. In addition it has been shown to cause allergic reactions by patch tests in 1.7%-75% of patients with eczema from cosmetic products.
Cinnamal	Cinnamal is a well proven allergen in the fragrance products. It has been shown to be a cause of allergic reactions by patch test in 1%-30% patients with eczema from cosmetic products in several studies.
Citral	Citral is a cause of allergic reactions in about 1% of patients as observed by a patch test. Citral caused contact allergic reactions in 2.6% of eczema patients.
Coumarin	Coumarin is a cause of allergic reactions in about 0.4-0.8% of patients as observed by a patch test. Coumarin from cosmetic products caused contact allergic reactions in 0.8-10% of patients with eczema.
Eugenol	Eugenol is a well known contact allergen. It caused sensitization in 1.2% of eczema patients and accounts for 4%-16% of reactions to fragrance products. Eugenol from cosmetic products has caused contact allergic reactions in 0.7-20% of patients with eczema.
Geraniol	Geraniol is a well-known contact allergen. It is a cause of sensitization in 0.4% of eczema patients and accounts 3%-7% of reactions to fragrance products. Geraniol from cosmetic products caused contact allergic reactions in 1.2-30% of patients with eczema.
Hydroxycitranellal	Hydroxycitranellal is a well known contact allergen. It is a cause of sensitization in 0.75% of eczema patients and accounts for 6%-16% of allergic reactions to fragrance products. Hydroxycitronellal from cosmetic products caused contact allergic reactions in 10%-45% of patients with eczema.
Hydroxymethyl-pentylcyclohexenecaraldehyde (Lyrall)	Lyrall was a cause of allergic reactions in about 2.8% of patients as shown by a patch test. In addition three relevant cases of contact allergy to Lyrall from cosmetic products were reported.
Isoeugenol	Isoeugenol is a well-known contact allergen. It is a cause of sensitization in 1.9% of eczema patients and accounts for 6-22% of reactions to fragrance products. Isoeugenol from cosmetic products caused contact allergic reactions in 2-25% of patients with eczema
Anisyl alcohol (4-methoxybenzyl alcohol)	Two studies reported contact allergy to anisyl alcohol in patients with cosmetic eczema.
Benzyl benzoate	Benzyl benzoate was shown to be positive for contact allergy in several studies.
Benzyl cinnamate	Benzyl cinnamate was positive in one study of patients with contact allergy to cosmetic products and in a high proportion of patients with contact allergy to Peru balsam.
Citronellol	One case of contact allergy to citronellol was reported.
Farnesol	One study of eczema patients with cosmetic eczema shows two cases of contact allergy to farnesol.
Hexyl cinnamaldehyde	Two studies with one case and one study with seven cases of contact allergy to hexyl cinnamic aldehyde from cosmetic products were found among patients with eczema
2-(4-tert-Butylbenzyl)propionaldehyde (Lilial)	Two cases of contact allergy to Lilial were found in a study of 176 eczema patients with cosmetic eczema. A single case with contact allergy to Lilial from a deodorant was also reported.
d-Limonene	Oxidization products of d-limonene are strong allergens. The frequency of contact allergy to oxidized limonene is 1-2% in consecutive eczema patients. However, the relationship between contact allergy to oxidized d-limonene and fragrances in cosmetic products need further study.
Linalool	One study with one case and one study with 3 cases of contact allergy in eczema patients to linalool from cosmetic products.
Methyl heptine carbonate	It is a strong sensitizer according to IFRA.
3-Methyl-4-(2,6,6-trimethyl-2-cyclohexen-1-yl)-3-buten-2-one	One study with two cases and two studies with 1 case of contact allergy to g-methylionone from cosmetic products in eczema patients

Source: *Fragrance Allergy in Consumers, A review of the problem, Analysis of the need for appropriate consumer information and identification of consumer allergens, The Scientific Committee on Cosmetic Products and Non-Food Products (SCCNFP 1999) Intended for Consumers.*

F.2.1 Guidelines

F.2.1.1 International Fragrance Association

The International Fragrance Association (IFRA) was formed in 1973 in Geneva. It originally consisted of fragrance manufacturers from Europe. Its current members are now found in Asia, Australia and the Americas. It aims at representing the collective interest of the fragrance industry worldwide and to promote the safe enjoyment of fragrance products. It has set standards and guidelines.

The product risk-assessment of IFRA is supported by its Research Institute for Fragrance Materials (RIFM) (IFRA 2012). The RIFM's work is evaluated by an independent scientific expert panel; however, the adequacy of its guidelines and standards for health protection is uncertain. The standards are divided into three categories: specification, prohibited and restricted. Readers who are interested in the standards are encouraged to refer to the IFRA website at http://www.ifraorg.org/en-us/standards_1

F.2.1.2 Environment Canada

Environment Canada has recommended limits for VOCs (volatile organic compounds) content and HVOC (high-volatility organic compounds) in different fragrance products (Table F-3). HVOC compounds have vapour pressure greater than 80 mm of Hg at 20°C. The following guidelines are not applicable to VOCs that:

- Have a vapour pressure of less than 0.1 mm of Hg at 20°C
 - Consists of more than 12 carbon atoms if vapour pressure is unknown
- or-
- If vapour pressure is unknown, set a melting point above 20°C that will not sublimate

Table F-2 VOC content limit in fragrance products

VOC Content Limit in Fragrance Products	
	Content limit (weight %VOC)
Air fresheners	
• Single-phase	70
• Double-phase	0
• Liquid/pump sprays	8
• Solids/Gels	3
Hair products	
• Hairsprays	80
• Hair mousses	16
• Hair styling gels	6
Shaving creams	5
Nail Polish removers	85

Source: Environment Canada. 1999. *Guidelines for Volatile Organic Compounds in Consumer Products*, Accessed on May 8, 2012 from <http://www.ec.gc.ca/lcpe-cepa/8B453EE9-EC82-4ADA-B945-5D45B04349F4/voc-eng.pdf>

F.2.1.3 Health Canada

The Health Canada Cosmetics Program has developed the *Cosmetic Ingredient Hotlist* to “keep the cosmetic industry aware of new substances Health Canada considers inappropriate for cosmetic use or which require avoidable hazard labeling.” The *Hotlist* is science-based and is updated a few times per year. Therefore, readers should refer to the most current “Hotlist” that is accessible at <http://www.hc-sc.gc.ca/cps-spc/cosmet-person/indust/hot-list-critique/index-eng.php>.

F.2.1.4 Scent Free Environment and Human Rights

Scented products are widely reported by individuals with asthma to trigger symptoms (Baldwin et al. 1995). Canadian federal and provincial laws are in place to cover the sensitive groups. For example, the Canadian Human Rights Commission states (CHRC 2007):

This medical condition [environmental sensitivities] is a disability and those living with environmental sensitivities are entitled to the protection of the Canadian Human Rights Act, which prohibits discrimination on the basis of disability. The Canadian Human Rights Commission will receive any inquiry and process any complaint from any person who believes that he or she has been discriminated against because of an environmental sensitivity. Like others with a disability, those with environmental sensitivities are required by law to be accommodated.

The CHRC encourages employers and service providers to proactively address issues of accommodation by ensuring that their workplaces and facilities are accessible for persons with a wide range of disabilities.

—Canadian Human Rights Commission (2007)

F.3 Cleaning products

Cleaning products and cleaning activities have been well-documented for their contributions to indoor air contamination. Consequently, all the effort that is put into cleaning floors, ovens, rugs and washrooms, may expose people to various chemicals (Table F-3) that are often invisible and odourless (Calgary Health Region 1993).

Table F-3 Typical residential cleaning products and associated contaminants

Cleaning products and activities	Pollutants
Carpet and rug shampoo	Sodium lauryl sulfate, sodium dodecyl sulfate, turpentine, naphthalene, 1,1,1-trichloroethene and petroleum distillates
Carpet deodorizers	Formaldehyde
Air fresheners and deodorizers	Formaldehyde, paradichlorobenzene
Oven cleaners	Potassium hydroxide (lye), perfumes and sodium hydroxide (caustic soda)
Spot removers	Ammonium hydroxide; amyl, butyl and ethyl acetate; sodium silicofluoride; benzene; 1,1,1-trichloroethane; naphtha and carbon tetrachloride
Floor wax and wax strippers	Turpentine and additional fumes
Drain cleaners	Hydrochloric acid, and sodium and potassium hydroxide
Disinfectants and germicides	Cresol, phenol and related chemicals
Furniture polish (solvent type)	Petroleum distillates
Bleach	Chlorine vapours
Shoe cleaner	Ammonium chloride and Ammonium hydroxide
Aerosols and spray bombs	Hydrocarbons (petroleum distillates), including propane, butane and isobutane; nitrogen; dimethyl ether; carbon dioxide; dichloromethane (commonly called methylene chloride); and nitrous oxide (occasionally used as a propellant for food products)

Source: *Indoor Air Quality Manual (1993), Calgary Health Region, Calgary, Canada*

F.1.1 Exposure

People tend to avoid products with strong odours. Kovacs et al. (1997) performed qualitative exposure and product avoidance experiments on 342 volunteers by asking them to choose different cleaning products used in their residential cleaning activities. Observations were based on product preferences, time taken to complete a task and the exhibition of avoidance behaviour. At the end, product odour was found to be associated with exhibition of avoidance behaviour. Favourable cleaning products with a mild odour were chosen more often than those with strong odour.

Exposure can occur even when household products are not being used. Killdeer and Scheinder (2001) cited a study by Vejrup (1996) where detergent residues up to 1,500 ppm were reported in dust samples from offices. The likely source of detergents was reported to be residues of cleaning agents left on surfaces after cleaning. In another experiment, Vejrup (1996) reported on the evaporation of cleaning agents and polishes from the floor of an experimental chamber. The VOC level peaked within two hours of product application and declined after two hours, with a dilution ventilation of 0.5 to 1.5 air changers per hour.

Exposure generally increases near the source and near the proximity of the source. Also, indoor exposure is more significant than the outdoor exposure (USEPA 2001). A study by Garetano and Gochfield (2000) measured concentrations of tetrachloroethylene in

apartment buildings housing a dry-cleaning facility. Air sampling in 12 residences from eight apartment complexes detected elevated levels of tetrachloroethylene, which exceeded the ATSDR minimal risk level (MRL) for chronic inhalation exposure of 0.27 mg/m³ or 40 ppb. The MRL for acute inhalation exposure is 1.36 mg/m³ or 0.2 ppm. The mean tetrachloroethylene concentration in these residential sites was 2.0 mg/m³ with a range from 0.47 mg/m³ to 4.2 mg/m³. The results show that people in those residences were exposed to tetrachloroethylene concentrations that exceeded minimal risk levels. The study concluded that residents who live in the buildings that house dry-cleaners may be exposed to tetrachloroethylene concentrations that are a public health concern.

F.3.1 Limits and guidelines

F.3.1.1 Environment Canada

Table F-4 presents the VOC content limits for various cleaning products that are often used in various household activities.

Table F-4 VOC Content limits for cleaning products

VOC content limit	
Bathroom and tile cleaners	Content limit (weight %VOC)
Aerosols	7
All other forms	5
Dusting aids	
Aerosols	35
All other forms	7
Fabric protectants	75
Floor polishes/waxes	
Products for flexible flooring materials	7
Products for non resilient flooring	10
Wood Floor Wax	90
Furniture maintenance products	25
General purpose cleaners	10
Glass cleaners	
Aerosols	12
All other forms	8
Laundry pre-wash	
Aerosol/solids	22
All other forms	5
Laundry starch products	5
Oven cleaners	
Aerosol/pump sprays	8
Liquids	5

Source: *Guidelines for Volatile Organic Compounds in Consumer Products (Draft)*, Canadian Environmental Protection Act (CEPA) 1999, Environment Canada 1999

F.3.2 Control measures

Spray increases the exposure; ventilation and dilution is an effective control measure. Aerosols and spray bombs are commercial products that are discharged under pressure from disposable containers and can exist either as a suspension of fine liquid or as solid particles scattered throughout the air (Health Canada 1995). Because of the small size of aerosol-propelled particles and their ability to stay airborne for longer periods of time, they can migrate to other rooms in a house and be inhaled deeply into the lungs and be quickly absorbed into the blood. The use of aerosols in closed spaces, such as bathrooms and workshops, should be avoided (Felten 1988). To help control exposure, an outside window or door should be kept open during cleaning activities. An exhaust fan should be used during cleaning activities.

Pressurized aerosol products or bombs have three main components:

- Active ingredients
- Propellant
- Various additives used for product improvement; for example, surfactants, synthetic resins, plasticizers and emulsifiers (Calgary Health Region 1993).

The main component of aerosol bombs contaminating indoor air is the propellant, constituting 60% to 70% of the total content. A simple control measure is to use a hand-pump spray or other non-aerosol cleaning and grooming products. From a toxicological perspective, the active ingredients and various additives in aerosol products may be more important than the propellant as they may be corrosive and present acute or chronic health risks. The use of hand pump or manually applied products would lower exposures but are not a guarantee of safety. Alternatives to pressurized or hand-pump aerosol products include cream, stick or roll-on products and the use of powder, paste or liquid cleaners (Faelten 1988).

F.4 Office equipment

Emissions from various electronic products, appliances, office equipment and office materials have the potential to cause SBS-type (Sick Building Syndrome) illnesses (Godish 2000). Exposure to particulates and several VOCs can occur from the following office products and appliances.

Office equipment and products that can cause “Sick Building Syndrome”	
• Blue print and signature machines	• Inkjet printers
• Carbonless copy paper (CCP)	• Laser printed paper
• Photocopied printed bond paper	• Laser printers
• Duplicators	• Matrix-printed paper
• Electrographic printers	• Microfiche
• Green-bar computer printing paper	• Computers and video display terminals (VDTs) or video display units (VDUs)

Individual office equipment can act as a point source of contamination. Exposure to contaminants from office equipment and supplies can occur to persons working nearby or passing through. USEPA has summarized the chemical emission rates from office equipment. Table F-5 presents emission rates, sources and preventative and control options available for these emissions. Table F-6 lists chemicals released from different office equipment. Table F-7 is a comparative list of chemicals emitted from photocopied, laser-printed and matrix-printed paper, and toner powders

Table F-5 Emission rates and indoor air concentrations of chemicals from office equipment and electronic products

Office equipment	Contaminants	IAQ/emission rate	Pollution prevention options	Comments
Dry-process photocopy	Machines	VOCs, respirable particulate (toner powder) and ozone (O ₃)-O ₃ : 40 µg/copy (average), with a peak conc. of 131 µg/copy, 0-1350 µg/min and average 259 µg/min	-Particulates: 0.001 µg/m ³ room concentration of carbon black; 90-460 µg/m ³ in exhaust air	-TVOC: 0.5 to 16.4 µg/sheet from paper . Lower voltage to reduce O ₃ (charged rollers), toner reformulation, improved transfer efficiency, lower maintenance machines, lower fuser temperature, changes in toner particle size, low emitting components. Large units of machines should have dedicated HVAC systems.
Wet-process photocopy machines	VOCs and O ₃	TVOC: 25g/h, 0.241 g/copy, observed high room concentration of 64 mg/m ³ ; 4150 mg/m ³ in exhaust air	Solvent reformulation; pressure fusing, decrease voltage, low-emitting components	
Laser printers	VOCs, respirable particulates and O ₃	-O ₃ : 100-4000 µg/m ³ room concentration; 438 µg/min (average); 100 µg/min (with filter) -Respirable particulates: 60 µg/min -TVOC: 2.0-6.5 µg/sheet	Same as for dry-process photocopying machines	
Ink/bubble jet printers	VOCs and O ₃	No published data up to 1994	Solvent reformulation, low emitting components	Primary use – personal home based
Impact Printers	VOCs	-TVOC: 0.7 – 1.0 µg/sheet from paper -No data on emissions from operation	Low-emitting components reformulated inks	Relatively low emission rates; generally used for personal printing purposes and home use
Fax Machines	O ₃ and VOCs	-No published emission rate or IAQ data up to 1994	Same as for dry-process photocopying machines	Found in most offices
Computer terminals	O ₃ and offgasing VOCs	-Limited published data until 1994. -TVOC: 175 ug/hour (max) from VDT drops quickly within 300 hours of operating time	Low emitting materials and/or lower voltage, alternative materials for cards used in integrated circuit boards	Relatively low emissions when compared to other sources. Approximately 10 million units sold annually (based on 1994 data)
Blueprint machines (dye-line)	Ammonia, carbon monoxide, methanol, ethanol, trinitrofluorene, trichloroethane	-1-40 ppm ammonia in breathing zone of operator, 8.2 ppm (average)	CAD/alternative technologies, improved maintenance	Older technology; therefore, losing market share to CAD/alternative technologies
Digital duplicator	VOCs-petroleum solvent and ethylene glycol	Combined VOCs: 20 mg/page	Lower VOC inks; can be replaced with photocopiers but not necessarily a pollution prevention approach	Limited market share of this technology
Spirit duplicator	Methanol	Breathing zone concentrations of 40-635 ppm; 195-3,000 ppm with no ventilation, 80-1,300 ppm with ventilation, and 9-135 ppm with enclosure and ventilation	Replacement with photocopiers (not necessarily a pollution prevention approach)	Limited market share of this technology (a very few schools and institutions)
Mimeo-graph machines	Hydrotreated heavy and light naphthenic distillates	-Heavy naphthenic distillate: 30 mg/page -10 mg/page light naphthenic distillate	Ink reformulation, replacement with photocopiers or other technologies (not necessarily a pollution prevention approach)	Limited market share of this technology
Plotters	VOCs	-No published emission rate or IAQ data (up to 1994)	Low-emitting components, reformulated inks	Limited market share, 250,000 a year worldwide (up to 1994)

Source: *Office Equipment: Design, Indoor Air Emissions and Pollution Prevention Opportunities, Project Summary, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC 27711, United States Environmental Protection Agency (1995)*

Table F-6 Chemicals from different office equipment

Office equipment	Contaminants	IAQ/emission rate	Pollution prevention options	Comments
Dry-process photocopier machines	VOCs, respirable particulate (toner powder) and ozone (O ₃)	-O ₃ : 40 µg/copy (average), with a peak conc. of 131 µg/copy, 0-1350 µg/min and average 259 µg/min -Particulates: 0.001 µg/m ³ room concentration of carbon black; 90-460 µg/m ³ in exhaust air -TVOC: 0.5 to 16.4 µg/sheet from paper	Lower voltage to reduce O ₃ (charged rollers), toner reformulation, improved transfer efficiency, low maintenance machines, lower fuser temperature, changes in toner particle size, low emitting components	Large units of machines should have dedicated HVAC system
Wet-process photocopier machines	VOCs and O ₃	TVOC: 25g/h, 0.241 g/copy, observed high room concentration of 64 mg/m ³ ; 4150 mg/m ³ in exhaust air	Solvent reformulation; pressure fusing, decrease voltage, low-emitting components	
Laser printers	VOCs, respirable particulates and O ₃	-O ₃ : 100-4000 µg/m ³ room concentration; 438 µg/min (average); 100 µg/min (with filter) -Respirable particulates: 60 µg/min -TVOC: 2.0-6.5 µg/sheet	Same as for dry-process photocopier machines	
Ink/bubble jet printers	VOCs and O ₃	No published data up to 1994	Solvent reformulation, low emitting components	Primary use – personal home based
Impact printers	VOCs	-TVOC: 0.7 – 1.0 µg/sheet from paper -No data on emissions from operation	Low-emitting components reformulated inks	Relatively low emission rates; generally used for personal printing purposes and home use
Fax machines	O ₃ and VOCs	-No published emission rate or IAQ data up to 1994	Same as for dry-process photocopier machines	Found in most offices
Computer terminals	O ₃ and offgasing VOCs	-Limited published data until 1994. -TVOC: 175 ug/hour (max) from VDT drops quickly within 300 hours of operating time	Low emitting materials and/or lower voltage, alternative materials for cards used in integrated circuit boards	Relatively low emissions when compared to other sources. Approximately 10 million units sold annually (based on 1994 data)
Blueprint machines (dye-line)	Ammonia, carbon monoxide, methanol, ethanol, trinitrofluorene, trichloroethane	-1-40 ppm ammonia in breathing zone of operator, 8.2 ppm (average)	CAD/alternative technologies, improved maintenance	Older technology; therefore, losing market share to CAD/alternative technologies
Digital duplicator	VOCs-petroleum solvent and ethylene glycol	Combined VOCs: 20 mg/page	Lower VOC inks; can be replaced with photocopiers but not necessarily a pollution prevention approach	Limited market share of this technology
Spirit duplicator	Methanol	Breathing zone concentrations of 40-635 ppm; 195-3,000 ppm with no ventilation, 80-1,300 ppm with ventilation and 9-135 ppm with enclosure and ventilation	Replacement with photocopiers (not necessarily a pollution prevention approach)	Limited market share of this technology (a very few schools and institutions)
Mimeo-graph machines	Hydrotreated heavy and light naphthenic distillates	-Heavy naphthenic distillate: 30 mg/page -10 mg/page light naphthenic distillate	Ink reformulation, replacement with photocopiers or other technologies (not necessarily a pollution prevention approach)	Limited market share of this technology
Plotters	VOCs	-No published emission rate or IAQ data (up to 1994)	Low-emitting components, reformulated inks	Limited market share, 250,000 a year worldwide (up to 1994)

Source: Information summarized from *Indoor Environmental Quality, Chapter 7, Thad Godish (2000), Lewis publishers*

Table F-7 Chemicals emitted from photocopied, laser-printed and matrix-printed paper and toner powders

Compound	Photocopied papers	Laser Printed Papers	Matrix-Printed papers
Hexane	Detected in paper	Not detected	Not detected
1,1-Dichloro-1-nitroethane	Detected in paper	Not detected	Not detected
Benzene	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
Octene (isomer)	Detected in paper	Not detected	Not detected
Pentanal	Detected in paper and toner powder	Not detected	Not detected
Trichloroethane	Detected in paper and toner powder	Detected in paper and toner powder	Not detected
1-Butanol	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
Toluene	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
Pyridine	Detected in paper and toner powder	Not detected	Not detected
4-Methyl-2-pentanone	Detected in paper and toner powder	Not detected	Not detected
Hexanal	Detected in paper	Detected in paper	Detected in paper
C4-Cyclohexane isomers	Detected in paper and toner powder	Detected in toner powder	
1-Butyl ether	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
m- and p-Xylene	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
o-Xylene	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
Styrene	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
1-Butyl acrylate	Detected in paper and toner powder	Detected in paper and toner powder	Not detected
2-Phenylpropane	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
3-Heptanol	Detected in paper and toner powder	Not detected	Not detected
1-Phenylpropane	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
Ethyl Toluene (isomers)	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
3-Ethoxy-3-ethyl-4,4-dimethylpentane	Detected in paper and toner powder	Not detected	Not detected
1-Butyl methacrylate	Detected in paper and toner powder	Not detected	Not detected
Benzaldehyde	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
Diethylbenzene isomers	Detected in paper	Detected in paper and toner powder	Detected in paper
2-Ethyl-1-hexanol	Detected in paper and toner powder	Detected in paper and toner powder	Detected in paper
2-Ethylhexyl acetate	Detected in toner powder	Detected in paper and toner powder	Not detected
2,2-Azo-bis-isobutyronitrile	Detected in paper and toner powder	Detected in paper and toner powder	Not detected
2-Ethylhexyl acrylate	Detected in paper and toner powder	Detected in paper and toner powder	Not detected
Methylbiphenyl	Detected in toner powder	Detected in paper	Not detected

Source: Table modified from Chapter Seven: Problem Buildings, Indoor Environmental Quality, Thad Godish (2000), Lewis publishers.

F.4.1 Health effects

Many studies documenting health complaints in office building workers involve emissions from sources including office equipment. A case study by Skoner, Hodgson and Doyle (Etkin 1992) documented physician confirmed symptoms of nasal congestion, skin irritation, headache and chest and stomach pain in an office worker following the installation of a new computer and laser printer. Air monitoring revealed emissions of various VOCs would include various thermal degradation products from the styrene-butadiene toner. Exposure to these VOCs caused a 3 to 4 fold increase in nasal airway resistance in the worker. In a study by Jakkola (1999), self-copying papers were reported as significantly related to work-related eye, nasopharyngeal and skin symptoms, headache, lethargy, wheezing, cough, mucus production, sinusitis and acute bronchitis. Photocopying activities were associated with nasal irritation and video display unit (VDU) terminal work with eye symptoms, headache and lethargy.

F.4.2 Exposure

Several studies conducted by the United States Environmental Protection Agency (USEPA) have shown concentration of many indoor pollutants from office equipment can increase up to 1,000 times above outdoor levels (USEPA 1995). Exposure to VOCs from office equipment can occur through offgasing and electro-chemical processes. In addition, poor maintenance can contribute to emissions from office equipment. For example, in one study, ozone emissions from five photocopiers before routine maintenance ranged from 16 to 131 µg/copy. However, after routine maintenance, concentrations of ozone were reduced to <1 to 4 µg/copy (USEPA 1995). A research team in Australia has noted that office printers emit various levels of fine particles; they can be classified as non-, low, medium and high emitters (He et al. 2007). The same study has implied that emission and exposure can be reduced by a proper choice of equipment.

When assessing indoor air quality and human exposure related to office equipment, it is important to consider the following factors:

- Emission rates and operating times
- Toxicity and irritation potential of substances emitted
- Physical relationships and position of source equipment and the user

The breathing distance of a person from office equipment is very important because breathing distance affects the dispersion and dilution of emissions, and the amount of pollutants inhaled by the user and other occupants

- Sensitivity of the occupants

Some individuals can be more susceptible to office equipment emissions.

F.5 Ritual and aesthetic products

F.5.1 Candles

Candles are used primarily for the aesthetic lighting of indoor environments. Candles and incense sticks are also used in religious and spiritual practice. Both candle and incense burning can significantly affect indoor air quality. Emissions of respirable particulate matters and other contaminants, such as aldehydes, NO_x and CO, may vary from candle to candle. Aromatic candles can release higher VOCs and particulate matters than non-aromatic candles. Scented candles can also emit PAHs, alcohols and esters (Godish 2000).

Health Canada has completed an extensive study on distribution of metallic core wick candles in the Canadian marketplace. Table F-8 presents the distribution of metallic core wick candles in Canada from different parts of the world. Health Canada inspected 2,400 candles across Canada and estimated that approximately 30 per cent contained metallic wicks. Out of those 2,400 candles, 65 candles were further tested for lead metal wicks. Almost 10 per cent of the candles had lead metal wicks (Health Canada 2001).

Table F-8 Health Canada test results of sixty-five candles with metallic core wicks from the Canadian market place

Country of origin of candle samples m.c.* wick	No. of candle samples with m.c. wick tested	No. of candle samples with m.c. wick with 50% or more lead		No. of candle samples with m.c. wick with 50% or more zinc		No. of candle samples with m.c. wick made of 100% tin	
Canada	18	2	11.1%	15	83.3%	1	6.0%
China	16	15	93.8%	1	6.2%	0	0.0%
Mexico	5	2	40.0%	3	60.0%	0	0.0%
Taiwan	1	1	100.0%	0	0.0%	0	0%
Thailand	2	0	0.0%	1	50.0%	1	50.0%
USA	13	3	23.1%	8	61.5%	2	15.4%
Unknown	10	5	50.0%	5	50.0%	0	0.0%
Total	65	28	43.1%**	33	50.8%**	4	6.1%**

*m.c. – metal-core

* average

In European churches, soot-stained frescoes and paintings are a living proof to building contamination associated with long-term candle use. When an investigator notices “ghosting” on walls, it may suggest the presence of soot or the burning of candles. Candles have the potential to cause “ghosting” on walls and home appliances. Ghosting refers to the black soot staining that occurs on inside finishes, such as mortar, that mirrors the location of construction beams. The beams provide thermal bridges that conduct cold exterior air temperatures to interior surface creating elevated relative humidities that preferentially bind or sorb airborne particulate matters (Godish 2000) producing “ghost-like” images.

- **Candle risk assessment study**

According to a study by Krause (1999), the effects on public health from consumer use of scented candles includes increased risk of cancer, neurological and behavioural deficits and acute aggravation of existing respiratory diseases such as asthma. In the same study (Krause 1999), a risk assessment study of residential exposure to candle

emissions revealed exposure to PAHs, benzene and lead. The highest risk was attributed to PAHs exposure from candle soot. Scented candle emissions were reported to have both vapour phase and particle-phase components. It was determined from the study that the blood lead level of children two to three years old would exceed 10 µg/dl if exposed to daily emissions from lead-containing candles.

F.5.2 Policies to reduce use and manufacturing of lead- wick candles

F.5.2.1 U.S. Consumer Products Safety Commission (2000)

In February 2000, the U.S. Consumer Products Safety Commission (CPSC) received petitions from citizens, the National Apartment Association (NAA) and the National Multi Housing Council (NMHC) urging for the complete ban on lead-wick candles manufacturing and sales. Later CPSC disclosed that U.S. candle manufacturers had not adhered to their 1974 voluntary agreement on the discontinuation of lead wicks in candles. Recently, candle manufacturers have again agreed to comply with the 1974 agreement. CPSC and other researchers have disclosed that lead emissions from candles (2,200 µg/hour) and other contaminants from the candles can significantly affect indoor air quality and human health (CPSC 2000). Alternatives to lead are wicks made of zinc and tin, which might contain trace amounts of lead. Studies suggest that burning of metal wicks with a lead content less than 0.06% would result in negligible hazardous concentrations in indoor air (CPSC 2002).

Based on relevant scientific data, CPSC has recommended that a mandatory standard should be in place for candle manufacturers. That mandatory standard, which is expected to be announced in near future and will do the following (CPSC 2002):

- Be applied to domestic and imported candle wicks and products regardless of a company's membership in a trade organization or knowledge of the ASTM standard
- Deter manufacturers from producing non-conforming candles and wicks, and enables enforcement through civil penalties for violations
- Increase compliance in retailers and distributors who often require that products meet applicable federal standards
- Prevent non-compliant products from entering the United States

F.5.2.2 Health Canada

Candles with lead wicks present a significant health risk and Health Canada proposed *Candles Regulations* in 2003; however, stakeholders raised no concerns on the lead limit. In subsequent consultations, Health Canada attempted to re-introduce the total lead limit of 600 mg/kg for all components in the candle; nevertheless the *Candles Regulations* passed in 2011 mentioned no lead limit (Canada 2011).

Health Canada continues to recommend Canadians not to use candles that have lead core wicks. It also urges Canadian candle industries to completely stop manufacturing and importing candles with lead wicks. Safer alternatives, such as zinc, tin or plain cotton wicks without a metallic core, are recommended. In addition, Health Canada has

recommended the following steps to Canadians to minimize indoor air quality-related health risks when burning candles in homes (Health Canada 2011):

- Follow the instructions printed on the label.
- Trim candle wicks to a height of 5 mm to 7 mm or about ¼ in. Trim them again every two or three hours to prevent a high candle flame.
- Take extra care if you are burning candles with more than one wick. Avoid buying candles with multiple wicks close together.

For more information on candles and their safety, environmental public health professionals are encouraged to refer to the Health Canada website at: <http://www.hc-sc.gc.ca/cps-spc/house-domes/fire-feu/cand-boug-eng.php>. Practitioners are also encouraged to distribute and transfer the information whenever appropriate to community partners so as to educate, empower and to promote public health.

F.6 Hobbies and other activities

Many arts and crafts materials are sources of a broad range of toxic contaminants, such as heavy metals, silica, asbestos, solvents, cyanide, acids and allergens. Arts and crafts materials also may involve exposure to other physical hazards such as heat, UV and IR radiation (Hart 1987). Arts and crafts materials can be used individually as a hobby, institutionally in schools as part of the curriculum, or commercially in art studios. Regardless of the user, these products can affect indoor air quality and health.

Michael McCann in his book *Artist Beware: The Hazards in Working With All Art And Craft Materials And....* (McCann 2005) has provided an endless list of chemicals that can be emitted from arts and crafts products affecting the indoor air quality. These chemicals include nitrogen dioxide from arc welding, chlorine gas from preparing Dutch mordant, hydrogen chloride from heating polyvinyl chloride, ozone, sulfur dioxide, formaldehyde, ammonia and so on.

The list of adverse effects because of the inhalation of these chemicals is similarly as long. In addition to the inherent toxicity of the concerned chemicals, the exposure to these chemicals is further exacerbated by the following: inadequate housekeeping and spill control, personal health including taking of medications, inadequate and improper labeling, inadequate training, lack of functional local exhaust fans and fume hoods, procurement and use of improper materials and products, and improper handling and storage practices (McCann 2005, Health Canada 2007).

The California Office of Environmental Health Hazard Assessment publication *Guidelines for the Safe Use of Art and Craft Materials* provides a list of approved suppliers and products of low toxicity supplies for schools, including arts and craft supplies, and general classroom items, such as an approved whiteboard markers and dry erasers. The report recognizes that arts and craft instruction in school and general school supplies may pose a significant health risk to school children, especially for preschool and grades 1 to 6. The California Education Code (Section 32064) prohibits the ordering or purchasing of any product that contains toxic or carcinogenic substances for use in grades 6 and under. The report can be downloaded at <http://www.oehha.org/education/art/index.html>

F.6.1 Control measures

Control measures can be implemented to reduce or eliminate exposure to toxic contaminants from arts and craft supplies and related hobbies and activities. Health Canada has recommended the following control measures in its publication *Art Teacher, Be Aware*. The reader should refer to Chapter III as well as other publications for additional information. Public health inspectors can recommend the following control measures while conducting IAQ investigations in both residential and non-residential settings. Although these recommendations have been provided for school teachers and students, they can be used for other indoor settings.

- **Solvents**

Because of their toxicity, organic solvents should not be used by children from grades 1 to 6. Older students and teachers should take necessary precautions (use of impermeable gloves or application of a barrier cream) while working with those

solvents. Appropriate ventilation should be provided to the area where such solvents are used. Respiratory protection should be worn when handling concentrated solvents. (Refer to specific Material Safety Data Sheets).

- **Pigments**

Be aware that some paint pigments may contain heavy metals. Review Materials Safety Data Sheets or contact the supplier or manufacturer to ensure pigments are free of heavy metals, or that they are present at background concentrations; for example, 0.06% for lead. Pigments that contain heavy metals should be avoided in schools. Dried paint may release contaminated dusts into the air and building. Avoid using powdered pigments.

- **Adhesives**

To prevent exposure to organic vapours, the uses of synthetic adhesives should be avoided by small children. Alternative products such as water-based glues and flour pastes can be used. Water based glues may contain preservatives that may also harm small children. Small children should strictly avoid instant glues, as they can be hazardous to skin.

- **Corrosives**

Corrosives, such as acids, should be handled carefully. Rubberized gloves, protective aprons and goggles should be worn at all times when handling corrosives. An eyewash station and fountain shower should be available in the vicinity of the area where corrosives are used. In case of eye contact, eye rinsing should be done for at least 15 minutes. Contact lenses should not be worn while working with corrosives. Proper instruction is essential to using any hazardous materials in a classroom setting, such as a chemistry lab.

- **Drawing**

Use of felt markers or correcting fluid should be avoided because of the release of organic vapours. Drawing ink may contain carbon black, which may harm some individuals. Children in primary classes should not use these products.

- **Painting**

For a detailed description on paints and associated contaminants, the reader should refer to *Appendix A.1, Chemical factors, Appendix H Built environment* and *Chapter III's Built environment* section.

- **Sculpting, modeling and carving**

Students and other individuals should not mix up clay or plaster from powder. Dusts both during the preparation of plaster mixtures and during activities that generate airborne dust, such as chipping, grinding, sanding, should be controlled by local exhaust ventilation. Vacuuming or wet mopping should be used to collect dusts instead of dry sweeping. Hot wire cutting, sawing and sanding of plastics can produce toxic fumes and dusts. These activities should be avoided and are not recommended in schools.

- **Silk screening and printmaking**

Students that are involved in these activities should be aware of the types of inks being used. Water-based inks should generally be used. In the case of solvent-based inks, the installation and maintenance of proper ventilation is necessary. In addition, follow the recommendations provided in the “Corrosives” section above.

- **Ceramics**

Follow the recommendations provided in the “Sculpting, Modeling and Carving” section. Ceramics can involve generation of some poisonous gases, such as CO and metal fumes. Refer to *Appendix A.1 Chemical factors: gases* for a discussion on control measures for CO and other gases.

- **Photo processing**

Although processing of camera film is rare in the digital age, some hobbyists are using the traditional process. In order to minimize exposure, pre-mixed solutions should be used instead of raw chemical solutions. Dry powder solutions should be prepared in control environments, such as one with a fume hood, following manufacturer instructions and MSDS information. Students developing film should avoid skin and inhalation exposure by using sealed glove boxes. A glove box should be used for the handling of concentrated solutions and powdered products.

- **Copper Enameling**

According to Health Canada, Copper enameling should only be carried out by students from senior grades (grade 7 and higher). The acids and alkalis used in this process should be handled carefully. Infrared goggles should be used to look into kilns. Proper ventilation should be provided in the kiln room and in additional areas as required. In addition, follow recommendations provided in the “corrosives” section above.

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Appendix G

Outdoor air factors

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G. Outdoor air factors

G.1 Introduction

Outdoor air can be defined as ambient air that enters a building through a ventilation system, through intentional openings for natural ventilation, or by infiltration. In mechanically ventilated buildings, outdoor air enters a building through the air intakes that are part of the HVAC system. In naturally ventilated buildings, the air intakes can be operable windows or other openings in the building's envelope (ASHRAE Standard 62.1- 2010).

As outdoor air enters a building through its air intakes, it brings with it any contaminants that exist outside the building near the intake. That is why the quality of the indoor air is greatly affected by the quality of the outdoor air delivered to a building. Therefore, it is important to evaluate the ambient air quality in the area where a building is located as well as the presence of local contaminant sources as this can influence the location and design of the air intakes.

Contaminants from outdoor sources can have a major influence on IAQ. These contaminants include particles and gases in outdoor air, volatile contaminants in underlying soil and groundwater, herbicides and pesticides applied around the building, and contaminants carried in by pests. The examples of outdoor or "ambient" air sources that can influence indoor air quality include (EPA, 1991; Health Canada, 2012):

- Contaminated outdoor air
 - Natural sources, such as pollen, dust, fungal spores and wildfire smoke
 - Anthropogenic sources including vehicle exhaust, industrial operation, incidental emissions, such as landfill fire, industrial fire, chemical spill and sour gas release
 - Secondary pollutants, such as ground level ozone in urban smog, formed when sunlight interacts with pollutants, such as Nox and volatile organic compounds (VOCs)
- Emissions from nearby sources
 - Exhaust from vehicles on nearby roads and in parking lots or indoor garages
 - Exhaust from vehicles in loading docks
 - Odours from dumpsters
 - Re-entrained (drawn back into the building) exhaust from the building itself or from neighbouring buildings

- Unsanitary debris near the outdoor air intake
- Pesticide application
- Soil gas and vapours
 - Radon
 - Leakage from underground fuel tanks
 - Contaminants from previous and adjoining land uses, such as landfills

Outdoor air pollutants entrained into a building through the ventilation system can have significant health effects. Combustion particulates emitted from vehicle exhaust and ozone are both associated with respiratory and cardiovascular diseases ranging from aggravation of asthma, or other respiratory ailments to premature death for people with heart or lung disease. Even in areas where regional ambient air quality is considered good, local air quality may be poor because of the influence of local sources. For example, living in proximity to busy roadways can affect ambient air quality, and in turn, indoor air quality and thus cause adverse health effects. Studies have demonstrated significant associations between living in proximity to high traffic areas and adverse health effects among children, such as childhood leukemia and other childhood cancers because of the chronic exposure of children to vehicle exhaust (Pearson *et. al.*, 2000; Levy *et. al.*, 2001; Korenstein and Piazza, 2002), and increased risk of wheezing in asthmatic children (Venn *et. al.*, 2001). In the absence of outdoor sources, cooking activities, such as frying and sautéing may be an important indoor source of PAH concentrations (Dubowsky *et. al.*, 1999).

There are differences and similarities between outdoor and indoor air quality, urban and rural air quality, and the health risks associated with these various environments. In this Chapter, these relationships will be explored, especially in the context of how outdoor air influences indoor air quality, personal exposure and human health interact.

G.2 Dynamics of indoor and outdoor air quality

The dynamics of indoor air and outdoor air interactions are based on the processes described below. None of these processes will occur independently of each other. All the processes described below interact in a complex manner to influence the behaviour, distribution and airborne concentration of indoor contaminants.

G.2.1 Processes in indoor and outdoor air interactions

- **Infiltration and natural ventilation**

Infiltration is a process in which uncontrolled inward air leakage to conditioned spaces through unintentional opening in ceilings, floors and walls from unconditioned spaces or the outdoors caused by pressure differences across these openings because of wind, inside-outside temperature / pressure differences (stack effect) and imbalances between supply and exhaust airflow rates. In natural ventilation, air moves through opened windows and doors (ASHRAE Standard 62.1-2010).

- **Exfiltration**

Exfiltration is a process in which uncontrolled outward air leakage from conditioned spaces through unintentional openings in ceilings, floors and walls to unconditioned spaces or the outdoors caused by the same pressure differences that induce infiltration (ASHRAE Standard 62.1-2010).

- **Absorption**

From an indoor air quality perspective, absorption can be defined as the process by which a contaminant in indoor or outdoor air is bound to and within a matrix by physical or chemical processes. In this process, contaminants can react with water, reactive chemicals or a solid media (Godish, 2000). For example, physically, water spilled on a surface can be removed by absorption using a sponge. Chemically, some gases can be absorbed into water because of their solubility and equilibrium phenomena.

- **Adsorption**

Adsorption is considered to be the most commonly used technique for removing gas and vapour-phase substances from indoor air and ventilation airstreams (Godish, 2000). It is a process by which gas, vapour or liquid-phase substances can be physically removed from fluids (including air) by adherence to and retention on solid sorbents. The adherence is because of Van der Waal's forces acting on the surface of a solid to hold molecules to that surface (Godish, 2000). Adsorption can be regarded as a surface phenomenon whereas absorption can be considered as a more complex interaction involving the penetration of a substance into the body of another.

The physical attraction between a sorbate (the adsorbed molecule) and another molecule is known as adsorbability. It is a direct function of a sorbate's critical temperature and boiling point. Therefore, gas- and vapour-phase contaminants can be categorized into three different groups based upon their adsorbability (Table G-1)

Table G-1 The adsorbability of various gas/vapour-phase contaminants (Godish, 2000)

Critical temperature	Boiling point	Adsorbability @ room temperature	Examples
below -50°C	Below -150°C	cannot be absorbed	O ₂ , N ₂ , H ₂ , CO and CH ₄
0 to 150°C	-100°C to 0°C	can be moderately adsorbed	Low boiling point gases or vapours (e.g., NH ₃ , HCl, H ₂ S, C ₂ H ₂ and HCHO)
	greater than 0°C	can be adsorbed and retained effectively	Organic vapours (e.g., higher aldehydes, ketones, alcohols, organic acids, ethers, esters, alkyl benzenes, halocarbons and nitrogen and sulfur compounds)

• **Other processes affecting IAQ**

Other processes that affect the ability of outdoor contaminants to influence indoor air quality, especially the indoor concentration of particulate matters, include chemical transformation, air exchange, particle deposition and particle penetration. Particle penetration, outdoor air exchange rate and indoor particle deposition are important processes that govern the effect of outdoor air on indoor air quality. Deposition typically applies to particulate matter that is removed from the air because of gravitational settling or impaction on indoor surfaces. Outdoor particulates can penetrate through imperfections in the building envelope to gain entry into buildings (USEPA, 2002). In this subsection, the following processes that affect the dynamics of outdoor-indoor particulate matter are discussed:

- ▶ Air exchange rates (AER)
- ▶ Particle deposition rates
- ▶ Particle penetration efficiency
- ▶ Formation of secondary organic aerosols, such as fine or ultrafine particles
- Air exchange rates (AER)

“Air exchange” is a term used to describe the rate at which the indoor air in a building or residence is replaced by outdoor air. Air exchange rates can be based on engineered ventilation systems or on infiltration and exfiltration and can vary in buildings because of the following factors:

 - Geographic location of the building
 - Age of the building
 - The amount of time windows and doors are kept open
 - HVAC design and operation
 - Meteorological conditions, such as the difference in temperature between indoors and outdoors, seasonal temperatures changes, wind speed and wind direction

The effects of temperature, wind, fans and window-opening behaviour on AERs have been investigated. Wallace *et.al.* (2002) concluded that opening windows can potentially have the largest effect on AER, causing increases ranging from a few

tenths of an air change per hour (ACH) to approximately two ACHs. In addition, an indoor-outdoor temperature difference has a clear effect on AER, with a very large temperature difference of 30°C accounting for an increase in the air change rate of about 0.6 h⁻¹ (Wallace *et.al.*, 2002).

- Particle deposition rates

When particles undergo collision with a surface, they adhere to that surface because of various forces, such as Van der Waal forces, electrostatic forces, and for liquids, surface tension. Re-suspension of particles from indoor surfaces may occur when they are disturbed by human activities, such as walking and vacuuming, or by high air velocities, such as air from a fan. Thatcher and Layton (1995) suggested that re-suspension occurs for particles that are >2 µm in diameter. Re-suspension can be an important source of exposure (Institute of Medicine, 2000).

A suspension of solid or liquid particles in the air is called an aerosol. Particle size is the most important physical parameter for characterization of aerosols (McDonald and Ouyang, 2001; Spengler *et. al.*, 2001). The particle size can be described in terms of aerodynamic diameter. Aerodynamic diameter is defined as the diameter of a smooth, unit density sphere which has the same settling velocity as the particle (settling velocity is the terminal velocity reached by a particle in the air falling under the influence of gravity). Aerodynamic diameter of a particle depends upon the density, shape and particle size (ACGIH 1989, cited in *Air Sampling Instrument for Evaluation of Atmospheric Contaminants*, 7th edition).

Indoor particle deposition rates can vary significantly depending on the particle size because of the viscous drag of air on the particles which hinders movement to varying degrees. The nature and composition of different particles can also affect deposition rates (USEPA, 2002). Heavy or larger diameter particles settle to the floor or the ground quicker than smaller diameter and lighter weight particles.

A study has been conducted to quantify the deposition rate of size-classified particles in the size range of 0.02 µm to 6 µm (He *et. al.*, 2005). The lowest deposition rates were found for particles in the size range of 0.2 µm to 0.3 µm for both minimum air exchange rate: 0.61 h⁻¹ ±0.45h⁻¹ and normal air exchange rate of 3.00 h⁻¹ ±1.23h⁻¹. The same study (He *et. al.*, 2005) also indicated that the air exchange rate was an important factor affecting deposition rates for particles in the size range of 0.08 µm to 1.0 µm, but had minimal influence on particles smaller than 0.08 µm because the smaller particles tended to remain airborne. However, particles larger than 1.0 µm tend to settle out. In other words, gravity causes the largest particles or those greater than a few micrometers in diameter to settle out. But for submicron particles less than 1 µm, processes other than gravity are more important in keeping these particles airborne for longer periods of time. However, particles between 5 µm and 10 µm can be easily re-suspended in the air during indoor activities after settling (Thatcher and Layton, 1995, cited in CEPA, 2000).

The velocity of typical indoor air is between 0.05 m/sec. to 0.3 m/sec. At these velocities, the smaller indoor particles can be transported a great distance before

settling on to different indoor surfaces (IOM, 2001). Table G-2 presents gravitational settling rates for particles of different sizes. Generally, dust-mite allergens range in size from 2 µm to 11 µm diameter, plant pollens 15 µm to 25 µm, grass and birch allergens less than 1 µm, fungal spores 2 µm to 10 µm, cat antigens 1 µm to 10 µm, cockroach antigen less than 10 µm, environmental tobacco smoke 0.09 µm to 1 µm, and droplet nuclei from coughing and sneezing less than 2 µm (IOM, 2000).

For additional information on particle sizes and other physical, chemical and biological agents including fungi, animal and insect allergens and pollen), refer to *Appendix E Biological factors* and *Appendix B.1 through Appendix B.5 Particulate matter* in this manual.

Table G-2 Theoretically predicted gravitational settling rates of unit density spheres in still air

Particles of different size	Particle aerodynamic diameter (µm)	Terminal settling velocity (m/s)	Time to fall 1 metre
• ETS 0.09 µm -1 µm	0.2	2.2×10^{-6}	5.3 day
• Grass & birch allergens < 1 µm	0.5	1.0×10^{-5}	28 hrs
• Droplet nuclei <2 µm	1.0	3.5×10^{-5}	7.9 hrs
• Fungal spores 2 µm -10 µm	5.0	7.8×10^{-4}	21 min
• Dust mite 2 µm -11 µm	10	0.003	330 sec
• Cat antigens <1 µm - >10 µm	20	0.012	83 sec
• Cockroach antigen >10 µm	30	0.027	37 sec
• Plant pollens 15 µm -25 µm	50	0.075	13 sec

Source: Institute of Medicine (IOM). 2001. Appendix A, Theoretical Considerations Relevant to the Influence of Ventilation and Air Cleaning on Exposures to Indoor Generated Pollutants, Clearing the air: Asthma and Indoor Air Exposures 2001

◦ **Particle penetration efficiency**

The ability of particles to penetrate into the indoors from the outdoors is dependent on particle size and, in terms of indoor air quality, the building air exchange rate and other factors. Particle size is important because physical processes, such as impaction, interception and diffusion, affects particle deposition as particles travel through imperfections in the building envelope and through the ventilation system into a building (USEPA, 2002). When air exchange rates are high, penetration efficiency approaches unity because ambient particles have fewer interactions with the building shell. If the air exchange rates are low, the penetration efficiency is governed by the ability of a particle to penetrate the building envelope. Smaller diameter particles more easily cross this barrier than larger ones (USEPA, 2002).

One factor influencing the relationship between ambient particle concentrations and total personal exposure to particles is the extent to which ambient particles penetrate indoors and remains suspended in the air. Particles penetration is heavily dependent on the air exchange rate, and also on penetration efficiency and deposition or removal rate, both of which vary with particle aerodynamic

size. Based on physical mass-balance considerations, usually the higher the air exchange rate the greater the personal exposure to ambient particles in the indoor and in vehicle microenvironments (Burke et.al., 2001). If the air exchange rate is low, then the indoor particle concentrations are mainly attributed to indoor sources rather than outdoor sources.

Generally, the penetration of particulate matter is a function of size. Infiltration rates will be higher for PM_1 and $PM_{2.5}$ than for PM_{10} , $PM_{10-2.5}$, with ultrafine particles ($<0.1 \mu m$) being the highest (USEPA, 2002). Personal exposure to $PM_{2.5}$ of outdoor origin will generally be similar to ambient $PM_{2.5}$ because $PM_{2.5}$ have increased penetration and reduced deposition rates in the indoors (California Air Resources Board, 2001). On a relative basis, personal exposure to $PM_{2.5}$ of outdoor origin will also generally be higher than ambient PM_{10} because $PM_{2.5}$ has increased penetration and reduced deposition rates indoors (California Air Resources Board, 2001).

A study done by Guo *et. al.* (2010) suggested that the indoor-to-outdoor $PM_{2.5}$ ratio (I/O ratio) varied with particle size, but occupancy had no influence on the I/O ratios of $PM_{2.5}$. Particles with diameters of $0.1 \mu m$ to $0.4 \mu m$ had the highest I/O ratios, while particles with diameters less than $0.03 \mu m$ or greater than $0.4 \mu m$ had lower I/O ratios, regardless of occupancy. This finding suggested a maximum penetration rate between $0.1 \mu m$ and $0.4 \mu m$.

o **Formation of secondary organic aerosols** (fine or ultrafine particles)

The secondary formation of Secondary Organic Aerosols (SOAs) is caused by chemical transformation reactions of gases or vapours in indoor and outdoor air to produce particles. Secondary particles formed in the atmosphere can also infiltrate indoors. The SOA formed is in the ultrafine ($<0.1 \mu m$) and lower fine ($0.1-2.5 \mu m$) particle size ranges (Waring, *et.al.*, 2011).

One example of secondary formation of SOA indoors is the reaction of ozone (O_3) molecules with terpenoids in household cleaning products, such as air fresheners. The ozone and terpenoid reactions lead to the stable products of secondary organic aerosol (SOA), aldehydes and carboxylic acids (Weschler and Shields, 1999; Kamens *et. al.*, 1999; Leungsakul *et. al.*, 2005). The ozone and terpenoid reactions also yield unstable intermediates, such as hydroxyl radicals ($\cdot OH$), alkylperoxy radicals (RO_2), and Criegee bi-radicals (Kamens *et. al.*, 1999; Leungsakul *et. al.*, 2005). It was evident that use of air fresheners in the presence of ozone in indoor environments creates submicron particles in the $0.01 \mu m$ to $0.3 \mu m$, along with low molecular weight carbonyls, such as formaldehyde, acetaldehyde, acetone, butanal and hexanal (Tirendi *et.al.*, 2011). Some of these low molecular weight carbonyls are known to irritate the mucous membranes of the eyes, the upper respiratory tract, and the skin (USNRC, 1981). Indoor hydroxyl radicals (OH) can adversely affect indoor air quality. For example, reactions of terpenes with OH produce multifunctional ($-OH$, $=O$, and $-COOH$) oxidized products, some of which have low vapor pressures and contribute to fine-particle growth in indoor environments (Sarwar *et.al.*, 2003).

Some devices, known as ozone generators, personal air purifiers, “super-oxygen” air purifiers, and “pure air” generators, are sold as air cleaners. The position of

public health agencies, including Health Canada, U.S. Environmental Protection Agency (USEPA) and the California Air Resources Board, is that these air cleaners do more harm than good (OEHHA, 2008). As discussed above, harmful byproducts such as aldehydes can be produced from the ozone and terpenoid reactions. On the other hand, these devices are designed to intentionally produce large amounts of ozone gas. Ozone generator manufacturers claim that ozone can remove mould and bacteria from the air, but this occurs only when ozone is released at levels many times higher than that known to harm human health. Relatively low levels of ozone can irritate the airways, causing coughing, chest pain and tightness, and shortness of breath. It can also worsen chronic respiratory diseases such as asthma, as well as compromise the body's ability to fight respiratory infections (OEHHA, 2008).

G.3 Ambient (outdoor) air

Ambient (outdoor) air pollution is the result of emissions from various point or stationary area and mobile sources that can variously affect a diverse geographic range. These effects can range from localized effects at the neighbourhood or community level, to transboundary pollution from other provinces, countries or continents. Although ambient air pollution is generally regarded as originating from anthropogenic sources, it can also result from naturally occurring events, such as forest fires and volcanic eruptions (Godish, 2000).

Outdoor air can play a significant role in influencing the quality of indoor air. In most inhabited spaces there is a continuous exchange of air with the outside. For example, most of the ozone in homes comes in from outside. The level of ozone indoors is generally lower than the level outside the home (Health Canada, 2012). Outdoor PM is a significant contributor to the level of PM_{2.5} indoors. In general, the indoor and outdoor (I/O) ratios for PM_{2.5} are smaller than one, indicating that indoor concentrations are largely determined by outdoor sources (Health Canada, 2011; Wallace, 1996; Wallace *et al.*, 2006).

Environment Canada (2012) categorizes air pollutants into four groups:

- **Criteria air contaminants (CACs)** (e.g. SO₂, NO_x, and VOCs)

This group of air pollutants can cause air problems, such as smog and acid rain. They are produced in varying quantities by a number of sources, including the burning of fossil fuels. CAC, in particular, refer to a group of pollutants that include sulphur oxides (SO_x); nitrogen oxides (NO_x); particulate matter (PM); volatile organic compounds (VOC); carbon monoxide (CO); and ammonia (NH₃).

In addition, ground-level ozone (O₃) and secondary particulate matter (PM) are often referred to among the CACs because both ground-level ozone and secondary particulate matter are byproducts of chemical reactions between the CAC.

- **Persistent organic pollutants (POPs)** (e.g. dioxins and furans)

This group of air pollutants are a collection of pollutants that can last in the environment for long periods of time and are capable of travelling great distances. Similar to heavy metals, POPs are of particular concern because they can enter the food supply, bioaccumulate in body tissues and have significant effects on human health and the environment, even in low concentrations.

- **Heavy metals (HMs)** (e.g. mercury)

This group of air pollutants include basic metal elements, such as mercury and lead. This group of pollutants can be transported by the air and enter our water and food supply. Although trace amounts of some metals are needed by our body, heavy metals are poisonous in low concentrations and can bioaccumulate in body tissues.

- **Toxics** (e.g. benzene)

This group of air pollutants form a broad category of pollutants that are poisonous or toxic to human health and the environment. Although this category has some overlap with the other types of air pollutants presented here, such as CACs, HMs

and POPs, this category also includes many more pollutants that have been determined to be toxic.

Outdoor air contaminants can significantly contribute to exposures that may pose health risks to individuals. Although people tend to spend more than 80% to 90% of their time indoors, the high rates of penetration of outdoor contaminants into indoor environments can severely compromise indoor air quality and affect the health of individuals (Rosenbaum *et. al.*, 1999). Caldwell *et. al.* (1998) has stated that long-term exposure to outdoor concentrations of air toxics which exceed health benchmark concentrations can be used as indicators for those locations where residents are exposed to unhealthy levels of pollutants.

G.4 Outdoor air contaminants and their influence on indoor air quality

Outdoor air has the potential to significantly affect indoor air quality. In some cases, indoor air sources will dominate or mask outdoor air influences; in other cases, outdoor sources may dominate indoor contributions. For example, the infiltration of combustion related pollutants, such as PAHs from vehicle exhaust originating in the outdoors, may significantly affect residential indoor air quality and dominate the contribution from any indoor sources. Conversely, VOCs such as formaldehyde off-gassing from indoor construction materials, furnishings and household products may dominate the contribution from the infiltration of formaldehyde from outdoor air. It is important to remember that these interactions are quite complex with many interacting factors and will vary for each situation.

Health Effect Institute (HEI) conducted an investigation on indoor, outdoor and personal exposure concentrations of 16 VOCs, 10 carbonyls and PM_{2.5} during two 48-hour sampling periods in different seasons between the summer of 1999 and the spring of 2001 (Weisel *et. al.*, 2005). The study included 100 homes with 100 adult residents in each of three cities with different air pollution sources and weather conditions: Los Angeles, CA; Houston, TX; and Elizabeth NJ. Homes were selected by distance from various sources. The analysis (2005) of the outdoor contributions to indoor air suggested that some VOCs including MTBE, benzene, carbon tetrachloride and trichloroethylene were primarily generated outdoors and contributed 90% to 100% of the indoor concentrations. Outdoor concentrations of other VOCs including chloroform, pinene, and d-limonene and most carbonyls, such as formaldehyde, acetaldehyde and hexaldehyde contributed less to indoor air (13% to 43% of indoor concentrations). The outdoor carbonyls that contributed most were acrolein, crotonaldehyde and propionaldehyde (50% to 63%). For PM_{2.5}, outdoor air contributed 60% of the indoor concentration.

The influence of a number of outdoor air quality indicators, such as particulate matter (PM), sulphates, PAHs and VOCs, on indoor air will be examined in this Chapter. Some of these chemical contaminants, including VOCs and PM have already been discussed in the “Vapours” section and “Particulates” section in *Appendix A2 Chemical factors: vapours* and *Appendix B2 Airborne particulate matter* of the manual.

G.4.1 Particulate matter (PM)

Particulate matter can be divided into two size fractions, coarse and fine. Coarse particulate matter is between 2.5 µm and 10 µm in aerodynamic diameter. Sources of coarse matter are very diverse and include wind-blown dust or soil, construction or demolition activity, biological sources (pollens and spores), farming, mining, mechanical and grinding processes, such as brake and tire wear and dust generated from traffic on unpaved and paved roads. Fine particulate matter (PM_{2.5}) is less than 2.5 µm in aerodynamic diameter.

Sources of PM_{2.5} include both outdoor, such as burning activities, fuel combustion in automobiles, power plants and other industrial facilities, and indoor sources including fireplaces and wood stoves (California ARB, 2001). When smoking is present, it is the

largest indoor source of PM_{2.5} (Wallace *et. al.*, 2003; Wallace *et. al.*, 2006; Health Canada, 2010b). Cooking has been the most consistently reported other indoor source of PM_{2.5}. Other identified sources include cleaning, grooming, incense, Re-suspension, and wood smoke. In addition, a fraction of indoor PM_{2.5} originates from unknown indoor sources. Generation of secondary sulphates can also contribute to particulate matter in the indoor air (USEPA, 2002).

Personal exposure to PM is greatly influenced by PM concentrations in indoor and outdoor air and the amount of time spent in different indoor and outdoor microenvironments. On average, people spend approximately 90 per cent of their time indoors, where many pollutant levels are often two to five times higher than outdoor levels (USEPA, 2005).

The general equation governing indoor air concentrations as a function of outdoor air levels and indoor sources can be described by a mass equilibrium equation. Four major processes that must be considered in this equation include (Kildeso and Schneider, 2001; Wallace, 2010). (1) infiltration (particles entering from outdoors through air exchange, including penetration through the building envelope), (2) exfiltration (particles leaving the house), (3) deposition (particles depositing on surfaces) (4) generation (particles created by indoor sources).

As we have mentioned elsewhere, the following factors can affect concentrations and exposure to particulate matter in the indoor environment:

- Air exchange rates
- Particle penetration efficiencies
- Indoor air chemistry
- Removal and re-suspension rates

Once inside, other processes, such as secondary formation, re-suspension, absorption and adsorption influence the concentration and distribution of outdoor contaminants in indoor air. Ambient particles that get indoors may settle out at various velocities because of gravitational forces and electrostatic forces. Particles with a size range of 0.1 µm to 1 µm have negligible settling velocities. For the largest particles greater than few micrometers in diameter, deposition can be dominated by gravitational settling (He. *et.al*, 2005). Particles between 5 µm and 10 µm can be easily re-suspended in the air during indoor activities after settling. Particles greater than 10 µm settle out of the air quickly (Thatcher and Layton, 1995, cited in CEPA, 2000).

During the course of wildfires and other biomass fire events, PM_{2.5} is the principal biomass fire pollutant of concern for the relatively short-term exposures (hours to days) typically experienced by the public (World Health Organization, 2005; Naeher *et. al.*, 2007; OEHHA, 2008). A biomass fire can produce high concentration of particulate matter and other combustion byproducts. Of primary concern during biomass fire is wood smoke particulate matter or PM_{2.5}, which can be inhaled deep into the lungs. PM_{2.5} is the criteria pollutant for tracking and forecasting smoke effects during biomass fires. However, concerns associated with fire and smoke events, such as shelter-in-place, smoke advisory and evacuation, are more related to emergency response and are out of the scope of this manual. Readers who are interested in wildfire effect and response can

refer to *Wildfire Smoke - A Guide for Public Health Officials* for more information (developed by California OEHHA, US EPA) and the Missoula County Health Department, 2008. That document is available at http://oehha.ca.gov/air/risk_assess/wildfirev8.pdf.

G.4.1.1 Difference between indoor and outdoor particulate matter

Many investigations that examine indoor exposures to PM_{2.5} in Canadian communities have been conducted in Canada (Health Canada, 2011). Most of these studies in Canada were performed in major population centres in Ontario. The ranges of average and median indoor PM_{2.5} 24-hour average concentrations observed in studies conducted by Health Canada in homes without smokers were 5.5 µg/m³ to 10.7 µg/m³ and 3.8 µg/m³ to 9.0 µg/m³, respectively (Health Canada, 2010a). Average and median indoor PM_{2.5} levels were generally higher in the summer than the winter in both non-smoker and smoker homes (Health Canada, 2010a; Pellizzari *et. al.*, 1999).

Although it is difficult to differentiate between indoor and outdoor PM, several differences have been reported (Wilson *et. al.*, 2000, cited in USEPA, 2002). Particles that are generated in the indoor environment may have different physical and chemical properties than those generated by outdoor sources. For example, elementary carbon soot particles generated indoors are different than outdoor soot particles generated from automotive sources. Combustion byproducts in the outdoor environment may come from sources, such as fossil fuel combustion originating from vehicles, industry, boilers and natural gas furnaces. In the indoor environment, combustion byproducts come from tobacco smoke, wood combustion and cooking (Cha *et. al.*, 1996; Kleenman and Cass, 1998; cited in USEPA, 2002).

In general, I/O values for PM_{2.5} were smaller than one, showing that indoor concentrations are largely determined by outdoor sources. However, in homes where environmental tobacco smoke (ETS) was present, and in studies in which homes with smokers were included, but stratified data were not presented, I/O values were greater than one (Health Canada, 2011), indicating the dominating influence of indoor sources on outdoor sources. (cigarette smoking).

G.4.1.2 Correlation between personal, indoor and outdoor concentrations of particulate matter

Pellizzari *et. al.* (1999) derived correlations for personal, indoor and ambient concentrations of particulate matter. Personal exposure to PM can be influenced by a vast array of factors both outdoors and indoors. PMs that are generated from outdoor sources have the potential to penetrate into indoor microenvironments, such as residences, offices and public buildings, in which individuals or populations spend approximately 90 per cent of their time. The correlations between total personal exposures and ambient or outdoor PM concentrations vary depending on the relative contributions of indoor PM sources to total personal exposure. In addition, outdoor concentrations of PM can vary according to different seasons and specific locations of buildings. As a result, the correlation between average population exposure and outdoor PM concentrations is variable. In the absence of indoor sources, the outdoor air toxic concentration significantly contributes to indoor levels and personal exposures and can be used for analyzing long-term exposure risks to air toxics, such as particulate matter, PAHs and VOCs (USEPA, 2002). However, concentrations of most VOCs are higher in

indoor air than outdoor air, indicating indoor VOC sources typically overwhelm outdoor contributions. For information about indoor VOCs sources, readers should refer to section and *Appendix A1 Chemical factors: gases* and *Appendix A2 Chemical factors-vapours*.

A few extensive studies, including the Particle Total Exposure Assessment Methodology (PTEAM, and longitudinal panel studies on elderly populations were conducted to derive correlations between personal exposure and indoor and outdoor concentrations (USEPA, 2002). Statistical correlation between personal exposure and indoor PM concentration vary significantly in different studies. Correlation coefficients from 0 to 1 will indicate the extent to which personal exposure correlates to a variety of factors, such as residence type, season of the year or indoor air exchange rate. As reported by USEPA (2002, longitudinal studies that followed exposures in a subpopulation over time found high correlations between personal and ambient sulphate particulate matter. Whereas, cross sectional studies, that determined exposures in a subpopulation at a moment in time, showed low pooled correlations because of large differences in the levels of non-ambient PM-generating activities from one subject to another. In several longitudinal studies where indoor sources of PM were absent, a high correlation between personal exposure and ambient PM was reported over time. Even for those longitudinal studies, the correlation was observed to vary significantly because of the influence of individual activities in different microenvironments (USEPA, 2002).

G.4.2 PAHs

For chemical and toxicological characteristics of PAHs, the reader should refer to the PAHs section in *Appendix A2 Chemical factors; vapours*. In this section, emphasis will be given on the interaction and chemical differences of outdoor and indoor PAHs, indoor penetrability and indoor air quality.

Indoor PAHs are typically generated from wood combustion, kerosene heaters, coal stoves, fireplaces, environmental tobacco smoke and fumes from cooking, grilling and frying (Dubowsky *et. al.*, 1999; National Toxicology Program, 1998; Schwartz-Miller *et. al.*, 1998; Shuguang *et. al.*, 1994; cited in Rudel, 2001, in *Indoor Air Quality Handbook*, Chapter 34). Elevated PAH concentrations can be found in the basement and foundation soil of houses contaminated with diesel oil from leaking storage tanks (Rudel, 2001).

The major outdoor sources of PAH emissions include:

- On-road motor vehicle activities, including light-duty gasoline vehicles, diesel-powered buses, and medium- and heavy-duty trucks
- Residential wood combustion
- Power generation from external combustion boilers, automobiles and power plants (Scheepers *et. al.*, 1994; Dubowsky *et. al.*, 1999; Lobscheida and McKone, 2004).
They can increase outdoor PAH concentrations and, in turn, affect indoor levels.

Lobscheida and McKone (2004) examined the magnitude of PAHs levels in outdoor air in the state of Minnesota as a case study. The study shows that sources of residential wood combustion and light-duty gasoline vehicles are the two largest contributors overall to outdoor emissions.

Emission of PAHs from different mobile sources, such as gasoline-fueled and diesel-fueled light-duty vehicles and heavy-duty vehicles were also analyzed at different starting temperatures. Various authors have demonstrated that higher PAHs concentration are seen in winter (Fang *et. al.*, 2005) and that this higher winter concentration can be attributed to various factors, such as increased consumption of combustible fossil fuels, and increased condensation of PAHs in the gaseous phase at low temperatures (Garban *et. al.*, 2002) and some PAHs undergoing only little photochemical degradation under solar radiation in winter (Lee *et. al.*, 2002). Moreover, PAHs concentration in winter is higher than in spring and summer, mainly because stationary and mobile source-emissions are higher. Lower PAHs concentrations during the summer sampling period have also been attributed to the washing out effect of particulates during rainy days and photochemical degradation during high solar radiation (Fang *et. al.*, 2006). Most PAHs are attached to particulates and they are washed out in rainy summer days.

Residential wood combustion significantly affects PAH concentrations in indoor and outdoor air. Table G-3 presents a comparative account of emissions of PAHs from the domestic burning of wood and oil (ug/MJ). From the emission data presented below, it can be concluded, on an equivalent energy basis, that the residential wood combustion contributes significantly higher concentrations of PAHs than the oil combustion.

Table G-3 Emissions of gas phase and particle bound PAHs from domestic burning of wood and oil (µg/MJ)

PAH Compound	Wood	Oil
Phenanthrene	690	1.3
Anthracene	97	0.03
Fluoranthene	148	0.09
Pyrene	114	0.02
1-Methylpyrene	ND ¹	0.05
Benzo[b]fluorene	ND	0.1
Benzo[ghi]fluoranthene	22	ND
Cyklopenta[co]pyrene	23	ND
Benzo[a]anthracene	37	<0.003
Chrysene/triphenylene	ND	<0.003
Benzo[b,k]fluoranthene	7	<0.003
Benzo[e]pyrene	5	ND
Benzo[a]pyrene	10	<0.003
Indeno[1,2,3-co]pyrene	3	ND
Dibenzo[a,h]anthracene	ND	<0.003
Benzo[ghi]perylene	3	ND
Coronene	<1	ND

¹ Not determined

Source: Bostrom et al. (2002), Cancer Risk Assessment, Indicators, and Guidelines for Polycyclic Aromatic Hydrocarbons in the Ambient Air

G.4.2.1 Indoor and outdoor air dynamics of PAHs

USEPA (2002) has reported various studies (Sheldon *et. al.*, 1992a,b; Ozkaynak *et. al.*, 1996b) that show indoor concentrations of PAHs to be similar to outdoor concentration in that:

- Indoor particulate phase PAHs are also dominated by three- to four-ring structures.
- The 12-hour indoor-to-outdoor ratios were 1:1 to 1:4 during the daytime and 0.6 to 0.8 during the night (Sheldon *et. al.*, 1993a). During the day, indoor sources overwhelm the influence of outdoor sources and during the night, infiltration, penetration and sorption effects mitigate the indoor concentration of outdoor sources.
- Cigarette smoking was a strong indoor source of PAHs. Other sources, including cooking, such as broiling, sautéing and frying, can also contribute to indoor PAH concentrations (Sheldon *et. al.*, 1993a,b).

In general, higher indoor PAH levels were seen in homes with smokers than with non-smokers and in urban versus rural areas (Chuang *et. al.*, 1999, cited in USEPA, 2002). Vehicular exhaust and industrial activities are major sources of outdoor and indoor PAHs, especially in the absence of indoor smokers (Dubowsky *et. al.*, 1999, cited in USEPA, 2002).

The chemical reactivity of PAHs depends on temperature, light, oxygen and ozone levels, the presence of co-pollutants and the nature of the particulate matter to which PAHs are adsorbed (Muller, 1997). It is difficult to characterize the indoor and outdoor air dynamics of PAHs because of the presence of different PAH sources indoors and outdoors. However, in the United States and Sweden, residential wood-burning is regarded as the largest indoor source of PAHs at the community level. However, in larger urban areas, diesel- and gasoline-powered automobiles, heavy equipment and industrial facilities are the major sources PAH emissions. Usually, the outdoor natural background concentration of PAH is very low (Bostrom *et. al.*, 2002) but forest fires can significantly increase the background level of PAHs in the air.

In general, indoor PAHs concentrations are higher than outdoor PAHs concentrations. There are several studies available on the correlation between indoor and outdoor air concentrations of PAHs. In a study in Italy, PAH levels in indoor air were almost ten times lower than levels in outdoor air because some of the outdoor air samples were collected near high-traffic areas. The mean indoor and outdoor benzo(a)pyrene (B[a]P) concentrations were 0.11 ng/m³ and 1.19 ng/m³, respectively. The researchers also reported that sampling during summer measured lower outdoor PAHs than the winter (Minoia *et. al.*, 1997). In another study, indoor and outdoor PAH measurements in a low-traffic area in Ohio during winter showed indoor PAHs levels to be higher than outdoors levels. The average indoor B[a]P levels were 0.99 ng/m³ in smokers homes compared to 0.44 ng/m³ non-smokers' homes. The average B[a]P level outdoors was 0.23 ng/m³ (Chuang *et. al.*, 1991).

Chuang *et. al.* (1999) measured PAH levels in 24 homes in North Carolina. Indoor PAH levels were found to be higher than outdoor levels. An average 0.70 ng/m³ was recorded indoors; whereas, 0.46 ng/m³ was recorded outdoors. Sheldon *et. al.* (1992) measured PAHs levels in the indoor and outdoor air of 125 homes in Riverside, California. A

median level of 0.19 ng/m³ and 0.16 ng/m³ was reported for B[a]P in indoor and outdoor air, respectively.

The above studies showed a correlation between indoor and outdoor air concentrations of PAHs. Specifically, the study by Sheldon *et. al.* (1992) suggested that PAHs from outdoor sources, such as automobile traffic significantly influenced indoor concentrations. Indoor PAH concentrations are significantly affected by the presence or absence of smokers. Another finding from the Sheldon *et. al.* (1993a) study was that there were differences in daytime and nighttime PAH concentrations. The studies showed that indoor sources overwhelmed outdoor influences during the day and that outdoor sources dominated at night. It was hypothesized that the difference of outdoor PAH concentrations during the daytime and nighttime might be because of the photodegradation of outdoor PAHs during the day (Rudel, 2001, cited in Spengler *et. al.*, 2001).

G.4.3 Volative organic compounds (VOCs)

Human exposure to air pollution will depend on the presence of both indoor and outdoor sources and the amount of time spent by individuals in these microenvironments (Lewis, 1991). Sampling of indoor and outdoor VOC concentrations shows that most of these contaminants could readily penetrate from the outdoors to the indoors, even in the event of low air exchange rates (Morrello-Frosch *et. al.*, 2000).

Concentrations of most VOCs are higher in indoor air than outdoor air, showing indoor VOC sources typically overwhelm outdoor contributions. The indoor concentrations of several VOCs including acetaldehyde, benzene, carbon tetrachloride, chloroform, formaldehyde, methylene chloride, styrene, trichloroethylene, tetrachloroethylene and toluene are one to five times higher than outdoor air concentrations. Because most people spend a significant portion of their time indoors, exposure to indoor pollutants can be 10 to 50 times higher than outdoors (Tucker, 2001, cited in Spengler *et. al.*, 2001). As was shown for other chemicals, such as particulate matter and PAHs, the correlation between personal exposure and indoor and outdoor air is dynamic and complex.

Several studies involving measurement of VOCs concentrations in 300 to 800 homes were completed in the Netherlands (Lebret *et. al.*, 1986), Germany (Krause *et. al.*, 1987) and the United States (Wallace, 1987). These studies concluded the following:

- Indoor levels of VOCs were several times higher than outdoor levels because of the presence of several sources, such as dry-cleaned clothes, cosmetics, air fresheners and cleaning materials.
- Personal exposures were two to five times higher than outdoor levels for most of the 11 to 19 VOCs tested. Major VOCs sources were consumer products, such as bathroom deodorizers and moth repellents; personal activities including smoking and driving; and building materials, such as paints and adhesives. Tested VOCs included benzene, xylene, PERC, dichlorobenzene, ethylbenzene, chloroform and styrene.
- Indoors VOC concentrations in new buildings were 100 times higher than outdoor concentrations. Within couple of months, the indoor concentrations were reduced but still found to be 10 times higher than outdoors.

In general, the concentration and distribution of VOCs in indoor air is complex. The diversity of indoor and outdoor sources can produce chemical emissions profiles that are either similar or different. Other relevant factors that influence VOC concentrations indoors include building proximity to outdoor sources, building air exchange rates and ventilation rates. In addition, sorption and desorption phenomena and chemical transformations further contribute to the complex behaviour of VOCs in indoor air.

G.5 Urban versus rural environment

More than 75 per cent or almost 23 million of Canada's 30 million population live in urban centers with populations of 10,000 or more. Generally, concentrations of pollutants in urban settings are higher than those in rural areas. Because air pollution in urban areas is high, particulates form a shield that traps heat. This difference between urban and rural temperatures is called the "urban-heat-island" effect", and it has been intensifying throughout this century. During hot months a heat island creates considerable discomfort and stress and also increases air-conditioning loads and the incidence of urban smog.

G.5.1 Particulate matter

In an early study (Hosein *et.al.*, 1977), outdoor air quality in rural and urban communities in the United States were compared. Significant differences in pollutant concentrations, such as SO_2 , SO_4^{-2} , NO_2 , NO_3 , O_3 and total suspended particulates, were reported between rural and urban communities, with higher levels in urban centres. A national study on comparing PM_{10} and $\text{PM}_{2.5}$ distributions in rural and urban area has been performed in Canada since 1984 (CEPA, 2000). A significant difference between urban and rural PM_{10} level has been recorded in different provinces in Canada. The 24-hour mean PM_{10} levels across Canada (mostly urban) ranged from $11 \mu\text{g}/\text{m}^3$ to $42 \mu\text{g}/\text{m}^3$. In three rural Canadian cities, 24-hour average PM_{10} concentrations were ranged from $11 \mu\text{g}/\text{m}^3$ to $17 \mu\text{g}/\text{m}^3$. The urban cities had higher concentrations of PM_{10} than rural towns. Seasonal variations of particulate matter concentrations are commonly observed in urban and rural areas (CEPA, 2000). Similarly, $\text{PM}_{2.5}$ levels were also higher in urban cities than rural towns. The mean $\text{PM}_{2.5}$ concentrations in different Canadian urban cities were found to be more spatially heterogeneous than PM_{10} concentrations. The 24-hour mean concentrations of $\text{PM}_{2.5}$ ranged from $6.9 \mu\text{g}/\text{m}^3$ to $20.2 \mu\text{g}/\text{m}^3$ for urban cities while those in rural areas ranged from $7.0 \mu\text{g}/\text{m}^3$ to $10.5 \mu\text{g}/\text{m}^3$ (CEPA, 2000).

Roemer and Wijnen (2001) measured airborne particulate matter (PM) in Netherlands during the 1998-1999 winter seasons. Daily averages of PM_{10} and $\text{PM}_{1.0}$ levels were highly correlated over time. Median daily concentrations of PM were reported at elevated concentrations near dense traffic areas. PM_{10} and $\text{PM}_{1.0}$ levels were found to be lowest at the background site (a control site), higher at the street site, and highest at the motorway area. The 95th percentile 24-hour concentrations of PM_{10} measured at these three different sites were $36 \mu\text{g}/\text{m}^3$, $40 \mu\text{g}/\text{m}^3$ and $52 \mu\text{g}/\text{m}^3$ respectively. The same pattern was found for $\text{PM}_{1.0}$ measured at these sites, being $20 \mu\text{g}/\text{m}^3$, $23 \mu\text{g}/\text{m}^3$ and $26 \mu\text{g}/\text{m}^3$ measured at the background site, the street site and the motorway area.

G.5.2 Benzene

Exposure to benzene by the general population in Canada can originate from various environmental media, including ambient air, drinking water, food, automobile-related activities, household products, cigarette smoking activities and second-hand smoking (Health Canada, 1993). According to Health Canada's human exposure assessment (1993), ambient air is the main source of exposure to benzene for the general human population, with estimated intakes ranging from 1.3 to 3.0. Automobile-related activities are estimated to contribute an additional 0.7 to 0.9 $\mu\text{g}/(\text{kg b.w.}\cdot\text{day})$ while use of

household products, indirectly estimated from the difference between the concentration of benzene in outdoor and indoor air in the homes of non-smokers, is estimated to increase intake by 0.4 to 0.6 $\mu\text{g}/(\text{kg b.w.} \cdot \text{day})$. Estimated intake from food and drinking water is considerably less, ranging from 0.02 to 0.07 and 0.02 to 0.06 $\mu\text{g}/(\text{kg b.w.} \cdot \text{day})$, respectively. Total daily intake from these sources for five different age groups in the general population is estimated to range from 2.1 to 3.2 $\mu\text{g}/(\text{kg b.w.} \cdot \text{day})$. Cigarette smoking may contribute an additional 26 to 33 $\mu\text{g}/(\text{kg b.w.} \cdot \text{day})$ to the daily intake of benzene, while passive smoking may contribute 0.9 to 1.3 $\mu\text{g}/(\text{kg b.w.} \cdot \text{day})$.

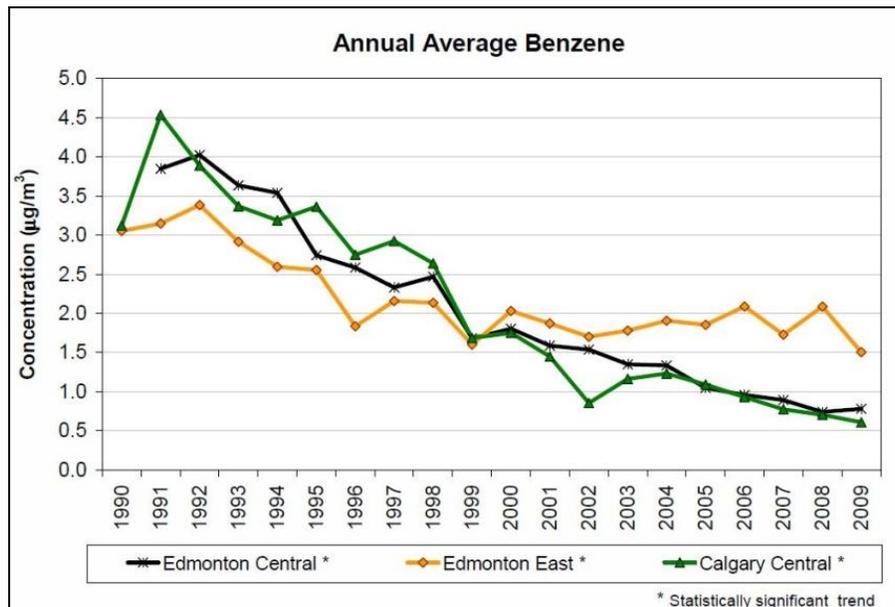
There are differences in outdoor air and indoor air benzene concentrations in urban and rural areas. Compared to rural areas, urban cities have higher population densities and heavier traffic. The major source of benzene in urban air is the combustion of diesel and gasoline fuels, which constitutes 76 per cent of total atmospheric releases (CEPA, 1993). In 1995, approximately 56 per cent of the Canadian emissions of benzene were from the combustion of gasoline in the engines of vehicles. In urban areas, this source was responsible for over 80 per cent of the emissions of benzene. Emissions of benzene from vehicles are from benzene in the gasoline that survives combustion and from aromatics that are converted to benzene during the combustion process (Environment Canada, 2010).

Benzene does not persist in water or soil because it biodegrades and volatilizes rapidly to the atmosphere. It also does not persist in the atmosphere because it undergoes rapid photo-oxidation. Benzene does not appreciably absorb ultraviolet light at wavelengths passing through the upper atmosphere, or infrared radiation at wavelengths of 7 $\mu\text{g}/\text{m}^3$ to 13 μm . Airborne concentrations of benzene in rural areas of Canada are generally below 1.2 $\mu\text{g}/\text{m}^3$. Mean concentrations at urban sites have ranged from 1.2 $\mu\text{g}/\text{m}^3$ to 14.6 $\mu\text{g}/\text{m}^3$, with an overall mean concentration of 4.4 $\mu\text{g}/\text{m}^3$ and a maximum 24-hour average recorded at one site of 41.9 $\mu\text{g}/\text{m}^3$ (Health Canada, 1993).

In July 1995, the federal Minister of the Environment announced regulations on benzene in gasoline. In October 1995, the Canadian Council of Ministers of the Environment (CCME) endorsed the regulation of benzene in gasoline and tailpipe emission performance of benzene (Environment Canada, 2010). In July 1999, Environment Canada established the acceptable range for benzene in gasoline to be 0.0% to 1.5% by volume. Gasoline that was supplied in Canada before July 1, 1999, was anticipated to contain benzene outside this range. Analyzing data collected from Edmonton Central station between 1990 and 2008 (Data source: <http://www.casadata.org>) reveals that the 24-hour concentration of benzene have decreased substantially since 1995.

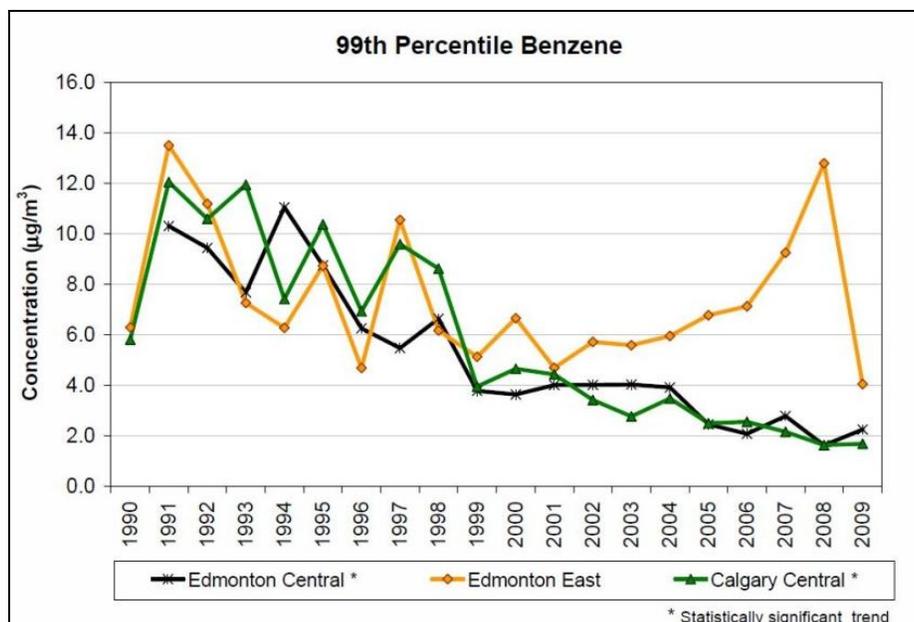
Figures G-1 and Figures G-2 show that annual 99th percentile concentrations of benzene have generally declined between 1990 and 2009, according to trend analysis. Statistically significant trends were found at Edmonton Central (a decrease of 90 per cent) and at Calgary Central (a decrease of 89 per cent). Peak benzene concentrations at Edmonton East decreased by 12 per cent from 1991 to 2001, but then peak concentrations increased between 2002 and 2008. In 2009, however, the 99th percentile concentration fell substantially to a level just above those recorded at the other two stations. The main source of benzene at the Edmonton East station is nearby petrochemical refinery and storage facilities (AEW, 2011, available at <http://environment.alberta.ca/01711.html>).

Figure G-1. Annual average benzene (peak value) for Edmonton Central, Edmonton East and Calgary Central from 1990 to 2009



Source: <http://environment.alberta.ca/01711.html>

Figure G-2. Annual average benzene (99th percentile) for Edmonton Central, Edmonton East and Calgary Central from 1990 to 2009



Source: <http://environment.alberta.ca/01711.html>

In Alberta, benzene is monitored at various stations cross the province. Table G-4 summarizes airborne benzene concentrations monitored in all stations across Alberta from 1995 to 2010. The data demonstrate the difference between benzene air concentrations in rural and urban areas: the average one-hour concentrations at urban

sites (Calgary Central, Edmonton Central, and Edmonton East) ranged from 1.6 $\mu\text{g}/\text{m}^3$ to 1.9 $\mu\text{g}/\text{m}^3$ with one-hour maximums recorded at both Calgary Central and Edmonton Central of 11 $\mu\text{g}/\text{m}^3$ ~ 15 $\mu\text{g}/\text{m}^3$.

Table G-4 Summary Information for all Stations from 01 Jan 1995 to 31 Dec 2008 for Parameter Benzene

Station	Units	Air Quality Objectives		For Requested Time Period		
		1-hour	24-hour	Avg	Max	Exceedences
						Hourly Daily
Barge Landing	ug/m3	9.0	n/a	0.145	1.15	n/a
Calgary Central	ug/m3	9.0	n/a	1.555	11.44	n/a
Cold Lake South	ug/m3	9.0	n/a	0.587	0.85	n/a
Edmonton Central	ug/m3	9.0	n/a	1.669	9.67	n/a
Edmonton East	ug/m3	9.0	n/a	1.949	15.09	n/a
Fort McKay (WBEA)	ug/m3	9.0	n/a	0.151	0.54	n/a
Fort McMurray-Athabasca Valley	ug/m3	9.0	n/a	0.266	1.11	n/a
Fort McMurray-Patricia McInnes	ug/m3	9.0	n/a	0.189	0.70	n/a
Hightower Ridge	ug/m3	9.0	n/a	0.273	1.17	n/a
LICA (Portable)	ug/m3	9.0	n/a	0.584	0.68	n/a
Millennium	ug/m3	9.0	n/a	0.172	0.47	n/a
Syncrude UE1	ug/m3	9.0	n/a	0.130	0.22	n/a

Source: <http://www.casadata.org>. Data were accessed on March 7, 2012

For detailed information on benzene, the reader should refer to *Appendix A.2 Chemical factors:vapours*.

G.5.3 Effects of temperature inversion

A temperature inversion is a meteorological phenomenon in which a warm layer of air is above the top of a cooler and denser layer. Under inversion conditions, air pollutants released at or near ground level are trapped, and cannot rise or dissipate into the atmosphere. Cities that are surrounded by mountains can be particularly vulnerable to the temperature inversion phenomenon (because of night-time cooling and the accumulation of cooler air in topographic bowls) (Lawrence Berkley Laboratory, 2012, <http://www.lbl.gov/Education/ELSI/pollution-main.html> (accessed: March 4, 2012).

Although temperature inversion can occur in any season, they are more common in the fall and winter season. Winter inversions are likely to cause particulate and carbon monoxide pollution. Summer inversions are more likely to create smog. A stagnant air mass can develop in the summer that can prevent the dispersion of pollutants and is problematic for urban air quality. In addition, the summer season can produce photochemical smog (Lawrence Berkley Laboratory, 2012).

Atmospheric stability is an indicator of atmospheric turbulence or mixing and is dependent upon the following factors (AES Calgary project application 2001):

- Static stability (change in temperature with height)
- Thermal turbulence (heating of the air at the ground level)
- Mechanical turbulence (a function of wind speed and surface roughness)

Atmospheric mixing is promoted by the fact that air temperature and density normally decreases with increasing elevation. This fact contributes to the natural tendency for a parcel of air at ground level to rise and mix into the upper atmosphere. In an unstable atmosphere, atmospheric mixing of the lower and upper atmosphere (troposphere) is optimized because of solar heating, creating convective movements, as warmer layers near the ground rise and mix with falling cooler layers above and by high wind speeds.

A stable atmosphere has cooler air below and warmer layers above. In a stable atmosphere, less vertical mixing between different layers occurs because of very low or calm wind speeds and the lack of solar heating (AES Calgary project application 2001). These factors tend to trap and increase pollutant concentrations at or near ground level. The increase in ground-level pollution associated with thermal inversions can result in increased health risk for vulnerable persons in the general population. Temperature inversions usually break down because of increased winds or solar heating.

Pasquill (1961) has devised a classification system for the atmosphere, which range from unstable (A, B, C) to neutral (D) to stable (E, F) (ERCB, 1990). In Alberta, very unstable meteorology (category A) does not occur during the winter months but peaks during summer months. Whereas, the stable conditions (category F) are typically observed during the winter months. Thermal inversions occur during stable meteorology (category E and F) and require warm air aloft, low or calm winds at ground level and poor solar heating.

G.6 Alberta ambient air quality goals

Historically Canada's National Ambient Air Quality Objectives (NAAQOs) identified benchmark levels of protection for people and the environment, and guided federal, provincial, territorial and regional governments in making risk-management decisions. NAAQOs played an important role in air quality management (e.g. local source permitting, for air quality index and as benchmarks for developing provincial goals and standards). NAAQOs were viewed as effects-based long-term air quality goals. Industrial operations may not release substances into the air without obtaining approval from provincial governments; the provincial approval process imposes restrictions on emissions sources to ensure local pollution levels do not exceed provincial ambient air quality goals. Emissions from diffuse and mobile sources, such as motor vehicles, are controlled through standards and regulations set by the federal government (Environment Canada, 2012).

Alberta Environment has developed Alberta Ambient Air Quality Objectives (AAAQOs) for more than 30 substances. Some of these goals, such as for SO₂, H₂S, CO, were initially adopted from NAAQOs decades ago. For PM_{2.5} and ozone, the AAAQOs are more stringent or equivalent to the existing Canada Wide Standards (CWS), respectively. Alberta has also developed or adopted goals from other jurisdictions (AEW, 2012). Table G-5 presents the AAAQOs as of February 2012. The Alberta AAQO setting process considers the health of the public, animals including wildlife and livestock, plants including agricultural crops and the ecosystem. Also considered in setting AAQOs are technological, economic and social factors. These include, for example, the availability and cost of emission control technology and the implications to the Alberta economy.

G.6.1 Alberta ambient air quality objectives (AAAQOs)

The AAAQOs are applicable to all the regions of Alberta and are part of the Alberta Air Quality Management system. The management system was designed to ensure that emissions are minimized through the use of Best Available and Economically Feasible Technology (BAEFT) and that residual emissions are dispersed so that the goals are met (Alberta Environment, 2010). The Alberta AAQOs are periodically reviewed and amended and new goals are created as necessary. The following are the AAQOs as of April 2012 (Table G-5).

Table G-5 Alberta Ambient Air Quality Objectives as of April 2011

Substance	$\mu\text{g m}^{-3}$	ppbv	Basis	Effective/Review Date
Acetaldehyde				
1-hour average	<u>90</u>	<u>50</u>	Adopted from Texas	1999
Acetic acid				
1-hour average	<u>250</u>	<u>102</u>	Adopted from Texas	1999
Acetone				
1-hour average	<u>5,900</u>	<u>2,400</u>	Adopted from Texas	1999, reviewed 2005
Acrylic Acid				
1-hour average	<u>60</u>	<u>20</u>	Adopted from Texas	January 1, 2004
Annual Average	<u>1.0</u>	<u>0.34</u>	Adopted from California	
Acrylonitrile				
1-hour average	43	<u>19</u>	Adopted from Texas	January 1, 2004
Annual Average	<u>2</u>	<u>0.9</u>	Adopted from California	
Ammonia				
1-hour average	<u>1400</u>	<u>2000</u>	Odour perception	1976, reviewed 2004
Arsenic				
1-hour average	<u>0.1</u>	-	Adopted from Texas	May 1, 2005
Annual Average	<u>0.01</u>	-	Adopted from Texas	
Benzene				
1-hour average	<u>30</u>	<u>9.0</u>	Adopted from Texas	1999
Benzo[a]pyrene				
Annual average	<u>0.30</u> ng m^{-3}	<u>2.9</u> x 10^{-5}	Chronic and carcinogenic human health effects	June 1, 2009
Carbon disulphide				
1-hour average	<u>30</u>	<u>10</u>	Odour threshold	1999, reviewed 2005
Carbon monoxide				
1-hour average	<u>15,000</u>	<u>13,000</u>	Oxygen carrying capacity of blood	1975
Annual Average	<u>6,000</u>	<u>5,000</u>		
Chlorine				
1-hour average	<u>15</u>	<u>5.0</u>	Adopted from Texas	1999
Chlorine Dioxide				
1-hour average	<u>2.8</u>	<u>1.0</u>	Adopted from Texas	1999

Substance	$\mu\text{g m}^{-3}$	ppbv	Basis	Effective/Review Date
Chlorine				1999
1-hour average	15	5.0	Adopted from Texas	
Chromium				1999
1-hour average	1	-	Adopted from Texas	
Cumene				1999
1-hour average	500	100	Adopted from Texas	
Dimethyl ether				1999
1-hour average	19,100	10,100	Adopted from Texas	
Ethylexanol				May 1, 2005
1-hour average	600	110	Adopted from Ontario	
Ethylbenzene				May 1, 2005
1-hour average	2000	460	Adopted from Texas	
Ethyl Chlorofomate				1999
1-hour average	0.57	0.13	Stack emission limits	
Ethylene				January 1, 2004
1-hour average	1,200	1,050	Crop yield	
3-day Average	45	40	Crop yield	
Annual mean	30	26	Conifers and perennials	
Ethylene oxide				1999
1-hour average	15	8.0	Adopted from Texas	
Formaldehyde				1999, reviewed 2007
1-hour average	65	53	Adopted from Texas	
n-Hexane				August 1, 2008
1-hour average	21,000	5,960	Derived from 24-hour California objective	
24-hour average	7,000	1,990	Adopted from California	
Hydrogen chloride				1999
1-hour average	75	50	Adopted from Texas	
Hydrogen fluoride				1999, reviewed 2009
1-hour average	4.9	6.0	Adopted from Texas	
Fluoride content in forage-dry weight basis			Adopted from Ontario	1999
30-day average	35 $\mu\text{g g}^{-1}$		April 1 to October 31	

Average for any single 30-day period	80 $\mu\text{g g}^{-1}$		April 1 to October 31	
Average for two consecutive month	60 $\mu\text{g g}^{-1}$		April 1 to October 31	
Hydrogen sulphide				1975
1-hour average	14	10	Odour perception	
24-hour average	4	3		
Isopropanol				May 1, 2005
1-hour average	7,850	3,190	Adopted from Texas	
Lead				1999
1-hour average	1.5	-	Adopted from Texas	
Manganese				1999
1-hour average	2	-	Adopted from Texas	
Annual average	0.2	-	Adopted from Texas and California	
Methanol				1999
1-hour average	2,600	2,000	Adopted from Texas	
Methylene bispheny diisocyanate				1999
1-hour average	0.51	0.050	Adopted from Texas	
Monoethylamine				1999
1-hour average	1.19	0.645	Stack emission limits	
Nickel				May 1, 2005
1-hour average	6	-	Adopted from California	
Annual average	0.05	-	Adopted from California	
Nitrogen dioxide				1975, reviewed 2009
1-hour average	300	150	Respiratory effects	
Annual average	45	24	Vegetation	
Ozone (ground level)				1975, reviewed 2007
1-hour daily maximum	160	82	Pulmonary function	
Particulate Matter				
Fine-2.5 microns or less				2007
24-hour average	30	-	Canada Wide Standard	
Total suspended				1975
24-hour average	100		Pulmonary effects	

Annual geometric mean	<u>60</u>		
Pentachlorophenol			November 1, 2004
1-hour average	<u>5.0</u>	<u>0.44</u>	Adopted from Texas
Annual average	<u>0.5</u>	<u>0.04</u>	Adopted from Texas
Phenol			1999
1-hour average	<u>100</u>	<u>26.0</u>	Adopted from Ontario
Phosgene			1999
1-hour average	<u>4</u>	<u>1</u>	Adopted from Texas
Propylene oxide			January 1, 2004
1-hour average	<u>480</u>	<u>200</u>	Adopted from Oklahoma
Annual average	<u>30</u>	<u>13</u>	Adopted from California
Styrene			1999
1-hour average	<u>215</u>	<u>52.0</u>	Adopted from Texas
Sulphur dioxide			1975, reviewed 2008
1-hour average	<u>450</u>	<u>172</u>	Pulmonary function Adopted from European Union-human health
24-hour average	<u>125</u>	<u>48.0</u>	
30-day average	<u>30</u>	<u>11</u>	
Annual average	<u>20</u>	<u>8.0</u>	Adopted from European Union-ecosystems
Sulphuric acid			1999
1-hour average	<u>10</u>	<u>2.5</u>	Adopted from Texas
Toluene			May 1, 2005
1-hour average	<u>1,880</u>	<u>499</u>	Adopted from Texas
24-hour average	<u>400</u>	<u>106</u>	Adopted from Michigan and Washington
Xylenes			May 1, 2005
1-hour average	<u>2,300</u>	<u>530</u>	Adopted from Ontario
24-hour average	<u>700</u>	<u>161</u>	Adopted from California
Vinyl Chloride			1999
1-hour average	<u>130</u>	<u>51</u>	Adopted from Texas

Note: $\mu\text{g m}^{-3}$ is the weight, in micrograms, of the substance in one cubic meter of air.

Standard condition of 25°C and 101.325 kPa are used as the basis for conversion from $\mu\text{g m}^{-3}$ to ppbv (parts per billion by volume) or from mg m^{-3} to ppmv (parts per million by volume)

Underscore shows this digit is the last significant figure in the number e.g. 100 has two significant figures.

The least significant figure is underlined to indicate calculation accuracy when converting from one unit to the other (e.g. $\mu\text{g m}^{-3}$ to ppbv). These numbers do not indicate reporting accuracy or precision.

Sources: *Alberta Environment and Water (2011)*,

<http://environment.gov.ab.ca/info/library/5726.pdf>

G.6.2 Keeping clean areas clean framework and continuous improvement

Smog is an air quality problem in Alberta, across Canada and around the world. Fine particulate matter (PM_{2.5}) and ozone (O₃) are two principal components of smog. In June, 2000, the Canadian Council of Ministers of the Environment established the Canada-Wide Standards (CWS) for Fine Particulate Matter and Ozone.

The CASA (Clean Air Strategic Alliance) PM and Ozone Management Framework (Figure G-3) is Alberta's commitment to achieve CWS levels by the 2010 target date. Under the PM and Ozone Management Framework, Alberta Environment performs annual assessments of PM_{2.5} and ozone. These assessments follow the procedures set out by the CASA Framework and Canada-wide Standards. In these assessments, Alberta Environment assigned action levels to some areas of the province, and these areas have developed management plans accordingly. The purpose of the above framework is to effectively manage ambient air quality in areas in Alberta and other Canadian provinces to ensure ambient air quality is managed to below the numeric Canada Wide Standard (CWS).

- **Action triggers**

The following box presents the action triggers that define the action levels in the Alberta PM and O₃ Management Framework on the CWS. A description of the metrics and possible management activities associated with these action levels is found in Figure G-3 below and on the AEW website.

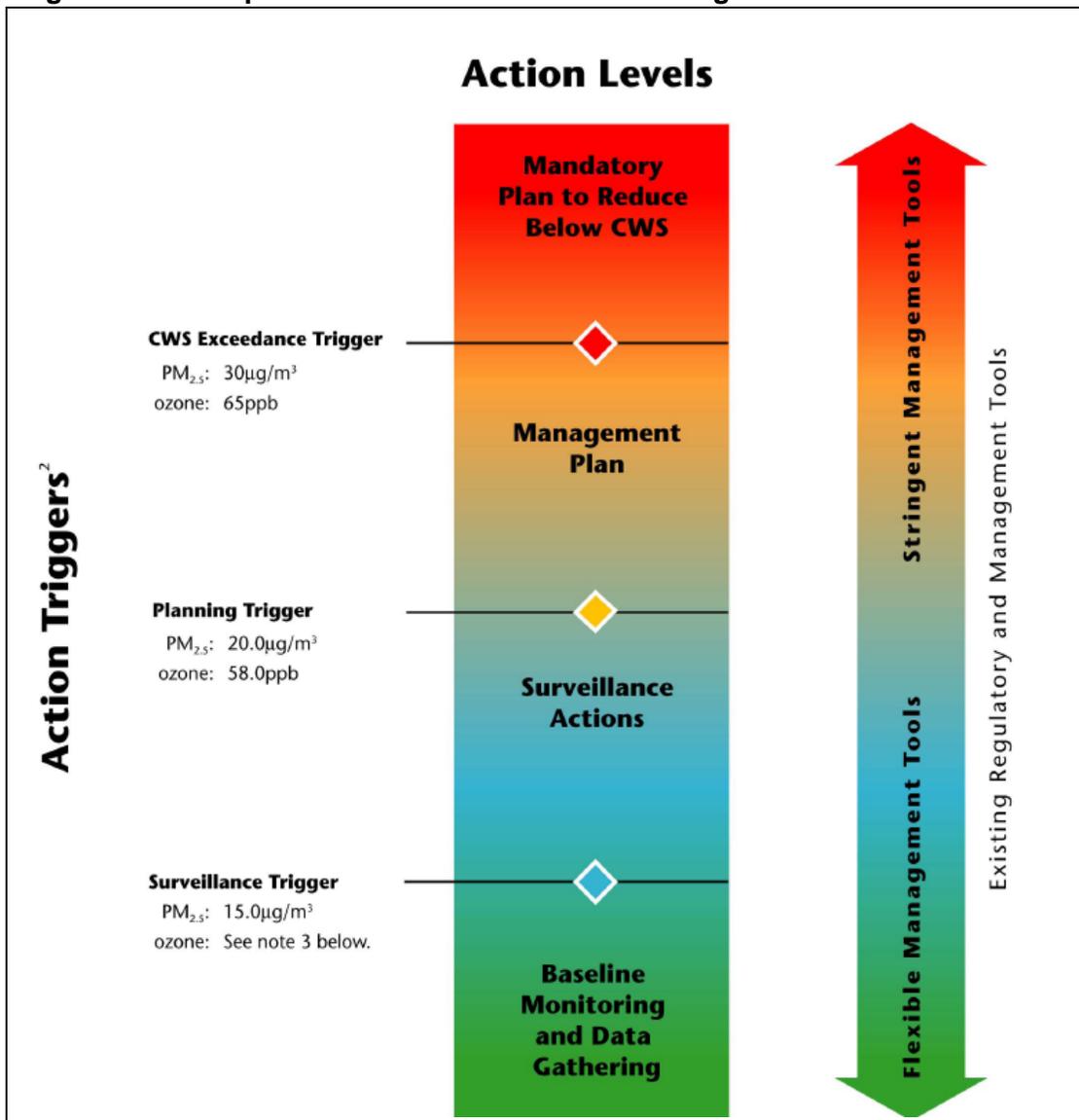
Action triggers that define action levels in the Alberta PM and Ozone Management Framework		
PM_{2.5}	Exceedance:	30 µg/m ³ CWS and CWS metric
	Management:	20.0 µg/m ³ CWS metric
	Surveillance:	15.0 µg/m ³ CWS metric
	Baseline:	Below 15.0 µg/m ³ CWS metric
Ozone:	Exceedance:	130 µg/m ³ (65 ppb) CWS and CWS metric
	Management:	116 µg/m ³ (58.0 ppb) CWS metric
	Surveillance:	at the discretion of AENV based on considerations described immediately below
	Baseline:	at the discretion of AENV based on considerations described immediately below

For ozone, Alberta Environment and Water will determine on an annual basis which areas of the province are in baseline and which areas are in surveillance. This determination will take into account the following:

- Location of existing monitoring
- Ambient ozone data (prepared using the three-year CWS metric)
- Available resources for baseline and surveillance activities
- Priorities for improving understanding of ozone sources, formation, concentrations and movement

The Canada Wide Standard (CWS) acknowledges that health effects can occur below the CWS ozone and PM_{2.5} metrics. As a result, the action trigger concentrations are neither “pollute up to” levels, or “not to exceed” levels. The “Keep Clean Areas Clean” (KCAC) and “Continuous Improvement” concepts were developed to ensure that levels of these pollutants are kept as low as reasonably possible using best efforts and air quality management strategies that strive for continuous improvement. The management framework works towards the long-term goal of minimizing risks to human health and the environment, balancing the desire to achieve the best health and environmental protection possible in the relative near-term and the feasibility and costs of reducing the pollutant emissions that contribute to elevated concentrations of PM and ozone in ambient air.

Figure G-3. Fine particulate matter and ozone management framework



Notes:

1. The framework must be applied in the context of its key elements, including guiding principles, existing programs and mechanisms that support management of PM & ozone, and the goals and objectives for each action level.
2. Action triggers for PM_{2.5} are based on a 24 hour average, and achievement is based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years. Action trigger levels for ozone are based on an 8 hour average, an achievement is based on the 4th highest measurement annually, averaged over 3 consecutive years.
3. For ozone, Alberta Environment and Water will determine on an annual basis which areas of the province are in baseline and which are in surveillance.

Sources: Clean Air Strategic Alliance. 2003. *Particulate Matter and Ozone Management Framework*. Available at: http://www.casahome.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=636&PortalId=0&TabId=78 (Accessed on March 4, 2012)

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Appendix H

Built environment, mechanical and physical factors

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H. Built environment, mechanical and physical factors

H.1 Introduction

Canadian researchers have pioneered the development of energy-efficient and healthy buildings. Several voluntary building initiatives including “Healthy Buildings,” “EnviroHome,” “R-2000” and “Alberta Sustainable Housing Initiative” have captured the attention of Canadians and developers. The new technologies from these alternative housing initiatives are being employed more often than in the past.

Although indoor air quality (IAQ) is an important determinant of healthy building design, it is not the only determinant. Building occupants experience effects from other factors, such as lighting, acoustics, vibration, aesthetics, comfort, security and ergonomic design (Spengler & Chen, 2000; NRC Canada, 2011).

In a typical office workplace scenario, expectations among workers for good IAQ are high. The perception of poor IAQ among workers is forcing building managers, owners and operators to reconsider the importance of IAQ. In a recent survey conducted by the International Facility Managers Association (IFMA), “IAQ and Thermal Comfort” were the top priority in all types of buildings.

A telephone survey by Building Owners Managers Association (BOMA 1999) in the United States indicated ‘control and quality of air’ as the fourth most important criterion for attracting and retaining tenants in rental dwellings. It was also reported in the same study that tenant retention was associated with the operation and efficiency of building HVAC systems.

—Spengler and Chen 2000

It is important to assess building components and building materials from a public health perspective. A broad-based knowledge of different building parameters is required to fully understand the dynamics between public health, building design, building construction and indoor air quality. In this section, the following topics will be discussed.

- IAQ perspective on building design, construction and on the differences between residential and non-residential buildings
- Thermal comfort and physical factors, such as heating, temperature and water vapour
- Building materials concerns including construction, finishing and furnishing materials

H.2 Perspective on modern building design and construction

IAQ health concerns in buildings came into prominence in the 1970s as buildings become more and more sealed under pressures to reduce energy consumption. Gradually, building envelope construction became tighter in an effort to control energy losses by exfiltration and infiltration processes (notwithstanding the necessity of adding make-up air through air handling units). In the early 1980s, the concept of the “Sick Building Syndrome” developed. Akimenko et. al. (1986) reported that up to 30 per cent of new or re-modeled buildings had unusually high rates of complaints. The revised ASHRAE ventilation guideline of the time also contributed to poor IAQ in some cases. In addition, the new buildings were constructed, finished and furnished with new synthetic products, such plywood, particleboard, synthetic fibre carpets, vinyl wall coverings, plastic moldings and foams, (Spengler et al., 2001). These building materials were associated with significant volatile organic compounds (VOC) off-gassing concerns and the popularity of wall-to-wall carpeting provided a large sink to VOCs in new and remodeled spaces. Table H-1 presents a list of VOCs that can be emitted from different building products used in residential and non-residential buildings.

Table H-1: Possible indoor sources of specific VOCs from different building materials

VOCs	Building materials
Benzaldehyde	Fibreboard, particleboard
Benzene	Adhesives, spot cleaners, paint removers, particleboard and silicone caulk
Carbon tetrachloride	Grease cleaners
Ethylbenzene	Floor/wall coverings, insulation foam, chipboard, fibreboard, caulking, adhesives, lacquer and grease cleaners
Formaldehyde	Plywood, particleboard, fibreboard, chipboard, gypsum board, urea foam insulation, carpets, linoleum, upholstery, latex-backed fabric, new clothing, wallpaper, fibreglass, gas-space heaters, range-top gas burners, gas ovens, caulking, floor varnish, floor lacquer and adhesives
Methylene Chloride	Paint remover, aerosol finishers
Styrene	Plastics, paints
Tetrachloroethylene	Upholstery
Toluene	Adhesives, edge-sealing, molding tape wallpaper, floor coverings, silicone caulk, paint, chipboard, linoleum, kerosene heaters
1,1,1-Trichloroethane	Upholstery
Trichloroethylene	Paints and varnishes, degreasing
Xylenes	Adhesives, wallpaper, caulking, floor coverings, floor lacquer, grease cleaners and varnish

Source: Spengler and Chen (2000), Indoor Air Quality Factors in Designing a Healthy Building, Annual Reviews Energy Environment (25): 567-601

H.2.1 Residential and non-residential building design and characteristics

Residential and non-residential buildings have different construction characteristics including size, design, building materials, substructure, cladding, insulation, quality of construction and site conditions. Also, within different residential or non-residential buildings, these construction features tend to vary according to the specific requirements of a particular building. Table H-2 presents different components of residential and non-residential buildings that can affect indoor air quality.

Table H-2: Building components affecting indoor air quality

Building components	Potential contributors to IAQ
Building site	<ul style="list-style-type: none"> • Traffic, parking • Upwind sources or change of air flow • Soil emissions of radon and other soil gasses • Moisture/drainage
Building envelope	<ul style="list-style-type: none"> • Moisture intrusions • Cooling/heating loads affecting dilution and condensation (if cooling capacity is oversized) • Unintended infiltration of untreated air • Lack of natural because of windows that do not open
Waste services, loading dock, entrances served by vehicles (hotels, emergency rooms, convention/recreational centers and schools)	<ul style="list-style-type: none"> • Odours from waste and diesel service trucks drawn in through loading dock and/or windows and/or vents and/or air intakes • Combustion byproduct intake and possible health risk (e.g., soot)
HVAC system, plumbing system and electrical system	<ul style="list-style-type: none"> • Filters, condensation traps, wet insulation, dirty return air ducts as source of odours, microbiologicals • Air intakes and exhaust venting, potential of re-entrainment • Operating set points can cause cool surfaces and unwanted condensation • Unintended contaminant movement pathways (i.e. path of least resistance) • Sweaty and leaking pipes, valves, joints, gaskets provide moisture leading to material damage and microbiological growth • Lack of mechanical ventilation • Lack of individual climate control
Plumbing vents, kitchen exhausts, fume hoods, cooling towers	<ul style="list-style-type: none"> • Potential chemical and biological exposures to workers on roof or to pedestrians around building • Entrainment into air intakes of present and neighbouring buildings
Communications	<ul style="list-style-type: none"> • Excessive wiring in ceiling space restricts repairs, off-gasses VOCs • Wire bundles, pipe chase provide unwanted pathways for contaminant air flow • EMF exposure near antennas
Materials used for internal finishing, furnishings, equipment and cleaning	<ul style="list-style-type: none"> • Sources of VOC, aldehydes, phthalates and particulates • Sources of nutrients for microorganisms
Building Use	<ul style="list-style-type: none"> • Ozone generated from office equipment • Moisture entrainment from cooking

Source: Spengler and Chen (2000), Indoor Air Quality Factors in Designing a Healthy Building, Annual Reviews Energy Environment (25): 567-601.

H.3 Thermal comfort and physical factors

Various organizations, such as ISO and ASHRAE, have defined thermal comfort according to their requirements. According to ISO 7330, thermal comfort is the condition of mind which expresses satisfaction with thermal environment. ASHRAE 55 has defined “thermal comfort” as absence of thermal discomfort and a condition in which 80 per cent of people don’t express dissatisfaction over thermal conditions.

Ventilation, water vapour and temperature are treated separately from common pollutants, as they are not generally considered as indoor air contaminants. However, these physical factors contribute to the presence, concentration and dissemination of common indoor air pollutants and to the general comfort of building occupants. Collectively, these three variables affect "thermal comfort" in an indoor environment. As the human body is a source of heat, thermal comfort is achieved when body heat is dispelled at the same rate at which it is generated. Therefore, the indoor requirements for an individual's thermal comfort include:

- Satisfactory water vapour level (humidity)
- Satisfactory air motion
- Satisfactory temperature
- Sufficient ventilation

In terms of their importance to indoor air, the requirements of thermal comfort will be expanded in the material detailed below. Temperature and water vapour will be dealt with separately while the remaining variables, air motion and adequate ventilation will be combined and explained jointly under the term "ventilation" and described separately in later in this section.

H.3.1 Water vapour

The amount of water vapour in the ambient atmosphere can be measured in several ways including dew point, relative humidity and by psychometric charts. Water vapour is usually measured as relative humidity (RH) which is the percentage of water vapour held by the air compared with the maximum amount of water vapour that the air can hold at a specific temperature. Water vapour is not generally considered as an indoor air contaminant, but can be a contributory agent to health problems. However, some level of humidity is required for comfort. The adage "it's not the heat but the humidity," usually relates to the discomfort that people experience at high humidity levels. High humidity combined with high temperature reduces the rate of evaporative cooling of the body and can cause considerable discomfort or lead to more serious health effects, such as heat stroke and exhaustion (Arundel 1986). High humidity levels can also be a factor in joint pain and rheumatism. Generally, humidity will not significantly affect the thermal comfort of building occupants in the middle temperature ranges (approximately 22°C to 24°C) (Laviana et. al., 1987).

Alberta generally experiences low humidity conditions for the majority of the year, with exceptionally dry conditions existing in indoor environments during the winter. Exposure to extreme or prolonged periods of low humidity can cause health effects including:

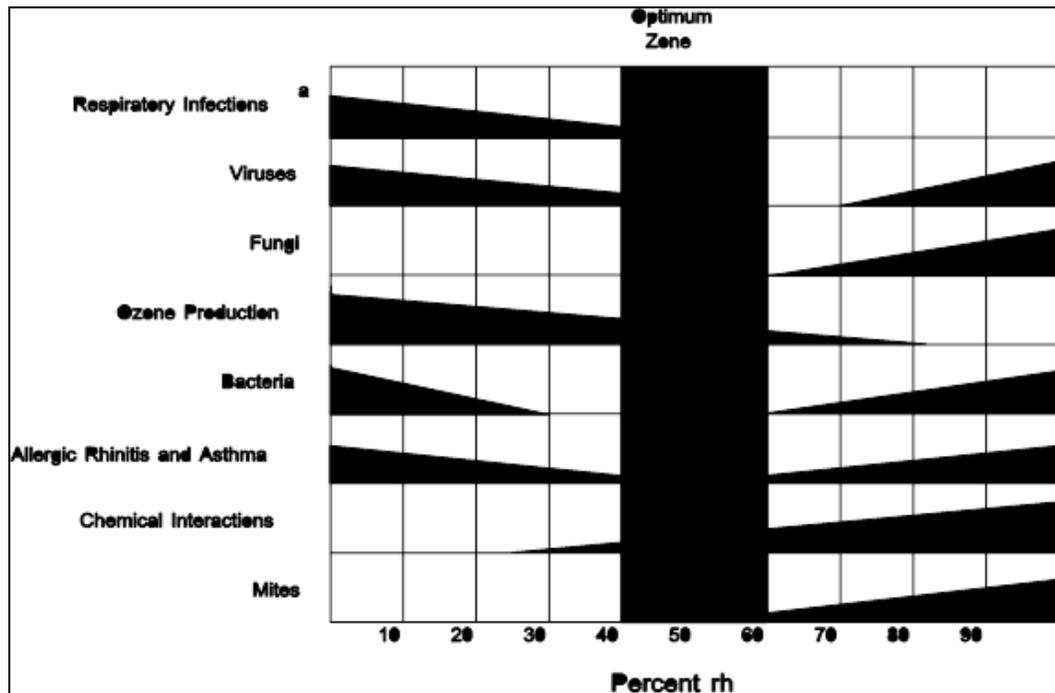
- Skin dryness and irritation
- Chapped lips

- Dryness in the nose and throat
- Nose bleeds
- Eye irritation – Contact lens wearers may experience an increase in ocular discomfort and annoyance when RH is below 40 per cent (Engineering Interface Limited, 1988)
- Shocks from static electricity buildup
- Increased sensitivity to odours and, in some situations, upper respiratory tract illness
- Low humidity levels can cause dryness of the nose, thus increasing irritation and sensitivity to airborne contaminants. Low humidity levels also affect the perception of the intensity of an odour. For instance, cigarette smoke odour is more noticeable and irritating at low humidity.

The health effects listed above are the result of the direct effect of RH on the physical discomfort of individuals. There are also the indirect effects of RH, which may include:

- An increased incidence of allergic reactions at very low and very high relative humidity and infectious respiratory diseases at very low relative humidity (refer to Figure H-1).

Figure H-1 Optimum all season relative humidity range for minimizing



Adverse health effects - decrease in bar width shows decrease in effect.

^a Insufficient data available for above 50% RH

Source: Anthony V. Arundel, et al., "Indirect Health Effects of Relative Humidity in Indoor Environments," *Environmental Health Perspectives*, Vol. 65, 1986 (Reprinted with permission)

Increased allergic reactions and infectious respiratory diseases are caused by the positive effect of relative humidity and humidification equipment on microbial growth and survival and, in turn, the increased probability of effective contact. The

increased probability of exposure to infectious or allergenic organisms including fungi, protozoans, mites, bacteria and viruses is also associated with an increased risk of disease or adverse symptoms (Arundel, 1986). Low relative humidity can dry up the upper respiratory tract to make it more susceptible to infection.

- The reaction or influence of water vapour with chemicals in the air, such as NO₂ and SO₂, or with building materials, such as formaldehyde in particleboard

Fluctuations in relative humidity may alter the rate of formaldehyde off-gassing. SO₂ can combine with water vapour to form aerosols containing sulphate salts and sulphuric acid, which are more irritating than SO₂ (Arundel, 1986). In addition, NO₂ can react with water vapour to form nitrous and nitric acid (Engineering Interface Limited, 1988).

H.3.2 Guidelines

When reviewing the following acceptable short-term exposure ranges (ASTER), the guidelines of the Federal Provincial Advisory Committee on Environmental and Occupational Health, one should bear in mind that wearers of soft contact lenses could experience eye discomfort below four per cent relative humidity and eye irritation at or below 30 per cent RH (Laviana et. al., 1987).

Acceptable short-term exposure ranges (ASTER)

- 30% to 80% relative humidity (RH) in summer
- 0% to 55% relative humidity (RH) in winter

^aThese are recommended winter relative humidity levels, unless window condensation is excessive, which prevents attaining the relative humidity winter guideline.

Source: Exposure Guidelines for Residential Indoor Air Quality. (1995) Health Canada website.

<http://www.hc-sc.gc.ca/ewh-semt/pubs/air/exposure-exposition/non-carcino-eng.php>

In addition, if relative humidity levels are increased to greater than 40 per cent the result could be a reduced incidence or severity of respiratory infections, asthmatic and allergic reactions (Arundel, 1986). Indoor ozone levels will also be reduced with higher humidity levels. However, high humidity levels are beneficial to fungi and mite growth and survival and can contribute to the increased chemical off-gassing and the heightened presence of nitrogen and sulphur acids in the air.

As a result, some researchers have proposed that a generic all-season standard for relative humidity should be between 40% and 60% (Engineering Interface Limited, 1988). Figure H-1 provides a graphical justification for the recommended 40% to 60% RH range on the basis of minimizing adverse health effects.

The reader should note that a relative humidity of 45 per cent could be problematic for the indoor air because dust mites grow favourably at this level. Therefore, relative humidity can be lowered to less than 45 per cent, if required. For additional information on biological factors and their relative humidity requirements, refer to *Appendix E - Biological factors* later in this manual.

- **Control Measures**

Because of Alberta's climate, portable or permanent humidifiers are recommended for use from October through April to help occupants maintain a comfortable RH level. However, if water condensation is visible on windows, then there is excessive humidity. Relative humidity should be measured in occupied indoor environments to enable occupants to adjust humidity up or down relative to guideline levels and current conditions. For high humidity levels, dehumidification equipment can be used to lower levels.

H.3.3 Temperature

The perception of satisfactory indoor temperature varies depending on the health of the individual, the type of indoor environment, clothing worn and the degree of activity, ranging from sedentary to light exercise. For instance, a healthy office worker may have a completely different sense of thermal comfort than an ill patient in a hospital ward. To try to accommodate some of the different perceptions that people may have as to what is an acceptable indoor temperature, ASHRAE (Standard 55) has established operative temperatures for thermal acceptability that incorporate measurable units for clothing (CLO). Table H-3 shows the thermalinsulating capacity for various pieces of clothing.

Table H-3 CLO units for individual items of clothing

Garment insulation*					
Garment description+	<i>I_{clu'}</i> clo	Garment description+	<i>I_{clu'}</i> clo	Garment description+	
Underwear		Long-sleeve sweatshirt	0.34	Straight trousers (thin)	0.15
Bra	0.01	Long underwear bottoms	0,34	Sleeveless vest (thick)	0.22
Panties	0.03	Trousers and coveralls		Long-sleeve sweater (thin)	0.25
Men's briefs	0.04	Short shorts	0.06	Long-sleeve sweater (thick)	0.36
T-shirt	0.08	Walking shorts	0.08	Suit jackets and vests	
Half-slip	0.14	Straight trousers (thin)	0.15	Sleeveless vest (thin)	0.10
Long underwear bottoms	0.15	Straight trousers (thick)	0.24	Sleeveless vest (thick)	0.17
Full slip	0.16	Sweatpants	0.28	Single-breasted (thin)	0.36
Long underwear top	0,20	Overalls	0.30	Single-breasted (thick)	0.44
Footwear		Coveralls	0.49	Double-breasted (thin)	0.42
Ankle-length athletic socks	0.02	Dresses and skirts**		Double-breasted (thick)	0.48
Pantyhose or stockings	0.02	Skirt (thin)	0.14	Sleepwear and robes	
Sandals or thongs	0.02	Skirt (thick)	0.23	Sleeveless short gown (thin)	0.18
Shoes	0.02	Sleeveless, scoop neck dress	0.23	Sleeveless short gown (thick)	0.20
Slippers (quilted, pile-lined)	0.03	Sleeveless scoop neck (thick)	0.27	Short-sleeve hospital gown	0.31
Calf-length socks	0.03	Short-sleeve shirtdress (thin)	0.29	Short-sleeve short robe (thin)	0.34
Knee socks (think)	0.06	Long-sleeve shirtdress (thin)	0.33	Short-sleeve pyjamas (thin)	0.42
Boots	0.10	Long-sleeve shirtdress (thick)	0.47	Long-sleeve long gown	0.46
Shirts and blouses		Sweaters		Long-sleeve short-wrap robe	0.48
Sleeveless or scoop-neck	0.12	Sleeveless vest (thin)	0.13	Long-sleeve pajamas (thin)	0.57
Short-sleeve knit sport shirt	0.17	Trousers and coveralls		Long-sleeve long-wrap robe	0.89
Short-sleeve dress shirt	0.19	Short shorts	0.06	Sleeveless vest (thick)	0.22
Long-sleeve dress shirt	0.25	Walking shorts	0.08	Long-sleeve sweater (thin)	0.25
				Long-sleeve sweater (thick)	0.36

*Data is from Chapter 8 in the 2009 *ASHRAE Handbook-Fundamentals*
+ "Refers to lightweight, thin fabrics often worn in summer, "thick" refers of heavyweight fabric often worn in winter
**Knee-length dresses and skirts ++ Lined vests

Notes: CLO value: a numerical representation of a clothing ensemble's thermal resistance, 1 CLO = 0.155 m²K/W (0.88 ft²hF/BTU)

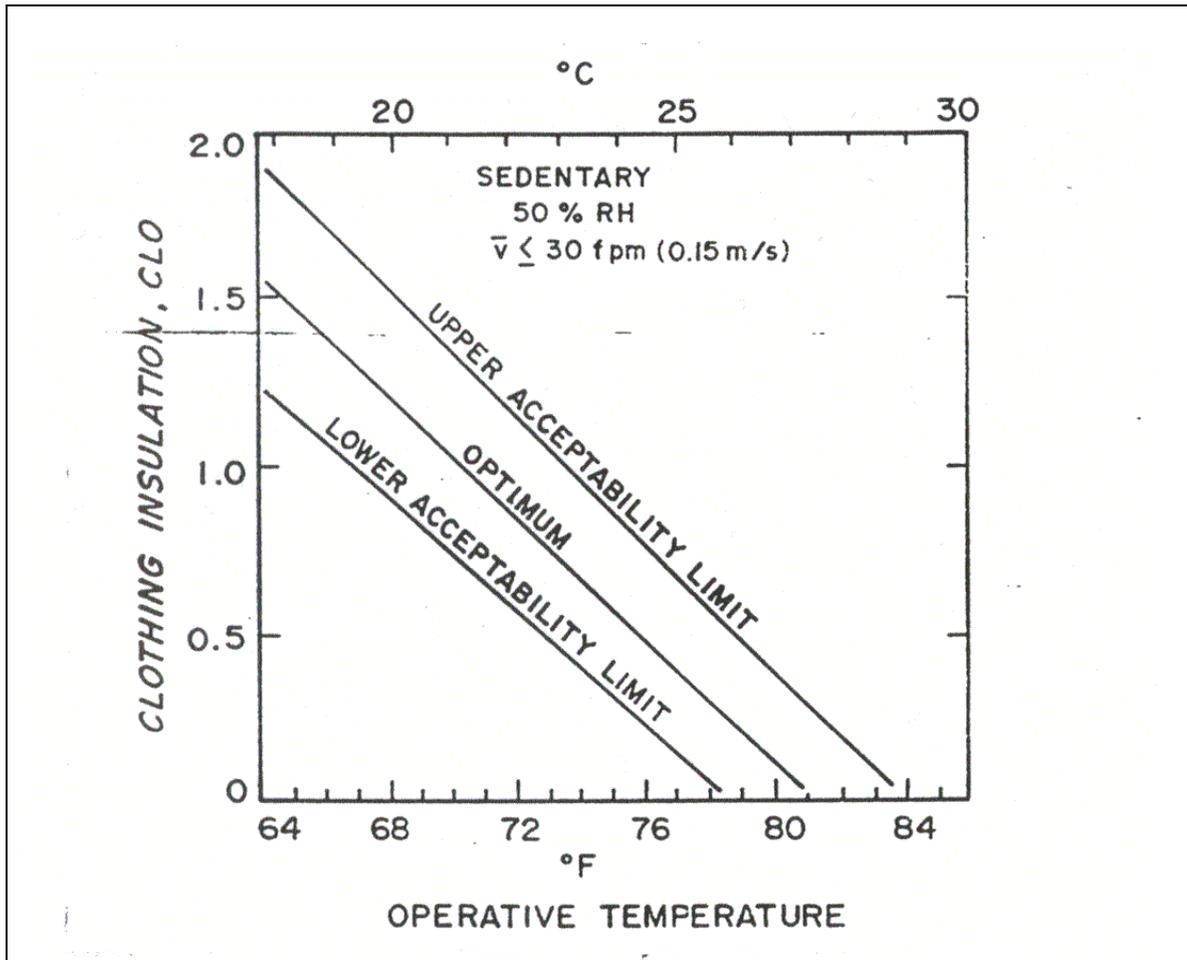
The formula for estimating the total intrinsic insulation value of a particular individual's ensemble, is to sum the values for the clothing worn as depicted above and multiply that sum by 0.82 CLO = 0.82(∑ individual clothing items). A rough approximation of the CLO value can also be estimated from the clothing weight of an individual's ensemble by using the relationship of 0.35 CLO per kilogram (0.15 CLO per pound) of clothing.

Source: © ASHRAE (*Thermal Environmental Conditions for Human Occupancy*), (Standard 55-2010), (2010).

By providing measurable values for the degree of clothing insulation, optimum temperatures for both the winter and summer seasons can be recommended depending on how little or how much a person wears.

When Table H-3 is used to estimate the total intrinsic value of insulation, the value can then be used along with Figure H-2 presented below and the recorded indoor temperature to determine if the degree of clothing insulation and the operative temperature is optimal.

Figure H-2 Clothing insulation necessary for various levels of comfort at a given temperature during light, mainly sedentary activities ($\leq 1.2 \text{ met}^a$)



^a Met: Refers to "metabolic rate" which is the rate of energy production of the body. Metabolism, which varies with activity, is expressed in "met" units in ASHRAE's 55-1992 Standard. One "met" is defined as 58.2 W/m^2 (18.4 BTU/h ft^2) which is equal to the energy produced per unit surface area of a seated person at rest. The surface area of an average man is about 1.8 m^2 (19 ft^2).

Source: © ASHRAE (*Thermal Environmental Conditions for Human Occupancy*), (Standard 55-1992), (1992).

As one's activity increases so does the metabolic rate in met units (refer to Table H-4); consequently, the operative or satisfactory indoor temperature is altered for active people compared to those who are seated quietly.

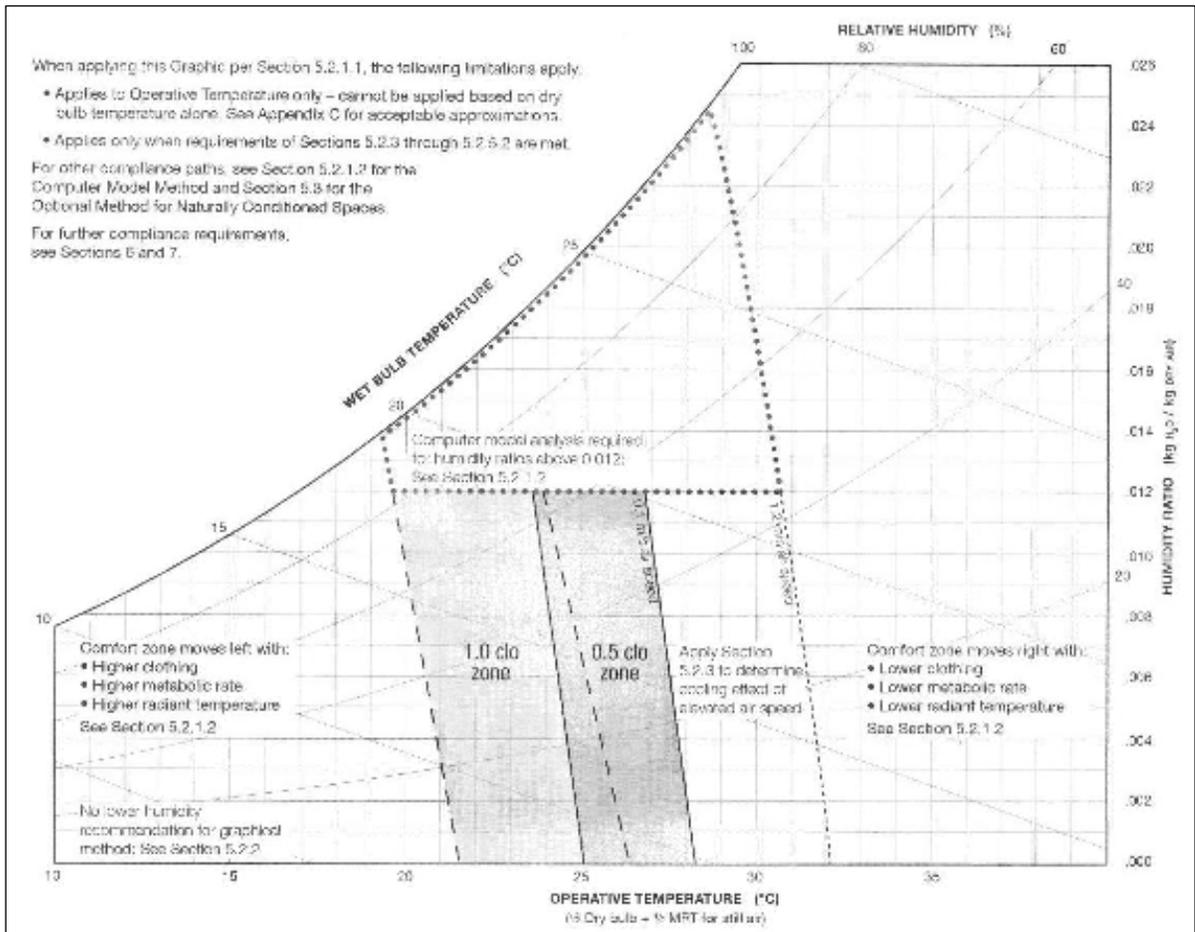
Table H-4: Metabolic rates of common tasks

Activity	Metabolic rate in met units	
Resting	Sleeping	0.7
	Reclining	0.8
	Seated, quietly	1.0
	Standing, Relaxed	1.2
Walking	0.9 m/s, 3.2 Km/h, 2.0 mph	2.0
	1.2 m/s, 4.3 Km/h, 2.7 mph	2.6
	1.8 m/s, 6.8 Km/h, 4.2 mph	3.8
Office activities	Filing, seated	1.2
	Filing, standing	1.4
	Walking about	1.7
	Lifting or packing	2.1
	Reading, seated	1.0
	Writing	1.0
	Typing	1.1
Machine work	Sawing (table saw)	1.8
	Light (electrical industry)	2.0-2.4
	Heavy machine works	4.0
Miscellaneous	Cooking	1.6-2.0
	House cleaning	2.0-3.4
	Seated, heavy limb movement	2.2
	Handling 50 Kg (100 lb)	4.0
	Pick and shovel	4.0-4.8
	Dancing, social	2.4-4.4
	Calisthenics and exercise	3.0-4.0
	Tennis, singles	3.6-4.0
	Basketball	5.0-7.6
	Wrestling, competitive	7.0-8.7

Source: © ASHRAE. *Thermal Environmental Conditions for Human Occupancy* Standard 55-2010 (2010).

Table H-4 above presents the met units expended for various activities performed at 15° C or 59 or at 59°F. Figure H-3 on the next page helps establish an acceptable temperature for various levels of activity, based on clothing insulation (CLO) and the activity level (met).

Figure H-3 Operative temperatures for thermal acceptability for sedentary or slightly active persons (1.1 mets)



Source: ©ASHRAE (Errata Sheet for ANSI / ASHRAE Standard 55-2010 – Thermal Environmental Conditions for Human Occupancy) (August) (2010).

The air temperature in a room can vary from one height to another because of the rising of warm air and sinking of cold air. Such a process can create a vertical gradient if the air flow is not adequate within the occupied space. If the difference in vertical temperature exceeds 2°C, such temperature stratification usually suggests an air distribution problem (Engineering Interface Limited, 1988, cited in Calgary Health Region, 1993).

All the information presented in this segment, which discusses operative temperatures in indoor environments (Figure H-3) can be used to assist in the establishment of indoor temperature. In addition to the tables, figures and formulas presented in this section, ASHRAE has also set recommended indoor temperatures.

Water vapour and temperature are interrelated in terms of their effect on people. Consequently, the recommendations will vary for winter and summer.

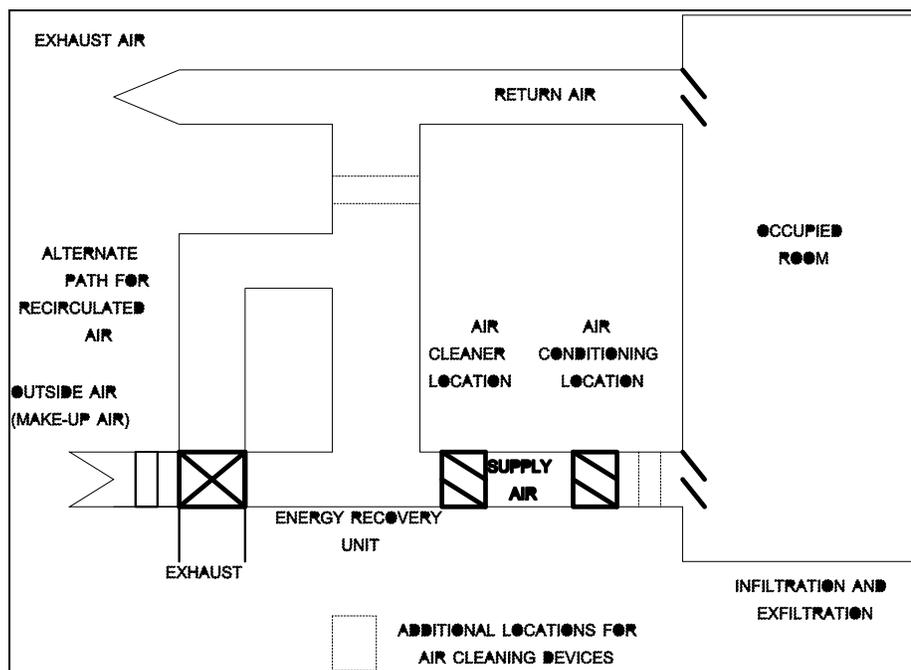
H.4 Ventilation systems, engineering principles, contamination and maintenance

H.4.1 Ventilation

Ventilation involves the supply, distribution and removal of air from a building. A ventilation system must allow sufficient fresh air to enter a building, circulate to the occupants and exhaust polluted or return air. The process of removing or supplying air within a building can be accomplished through either mechanical or natural processes.

Mechanical ventilation implies a forced air system, while natural ventilation involves the movement of outdoor air into a building through cracks, gaps and intentionally provided openings, such as doors and windows. Figure H-4 portrays a typical mechanical ventilation system for a commercial building.

Figure H-4: Standard ventilation system for a commercial building

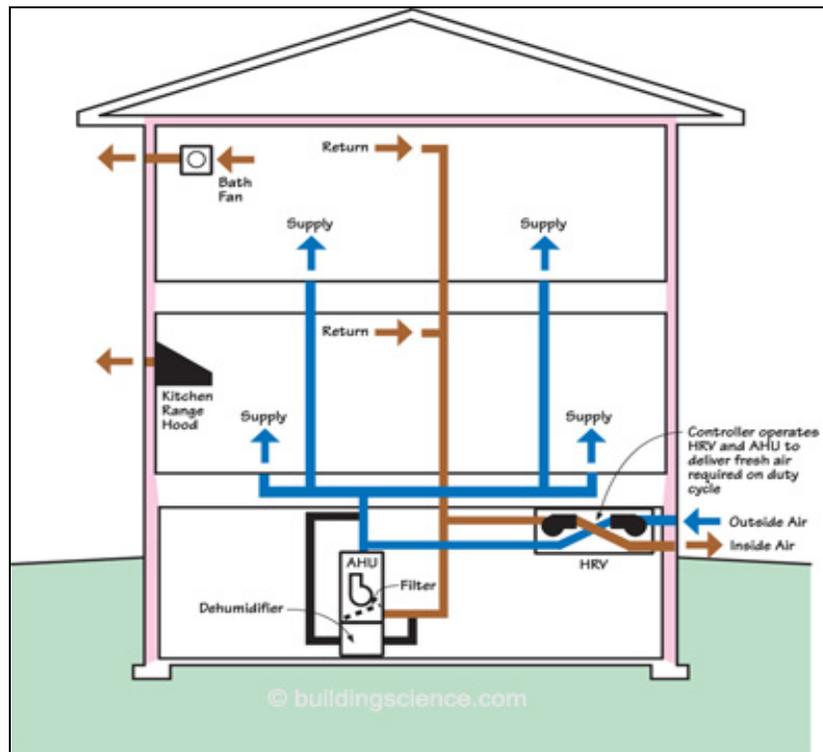


Note: Some rooms may have their own local make-up and exhaust systems (e.g., unit ventilators, which are common in schools) instead of being connected to a common building ventilation system.

Source: Alberta Energy, *Ventilating Your Home*, Energy Efficiency Branch, Information Services, Edmonton, 1988, reprinted with permission

The reader should understand that ventilation systems in commercial buildings can vary based on their unique requirements, era of construction and design. For example, commercial buildings may be associated with a variable air volume (VAV) system or a constant supply system. VAV systems supply varying quantities of heated or cooled air according to the specific needs of different parts of a building. The reader is encouraged to develop an understanding of these systems as required. Figure H-6 depicts a typical residential exhaust/supply-only system.

Figure H-6: A Residential exhaust/supply-only ventilation system



Source: Straube (2009). "The Perfect HVAC System" Building Science .com website: <http://www.buildingscience.com/documents/insights/bsi-022-the-perfect-hvac>

A decrease of fresh air in premises may result in the occupants experiencing:

- Tiredness
- Drowsiness
- General discomfort
- Eye irritation
- Stuffiness
- Nausea
- Stale air
-
-

The purpose of ASHRAE standard, "Ventilation for Acceptable Indoor Air Quality" (ASHRAE Standard 62-2010) is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants. The standard is intended to minimize the potential for adverse health effects. The standard can be applied to all indoor or enclosed spaces that people may occupy, except where other regulations dictate larger amounts of ventilation than this standard. ASHRAE guideline is recognized in Part 6 of the AB Building Code (2006).

Since the Arab oil embargo of 1973 and the subsequent oil crisis that followed, heating and ventilation engineers have been predominantly concerned with energy conservation. Consequently, architects have designed buildings with inoperable windows and with doors and walls that decrease outdoor/indoor exchanges in the hope of reducing energy costs. As building envelopes have been tightened to reduce air infiltration and exfiltration, complaints of eye irritation, dry throat, headaches and fatigue have increased. The current trend in new office building design is towards energy-efficient buildings;

therefore, the need to conserve energy often overrides the health and comfort concerns of building occupants.

The degree to what one classifies a "tight building" is dependent upon the proportionate supply of fresh outside air to recirculated air. An adequate supply of fresh air is necessary to satisfy the respiratory requirements of the occupants and to assist in the exhaust and dilution of indoor air contaminants. Greater amounts of recirculated air reduces the effect that a polluted outdoor air supply could have on the occupants, and the recirculated air would be of better quality than the make-up air.

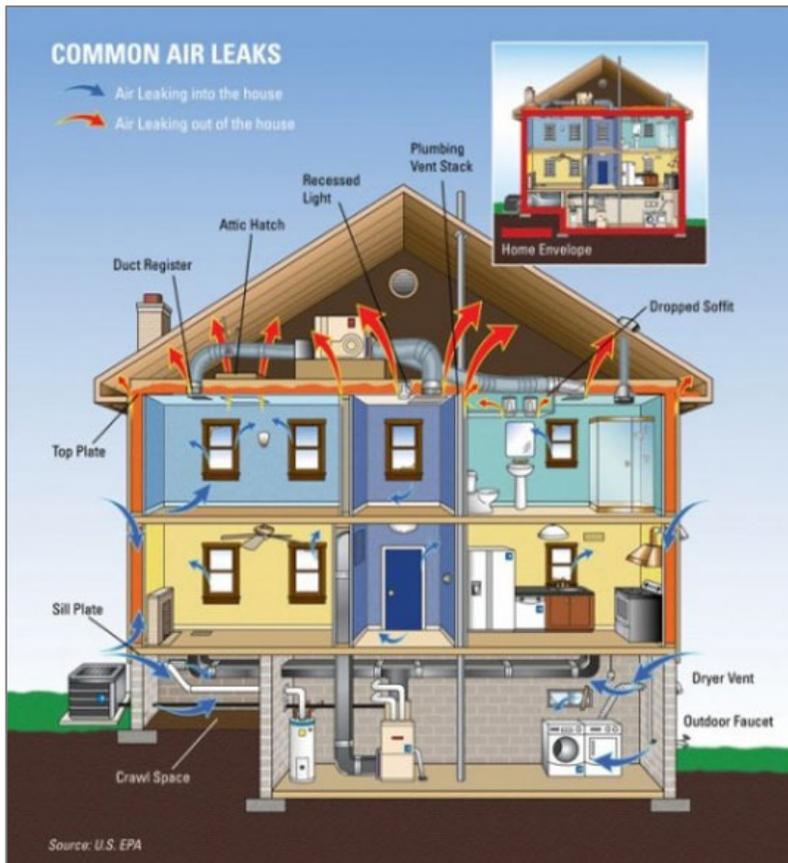
However, Alberta's ambient air is of better quality than indoor air (depending on the parameter being compared), so maximizing the percentage of recirculated air in a ventilation system will maximize the influence of indoor-generated pollutants, resulting in poorer indoor air quality. In many air-conditioned buildings, where energy conservation measures have been enacted, a larger volume of the air in the building is recirculated (Manitoba Hydro, <http://www.hydro.mb.ca/corporate/mhplace/features.shtml>).

Some IAQ consultants believe that reducing ventilation rates to conserve energy may be a more expensive measure to cut costs than it first appears. Life-cycle analysis and operating and maintenance costs suggest that cutting energy costs by reducing make-up air by an arbitrary 10% to 15% may not save as much money as one would think if one considers the total cost of owning and operating a building. Also the resulting inferior quality of indoor air could well increase worker absenteeism by 10% to 15% and possibly contribute to lowered productivity (Evans *et. al.*, 1998). Consequently, poor indoor air quality can dramatically increase the hidden cost of operating a business (Rajhans, 1986, cited in Calgary Health Region, 1993). Having said this, however, the use of outside air (make-up air) for dilution purposes already accounts for approximately one-tenth of all energy use in the United States. When building operators increase the amount of make-up air to meet recommended standards for air ventilation rates, building energy consumption also increases significantly, increasing HVAC equipment sizes and costs, and overall building operating expenses as more energy at greater cost is expended, cited in Calgary Health Region, 1993).

In the typical home, a high percentage of air leaks through the building envelope. Consequently, residential homeowners, in addition to commercial building owners, have made efforts to tighten their homes to reduce natural air exchange in the hope of reducing energy costs. Up to 45 per cent of warm air escapes and the infiltration of cold accounts for heat loss from a home (Applied Building Science Inc., 2009). Consequently, homeowners have tried to reduce air leakage through air vapour barriers, storm windows and doors, and seals at electrical and pipe wall penetrations. Figure H-7 also shows areas of a house where air leakage can occur. The most common areas for cold air infiltration and warm air escape include (Energy, Mines and Resources, Canada, 1986):

- Sill plates
- Doors
- Electrical switches
- Vents
- Plumbing stacks
- Attics (around wiring)
- Baseboards
- Basements
- Electrical outlets
- Fireplaces
- Attic hatches
- Windows

Figure H-6 Air leakage in homes

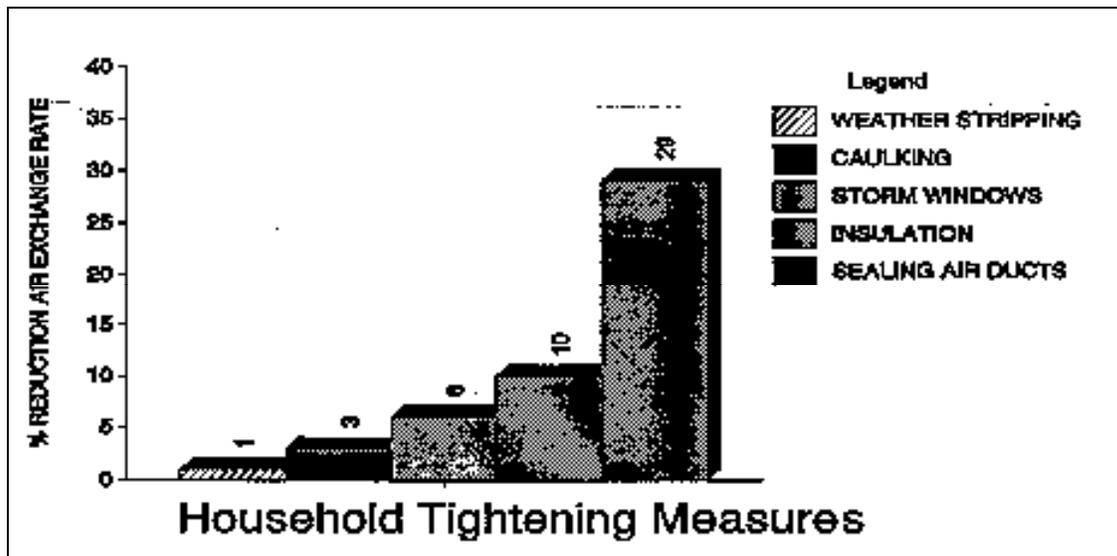


Source: USEPA, Energy Star website: http://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_sealing

Weatherizing a home is a very common practice in cold climates, federal and provincial governments recommend this initiative. Before the use of weatherizing techniques, many prairie homes leaked as many as five air changes every hour (ACH) during each day of the heating season. In general, good indoor air quality can be maintained with 0.3 ACH to 0.5 ACH.

Attempts made by homeowners to reduce the amount of energy needed for heating and cooling should not be discouraged. However, any weatherizing initiative must allow for the installation or upgrading of a mechanical system. Consequently, homeowners should be aware that if no provision is made for a mechanical ventilation system, the air in a weatherized home could become laden with excessive moisture, gaseous toxins and lingering odours. Figure H-8 shows the percentage reduction in the air-exchange rate using various weatherization techniques, such as house tightening measures.

Figure H-7: Per cent reduction in air Exchange rate by house tightening measures



Note: Depending on which weatherization technique is used, the natural infiltration rate of a home can be reduced by up to 30%.

Source: Adapted from U.S. Environmental Protection Agency, and U.S. Consumer Product Safety Commission, *The Inside Story: A Guide to Indoor Air Quality*, U.S. EPA and U.S. CPSC, Washington, D.C., September 1995.

H.4.2 Ventilation systems

The rate of air movement in buildings, whether exclusively by mechanical or natural means—or both—is referred to as the air exchange rate and is measured and reported as air changes per hour (ACH). One air change per hour theoretically means that one complete volume of building air has moved through the building and has been replaced with outdoor air during a period of one hour (Alberta Energy 1988).

H.4.3 Types of ventilation

H.4.3.1 Natural ventilation

The exchange of indoor and outdoor air from a space by natural or mechanical means is called ventilation. The term "natural ventilation" is used to describe the exchange of air without the use of mechanical devices (Alberta Energy, 1988). Natural ventilation through open doors and windows, vents, cracks and construction joints has long been used as a method to dilute indoor contaminants (Engineering Interface Limited, 1988, cited in Calgary Health Region, 1993).

“Natural” air change values vary greatly because of diurnal and seasonal temperature fluctuations as well as wind conditions. Consequently, infiltration-associated air exchange rates may range from a low of 0.1 ACH in tight, weatherized, energy-efficient homes under mild weather conditions, to 1.5 ACH in high infiltration conditions in leaky homes in severe weather conditions (Chan *et. al.*, 2005, <http://orise.orau.gov/csepp/documents/planning/reports/berkeley-reports/55575.pdf>).

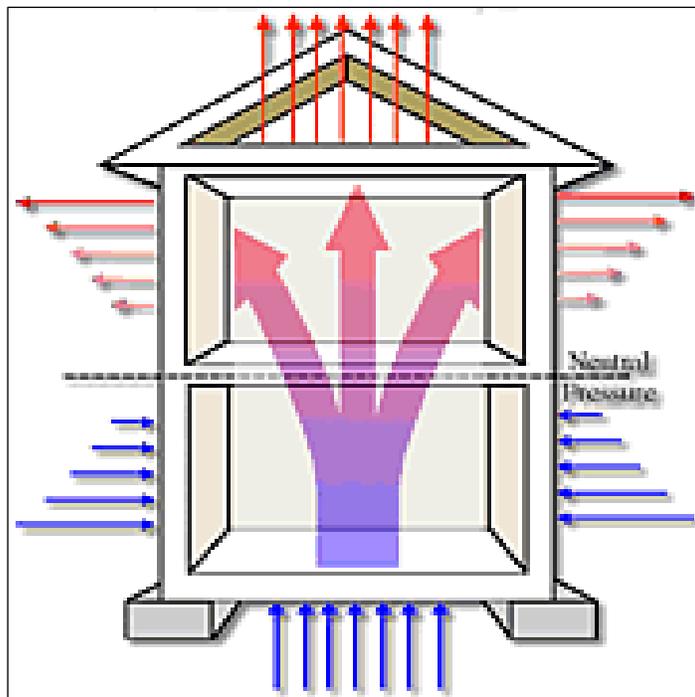
Infiltration-associated air change rates are usually higher during periods of higher wind speeds. When winds are calm and indoor and outdoor temperature differences are

minimal, tight energy-efficient homes may not have infiltration-associated air change rates that differ substantially from old and leaky homes (Chan *et al.*, 2005, <http://orise.orau.gov/csepp/documents/planning/reports/berkeley-reports/55575.pdf>) Wind and thermal forces affect air change rates and subsequently indoor air quality by causing pressure differences within buildings. Pressure differences drive the movement of air within a building through wind and temperature-driven mechanisms known as the "wind" and "stack" effects.

- **Stack effect**

The "stack" effect, also known as "chimney" effect, is caused by pressure gradients within a building. The "stack" effect is commonly seen in high rises as the outdoor pressure at the bottom of the building is higher than pressure at the top of the building, creating a pressure gradient for the movement of air upward and through the top of the building. Thermal-driven pressure effects can occur during the winter months when heated indoor air, which is less dense and more buoyant than cold outdoor air, rises to the top of the building. As a result, the lighter indoor air creates pressure differences within the building, such as positive air pressure at the top of the building and negative air pressure at the bottom half of the building. Since the natural air movement is from a high indoor pressure to a low outdoor pressure, the air in the building will move upwards. In the bottom of the building, air moves from a high outdoor pressure to a low indoor pressure. Figure H-8 delineates the "stack" effect.

Figure H-8 Stack effect in a two-storey house

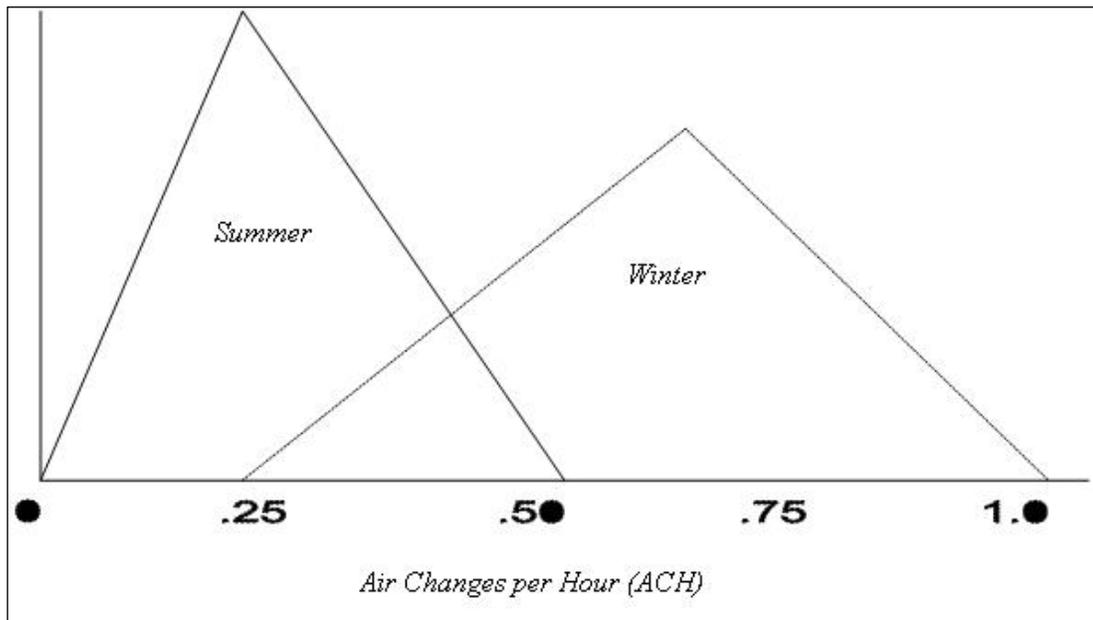


Source: Applied Building Science Inc. (2009). "Air Infiltration".
Applied Building Science Inc. website:
<http://www.stopdraftscold.com/air-infiltration.html>

The largest pressure differences occur during the heating season when indoor and outdoor temperature differences become very large. Therefore, the largest degree of air flow via the infiltration and exfiltration process will occur during the winter. One should also bear in mind that during the summer or air-conditioning season, the stack effect is reversed cool air flows out near the bottom of the building and warm air flows in at the top (Godish, 1989). The reversal of the stack effect is generally confined to high rises, and will not usually occur in homes as homeowners normally open windows and doors during the summer months. However, the reader should bear in mind that most office buildings are operated with the HVAC system creating a slight positive pressure. Open windows and doors in residential settings eliminate the pressure gradient necessary for the stack effect to occur.

Figure H-9 highlights the differences in infiltration-associated ACH with doors and windows closed and frequency of occurrence for specific infiltration-associated ACH in a house during summer and winter months.

Figure H-9: Summer versus winter infiltration associated air exchange in a house



Source: Engineering Interface Limited, Healthy Building Manual: Systems, Parameters, Problems and Solutions, Energy, Mines and Resources Canada, Ottawa, May 1988, reprinted with permission

Generally, the stack effect increases as the height of the building increases. Structural features such as elevator shafts, stairwells and other vertical passages, may also add to the stack effect. In houses and other buildings, there is a neutral pressure level (NPL) at which interior pressure is equal to outside pressure (Godish, 1989). The location of the NPL is dependent upon the distribution of air leakage sites in the building (Apple, 1988). For instance, if the leakage sites are uniformly distributed over the building envelope, the NPL is usually located at the half-way point or at the mid-height of a building. In single-family residences, the neutral pressure level is generally higher than the half-way point in the premises and, in most situations (at least those where a furnace with a flue is in use) the NPL may be even higher, even above the ceiling (Apple, 1988).

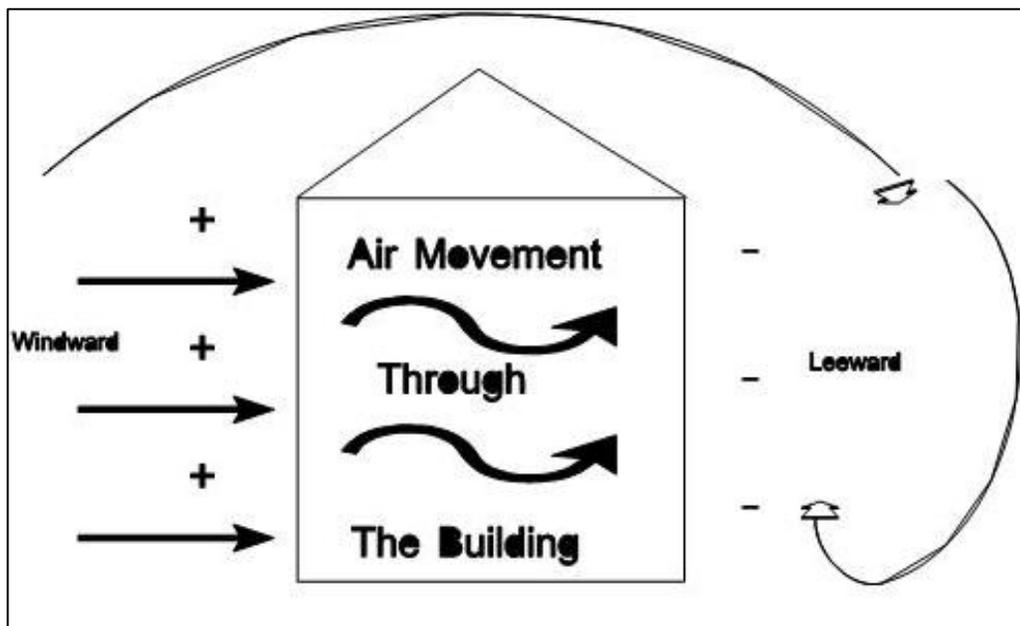
- **Wind effect**

Wind force is also a major driving force behind natural air movement. As wind approaches a building, it decelerates, creating positive air pressure on the windward side and negative air pressure on the leeward side, in the wake area. Figure H-10 depicts the movement of air and subsequent pressure differences experienced on the windward and leeward sides of a building.

The wind-induced pressure distributions on a building (which affect infiltration) will vary depending on a number of factors:

- Barriers to air movement, such as trees, shrubbery and adjacent buildings
- Wind speed
- Wind angle
- Building size and geometry
- Building finishes or overlays

Figure H-10: Side view of the wind effect



Barriers in front of buildings disrupt air flow, create turbulence and, through their shielding effect, reduce wind speed and alter wind direction (Apple, 1988). The stack and wind effects, although discussed separately in this section, tend to have a synergistic effect on buildings and, subsequently, on indoor air quality. For instance, with changing weather conditions, thermal and wind forces have been observed to cause the ventilation rate to vary by a factor of five (Apple, 1988).

Overall, weather conditions can have a direct effect on indoor air quality by affecting air exchange rates through indoor and outdoor temperature gradients and wind force. Indoor air quality can also be influenced by temperature inversions, which are

known to elevate the concentration of air pollutants at ground level. As a result, outdoor air entering a premise during a temperature inversion will influence the quality of that building's indoor air. Since natural ventilation is dependent on weather conditions, it provides limited control over indoor air movement. Consequently, the quality of indoor air in a premise with natural ventilation will fluctuate with natural forces. Table H-7 lists various advantages and disadvantages of natural ventilation.

Table H-7: Advantages and disadvantages of natural ventilation

Advantages	Disadvantages
It is suitable for buildings located in mild or moderate climates	Air flow rates and patterns of air flow are not constant. Because of less control over outdoor air, IAQ related problems could occur
Natural ventilation is inexpensive when compared to the capital, operational and maintenance costs of mechanical systems	Fresh air delivery and distribution of air in large buildings may not be possible
High air flow rates for cooling and purging are possible if there are plenty of openings coupled with wind driven exchange.	Natural ventilation is not suitable in noisy and polluted areas and is wind dependent.
Short periods of warm weather can be tolerated	Prolonged periods of warm weather are intolerable in the absence of air conditioning
No space for mechanical room is required.	Filtration and cleaning of air is not practicable
Occupants in naturally ventilated buildings adjust openings to suit prevailing demand	Occupants lack personal control

Source: Liddament 2001 (In Ventilation Strategies, Chapter 13, Indoor Air Quality Handbook, Spengler et al., 2001, McGraw Hill publications)

H.4.3.2 Mechanical ventilation

When natural forces cannot satisfy the ventilation requirements of a building, mechanical or forced ventilation is put into use. Mechanical systems can range in complexity from a simple propeller fan mounted in a window, to a sophisticated heating, ventilating and air conditioning (HVAC) system. Mechanical ventilation, unlike natural ventilation, provides the occupants of a building with far more technical control over their air environment. However, greater control over air quality parameters is achieved at the expense of individual control. Individuals lose their ability to exercise personal control over their space that results from being able to open a window at will. On a cost basis, mechanical ventilation is more expensive than natural ventilation. However, with mechanical ventilation, building occupants no longer have to rely fully on the vagaries of natural forces to obtain sufficient air exchange. Buildings can be sealed to reduce outside noise and air infiltration, and since supply and return air systems can be adjusted or conditioned, it is possible for mechanical ventilation systems to provide the occupants with a constant comfortable and relatively non-toxic internal environment. Mechanical ventilation systems assist in the improvement of indoor air through the dilution and exhaust of odours, CO₂, CO and other indoor air contaminants.

A typical HVAC system has a number of individual components. The performance efficiency of HVAC system depends on the proper design and maintenance of each individual component. A detailed description of each individual component is beyond the scope of this manual. For additional information, the reader should refer to other publications. A typical building mechanical system would generally contain the following components, briefly described below.

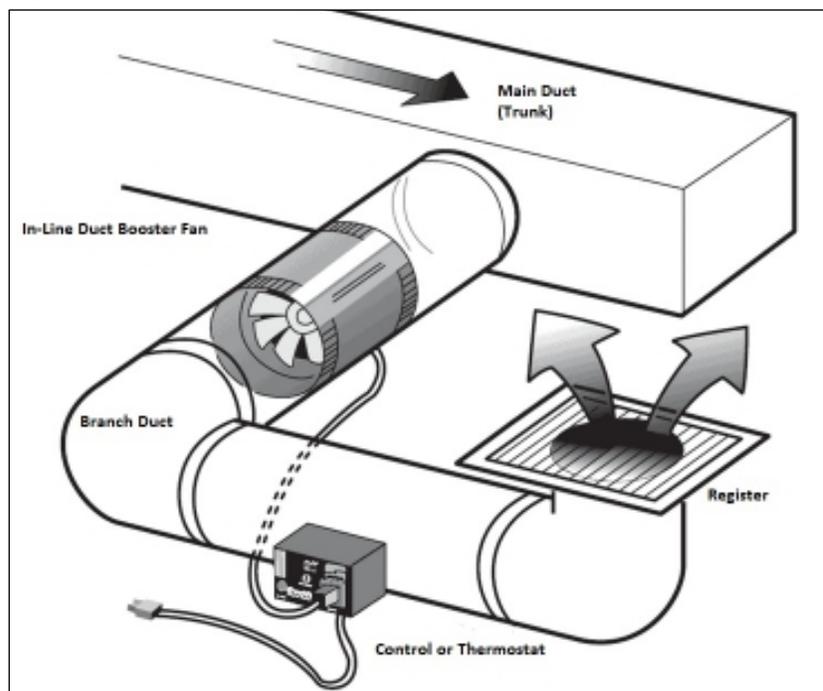
- Supply air system (ducts and diffusers)

- Return air system (ducts and grilles)
- Dampers to control the volume of air being exhausted or recirculated and the volume of makeup air
- Cooling coils and condensation trays
- Heat exchanger
- Humidifier
- In-duct fans (refer to Figure H-11), may also include supplemental heating and cooling units.
- Filters

Typically filters are limited to particulate filters of various efficiencies. Chemical or gaseous sorbent beds are rarely used in Alberta or across Canada. Sorbent beds must be specifically selected to capture specific compounds of concern, such as VOCs or acid gases, such as SO₂. For example, activated charcoal and alumina impregnated with potassium permanganate (Giles 1987, cited in Calgary Health Region 1993).

The central component of any mechanical ventilation system is fan operation. Fans affect the pressure profile of a building as they increase or decrease the pressure differences between the building and the outdoor air. Fans that exhaust air from a building will create negative air pressure inside the structure, which will draw in outside air, while fans supplying air from the outside will create a positive pressure inside and will push air out.

Figure H-11: Basic fan system



Source: Factoidz (2012). Duct Booster Fan Reviews. Factoidz website: <http://air-conditioning-hvac.factoidz.com/duct-booster-fan-reviews/>

Air flow or make-up air into a building and air flow or exhaust air out of the building are generally balanced to slightly pressurize the building (Engineering Interface Limited 1988, cited in Calgary Health Region 1993). Such a slight positive pressure will assist in reducing the infiltration of outside air into the building through openings in the building envelope (Bell and Khati 1983). Overall, air movement within buildings and their rooms is determined by the sum of pressure differences caused by three factors: (a) the stack (chimney) effect, (b) the wind effect and (c) fans (Engineering Interface Limited 1988, cited in Calgary Health Region 1993). Numerous types of mechanical systems are available. The following are a few types:

- Central forced-air systems (supply air only)
 - Heat recovery ventilators
 - Extraction or exhaust ventilation systems
 - Balanced-mixing ventilation systems
 - Balanced-displacement ventilation systems
 - Demand-controlled ventilation systems (variable air ventilation systems)
- **Central forced-air systems (supply only)**

Central-forced-air systems or supply-only systems are the most common method for distributing fresh air, often heated (sometimes cooled) throughout homes in Canada. Gravity air furnaces, although considered antiquated, may still be operating in some Alberta homes more than 50 years old. The use of furnace fans and ducts in combination with exhaust fans placed in kitchens, laundry rooms and bathrooms are capable of producing the pressure differences necessary to draw fresh air into the home ventilation system and exhaust stale air. However, one should bear in mind that these are not balanced systems. Central forced air systems, whether operating in the heat demand mode or operating continuously to provide fresh air, positively pressurize a space. The operation of these systems is not co-ordinated to exhaust return air automatically. Building air is usually exhausted via exfiltration or the intermittent operation of exhaust fans in bathrooms and kitchens. As a result, furnace systems, when operating, positively pressurize occupied spaces and can force indoor moisture into poorly sealed wall cavities.

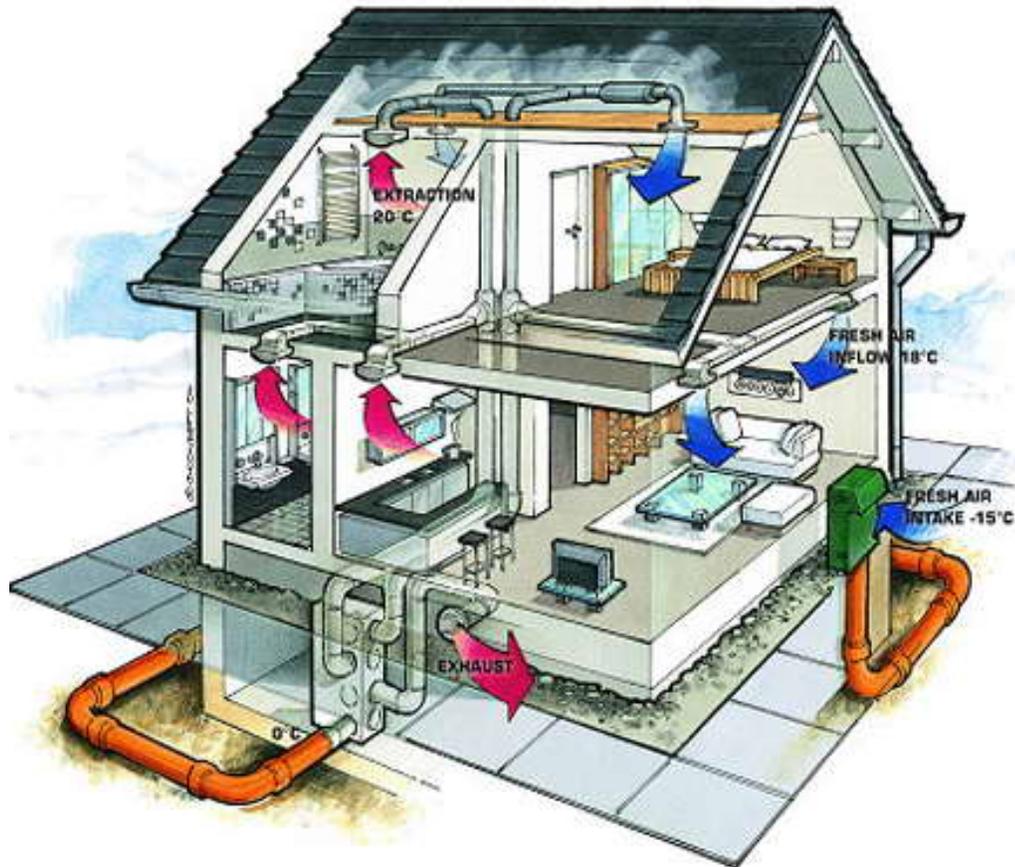
- **Heat recovery ventilators (HRVs)**

Another alternative for homeowners is heat recovery ventilators (HRVs) or heat exchangers. Heat recovery ventilators balance ventilation with reduced heating costs. Heat recovery ventilators are devices designed to extract and to transfer thermal energy from warm or cool exhaust air to outside air being drawn into the supply air system. This heat recovery system that transfers energy from one air stream to another, is known as air-to-air heat recovery ventilators (Godish, 1989).

The air-to-air heat exchanger (AAHX) is the most common type of heat exchangers in Alberta. AAHXs transfer energy from one air stream to another via thermal contact; that is, the air streams do not mix. AAHXs work by drawing stale warm air from within the house and transferring the heat energy from the warm air to the cold air within the ducting in the home (USEPA, 1995). AAHXs can be installed in

windows or as part of a central air system. Figure H-13 depicts a system design for an air-to-air heat exchanger.

Figure H-12 System design for a whole house air-to-air heat exchanger



Source: Heat Exchanger Design (2010). "Air-to-Air Heat Exchanger" Heat Exchanger Design website: <http://heatexchanger-design.com/2010/09/12/air-to-air-heat-exchanger/>

Heat exchangers or HRVs function to reduce heating costs in the winter and reduce cooling costs in the summer. During cold weather, heat is transferred from the exhaust air originating in the home to the outside air. When outdoor air temperature exceeds indoor air temperature, heat is transferred from the supply air to the exhaust air stream, cooling the supply air stream. In a heat exchanger, these two air streams come into thermal contact through the transfer of heat energy through the ducting; the air does not mix together. Air movement in a heat exchanger is either crossflow or counterflow (Godish, 1989).

Heat exchangers can be generally classified as follows:

- **Sensible heat exchangers**

Sensible heat is defined as heat that can be sensed or detected, by a change in the temperature of the system. These heat exchangers have transfer efficiencies that range from 65% to 75% (Reef, 1983, cited in Godish, 1989). With sensible heat exchangers, an impermeable barrier separates supply and exhaust air, making cross-contamination of supply and exhaust air an impossibility (Godish, 1989).

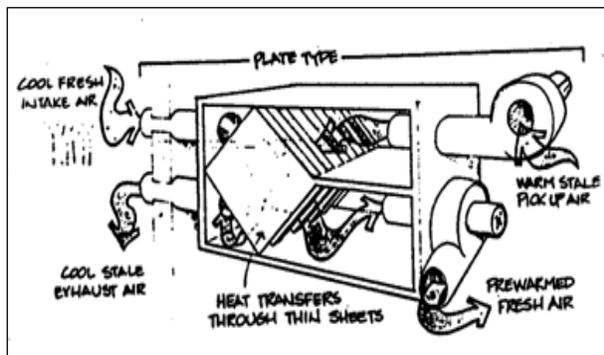
◦ Latent heat exchangers

Latent heat is defined as the heat which changes liquids to gases or solids to liquids. In a latent heat exchanger, the core of the exchanger is permeable, allowing for the transfer of latent heat from one air stream to another. In this case, cross contamination is possible (Shurcliff, 1983).

Heat exchangers that can transfer both “sensible heat” and “latent heat” are classified as “enthalpy exchangers”. Generally, enthalpy exchangers have high transfer efficiency that ranged from 75% to 85%. Enthalpy exchangers are permeable to water vapour and other water soluble gases, such as formaldehyde (Godish, 1989).

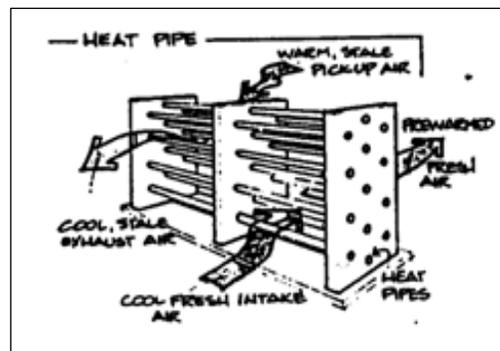
To prevent contamination of the air stream, both the incoming and outgoing air that passes through a heat recovery ventilator is kept physically separated by a heat exchange core (Alberta Energy, 1988). The core can consist of plastic, aluminium or treated paper. Although, there are many variations to the core design, the four main types of core configurations for AAHXs are portrayed below (Figures H-13.1 through H-13.4).

Figure H-13.1 Flat plate



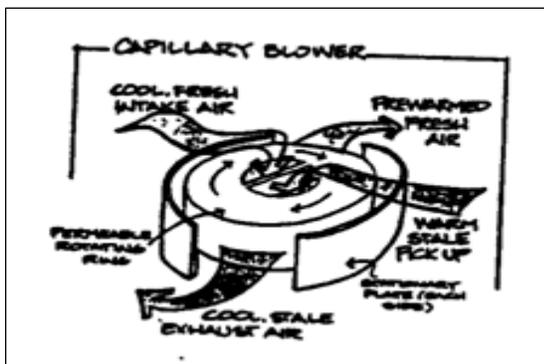
Source: Alberta Energy, *Ventilating Your Home*, Energy Efficiency Branch, Information Services, Edmonton, 1988, reprinted with permission

Figure H-13.3 Thermosyphon heat tube



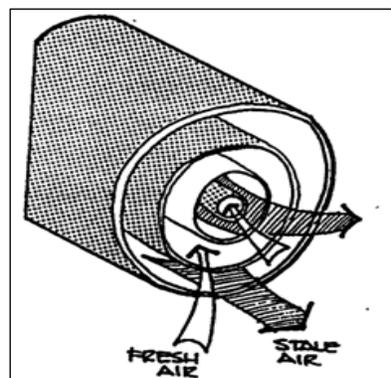
Source: Alberta Energy, *Ventilating Your Home*, Energy Efficiency Branch, Information Services, Edmonton, 1988, reprinted with permission

Figure H-13.2 Capillary wheel



Source: Alberta Energy, *Ventilating Your Home*, Energy Efficiency Branch, Information Services, Edmonton, 1988, reprinted with permission

Figure H-14.4 Concentric tube



Source: Alberta Energy, *Ventilating Your Home*, Energy Efficiency Branch, Information Services, Edmonton, 1988, reprinted with permission

Even though, AAHXs are a big improvement in providing better IAQ over more traditional types of home ventilation systems, there are still some operational concerns, which may affect performance and create health-related problems.

These concerns include:

- **Air leakage**

Leakage of air from AAHX ductwork appears to be a common occurrence, with leakage rates ranging from 5% to 8% (Godish, 1989).

- ▶ Freezing of exchanger cores

In cold climates, such as Alberta, the performance of AAHXs can be greatly reduced by the freezing of condensate water in the exchanger core (Alberta Energy, 1988)

- **Cross-contamination**

Some types of AAHXs, such as capillary-wheel heat exchangers, will allow for the crossover of small amounts of gaseous contaminants because of the configuration of the exchanger's core. Consequently, gases that are present in the exhaust air may contaminate the supply air.

- **Sizing**

Needless to say, if an AAHX is not sized properly for a specific premise, the AAHX will not provide sufficient ventilation for the maintenance of acceptable indoor air quality. Sizing needs to take into account the absolute volume of air to be moved and the expected static pressure of the ductwork.

- **Tightly constructed homes**

AAHXs are not expected to perform well, that is, provide sufficient ventilation for the maintenance of acceptable IAQ, unless the home is designed, constructed and sealed to current energy efficiency standards (Rousseau, 1994).

- **Bacteria and fungus growth**

This does not seem to be a problem in modern AAHXs, especially those using flat plate, concentric tube and thermosyphon heat tube core configurations. If biogenic activity occurred in the exhaust path, the flow of air would direct most spores out of the home. However, bacteria and fungus growth could be a problem with a paper enthalpy or capillary wheel AAHX that has not been maintained properly.

Air-to-air heat exchangers can certainly improve indoor air quality by providing sufficient quantities of fresh air. However, one major limiting factor for homeowners when a decision has to be made whether or not to install AAHXs is cost-effectiveness. Although the use of AAHXs can significantly reduce heating costs, there is an economic cost associated with installation, operation and maintenance. For instance, the cost of investing in a tightly constructed home and installing an AAHX system may not be economical from a homeowner's point of view as the payback period is too long (greater than 10 years) (Godish, 1989).

However, one should note that the move towards tighter home construction, homeowners' requests for more comfortable homes and the ventilation requirements in the 1997 Alberta Building Code have defeated many of the arguments against installing AAHXs. Consequently, AAHXs are becoming the system of choice in many new homes.

- **Heat pump ventilators**

Another type of heat recovery ventilation system which only occasionally may be seen in Alberta homes is the heat pump ventilator (HPV). A heat pump ventilator integrates the functions of an AAHX, a hot water heater and a dehumidifier into one unit. Although heat pump ventilators are increasing in popularity because they can heat domestic hot water tanks and provide good indoor air quality, HPVs are still rare in Alberta homes because these ventilators are very costly and consume large amounts of electrical energy. Nevertheless, an economic argument can be made in favour of HPVs if electricity is the only energy source available.

- **Balanced mixing ventilation system**

Balanced ventilation system combines exhaust and supply systems through separate duct networks. Air is supplied and mixed in occupied areas in a building and is extracted, sometimes from more contaminated or less occupied areas. For instance, conditioned outdoor air is delivered into the bedroom area of a home where it travels through the living room area before being exhausted out the kitchen. Most of the time, a balanced system incorporates heat recovery using a plate-to-plate heat recovery unit or similar air-to-air system. Sometimes, an internal flow imbalance may be introduced that creates negative air pressure in residential dwellings or positive pressure in commercial buildings (Liddament, 2001, cited in Spengler *et. al.*, 2001).

- **Balanced-displacement ventilation systems**

It is a form of balanced ventilation when the supply air displaces rather than mixes with the room air. It avoids the problem of ceiling mounted return-and-supply air and, in the case of homes, return and supply air both at floor level. Preconditioned air is introduced at 2°C or 3°C below ambient room temperature into the space at a low level and at a low velocity (at 0.1 to 0.3 m/s) (Liddament, 2001, cited in Spengler *et al.*, 2001).

The incoming air, because of gravitational effects, creeps at floor level and consequently, it reaches a thermal source (the occupant). Then the air rises around the heat source and into the breathing zone before being extracted at the ceiling level. This process avoids mixing of air; rather, it displaces the air, which is already present within the space. Although occupant activities tend to mix the two layers (Liddament, 2001, cited in Spengler *et. al.*, 2001).

- **Demand control ventilation (DCV)**

DCV systems, like variable air volume (VAV) systems, provide a way to control the rate of ventilation automatically, according to the variations in indoor air quality. Ventilation is provided only when and where it is required. At other times, the ventilation rate is reduced to minimize space heating or cooling losses (Liddament, 2001, cited in Spengler *et. al.*, 2001). For example, VAV systems can monitor indoor temperatures and provide more ventilation as the temperature goes up. They can also

be based on CO₂ measurement, providing air when CO₂ levels rise (measured by CO₂ sensors). In older systems, ventilation was provided on the basis of temperature, not CO₂ sensors.

H.4.3.3 Dilution ventilation systems

The aforementioned mechanical ventilation systems described above are all examples of general dilution ventilation. Dilution ventilation involves the incorporation of make-up air to replace the air exhausted.

H.4.3.4 Exhaust systems

Exhaust systems can remove local contaminants and prevent odours and fumes from accumulating indoors. However, they may depressurize the home creating disadvantages, of which, homeowners should be aware.

These disadvantages may include increased heating energy losses and an increased incidence of uncomfortable cold drafts through cracks in the building envelope.

Exhaust only systems can depressurize a building causing the “backdrafting” of combustion gases from furnaces and boilers into the building interior. In addition to exhaust fans, fireplaces, wood stoves and clothes dryers can contribute to incidents of backdrafting. Therefore, balanced systems are recommended for homeowners to avoid interstitial problems and to achieve optimal fresh air exchange.

There are two types of exhaust ventilation: general and local. Local exhaust is used more to control and capture hazardous emission sources, such as hazardous air pollutants released during welding or electroplating tanks in a building. Local exhaust can be achieved by a low capacity wall, window and cooker hood fans, which vent the contaminated air directly outside. In comparison, general exhaust ventilation provides complete exhaust ventilation to a building.

H.4.4 Typical ventilation systems for building types

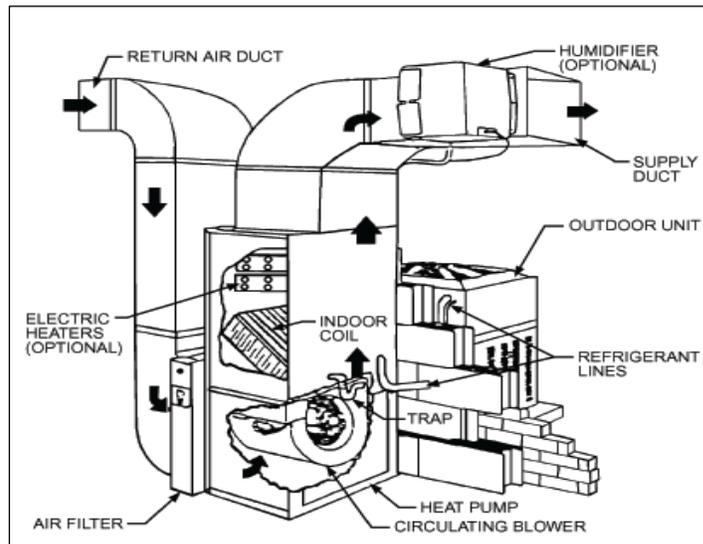
H.4.4.1 Residential

- **Single-family residential**

The ventilation system installed at the time of construction will be one of three configurations: central forced air, central hydronic or a zoned system (ASHRAE, 2011).

Central forced air systems condition air to be heated or cooled (if equipped for cooling) and distribute the conditioned air throughout the home via ductwork. The air in a central-forced-air system is typically conditioned by a heat pump or furnace and has a single heating zone (Figure H-14) or a two-zoned (Figure H-16) configured distribution (ASHRAE, 2011).

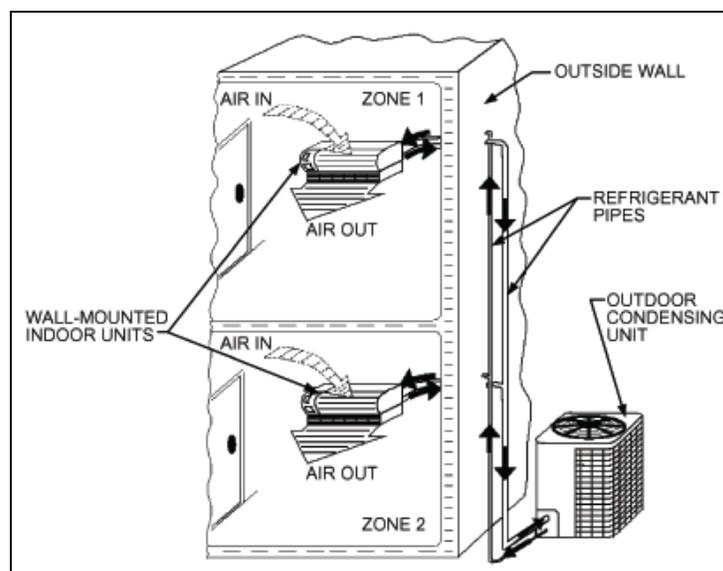
Figure H-14 Typical residential installation of air-couples heat pump



Source: ©ASHRAE (2011 ASHRAE HANDBOOK – HVAC Application (SI Edition)), (Chapter 1- Residences), (2011).

The most common heat pumps in North America are air-to-air (air-source) heat pumps that are electrically powered to heat with electrical-resistance heating elements (ASHRAE, 2011). Now becoming more common, ground-source or geothermal systems (Figure H-16), typically use water-to-air heat pumps to pull heat from an underground water-filled loop of piping and then distribute the heat through a conventional duct system as warm air Pro Star, 2011).

Figure H-15 Example of a two-zone system in a typical home

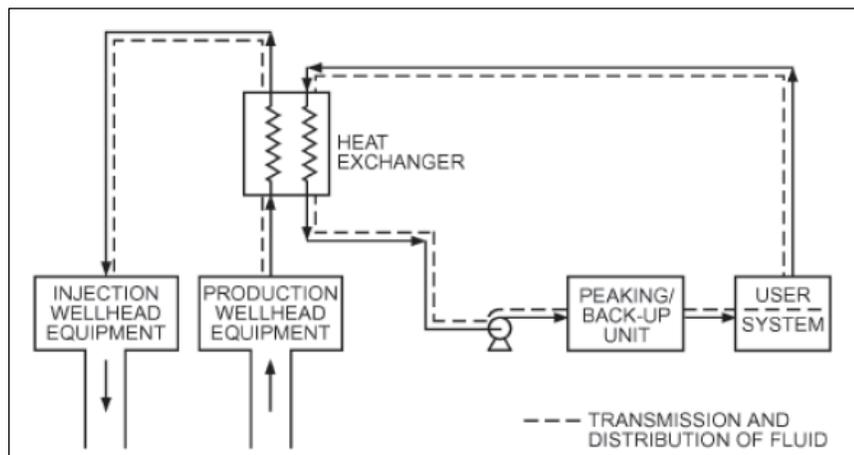


Source: ©ASHRAE (2011 ASHRAE HANDBOOK – HVAC Application (SI Edition)), (Chapter 1- Residences), (2011).

Furnaces can be fueled by natural gas, propane, oil, wood, other combustible materials or electricity. Furnaces fueled by combustibles can draw air for combustion from the home or from the outdoors. Systems that draw outdoor air for combustion are known as isolated combustion systems (ICS) (ASHRAE, 2011). High-efficiency furnaces are either non-condensing or condensing. The condensing type condenses water vapour from the combustion air and collects it before directing it to a drain (ASHRAE, 2011).

Central hydronic or hot-water heating systems condition the house through the use of tempered liquid circulated through piping and radiators or baseboard convectors that radiate the heat to the air. The circulating liquid is centrally heated one of three ways: (a) by a boiler fueled by fossil fuels or other combustible material, (b) by an electrically heated boiler or (c) by a geothermal system. This type of system can also be coupled with an air handler and space heating is provided by circulating indoor air across the heated coil (ASHRAE, 2011).

Figure H-16 Geothermal heating with heat exchanger



Source: ©ASHRAE (2011 *ASHRAE HANDBOOK– HVAC Application (SI Edition)*), Chapter 34 – Geothermal Energy (2011).

Zoned heating systems are configured in a manner that the air supplied to an area or zone of the house is conditioned according to the thermostat setting for that zone. There are both single-zone; that is, a whole house is conditioned through a central system, and multi-zone systems. Types of multi-zone systems include (ASHRAE, 2011):

- Individual heaters, electric or gas, located in each room
- Electric heat pumps for each zone, which is made up of one or more rooms
- Multi-split heat pump with a central compressor and an outdoor heat exchanger to service many zones
- Zone-damper system in which there is a central-ducted system and each zone is controlled with dampers and thermostats. These are available in variable air volume (VAV) and on-off types

- **Multifamily residential**

The systems found in attached homes or low-rise multifamily structures are generally similar to those found in single-family residences (ASHRAE, 2011).

High-rise structures can use single or multi-zoned forced air systems similar to those found in single-family residences (ASHRAE, 2011). These types of systems can be installed in a designated mechanical room, in a soffit, above a dropped ceiling in a common area, or mounted on a wall. Systems employing a condenser or heat pump are often found on roofs, balconies or on the ground (ASHRAE, 2011). In other cases, each unit is equipped with an individual small residential furnace. When furnaces fueled by fossil fuels or combustible materials are employed, ducting is required for combustion air and also includes exhaust venting that can be configured as a common exhaust stack, (a multi-vent chimney or manifold-type vent system) or individual exhaust stacks (direct-vent furnace vented through an exterior wall) (ASHRAE, 2011).

Central hydronic systems are also employed in high-rise apartments where each dwelling unit will have either individual room units (radiators or baseboard convectors) or ducted fan-coil units (ASHRAE, 2011).

Through-the-wall units, such as room air conditioners, packaged terminal air conditioners, packaged terminal heat pumps, are another common type of ventilation and air conditioning system found in dwelling units of multifamily structures (ASHRAE, 2011). To employ through-the-wall units, the dwelling must have an exterior wall.

- **Manufactured and mobile homes**

The heating system is factory-installed and usually consists of a forced-air downflow unit with subfloor supply ducting and floor registers. This type of system does not have return air ducting and the return air is brought to the unit through door undercuts, hallways and a door through a grill or louver on the access door (ASHRAE, 2011). The unit is usually of a “reduced-clearance” type and is located in a closet or alcove. Figure H-17 provides an illustration of the typical heating and cooling equipment for mobile or manufactured homes.

In some units, an oil, gas or electric furnace or heat pump may be installed. The furnace will be of a direct vent type with vertical, through the roof, concentric pipe-in-pipe venting configuration. This type of system draws all air for combustion from the outdoors and discharges all combustion air to the outdoors.

There is also the possibility that homes of these types are equipped with cooling units if the supply ducting is adequately sized. The two common types of cooling units are (ASHRAE, 2011):

- Split system

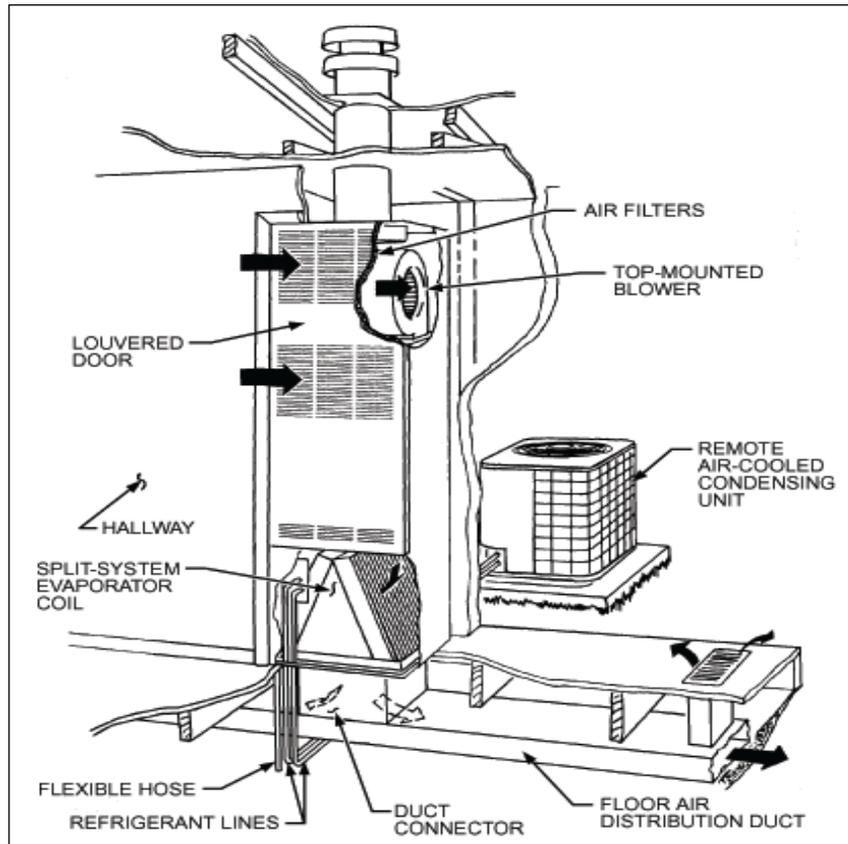
The evaporation coil may be housed in the integral coil cavity provided with the furnace.

- Single system

This system is a separate unit connected with flexible hoses and air ducts.

Both types of systems need dampers or another means to prevent cooled conditioned air from back-flowing through the furnace cabinet.

Figure H-17 Typical heating and cooling equipment for a manufactured home



Source: ©ASHRAE (2011 *ASHRAE HANDBOOK – HVAC Application (SI Edition)*), (Chapter 1- Residences), (2011).

- Split system
The evaporation coil may be housed in the integral coil cavity provided with the furnace.
- Single system
This system is a separate unit connected with flexible hoses and air ducts. Both types of systems need dampers or another means to prevent cooled conditioned air from back-flowing through the furnace cabinet.

H.4.4.2 Commercial

- **Multi-unit buildings**

Regional shopping centers vary widely in physical arrangement and architectural design. Single-level and smaller centers usually use unitary systems for mall and tenant air conditioning; while multi-level and larger centers usually use a central system (AHSRAE, 2011).

A central system may use variable-volume control and electric heating or all-air systems (ASHRAE, 2011). Air conditioning systems for department stores may use unitary or central station equipment. Most have central station systems consisting of air-handling units with chilled-water cooling coils, hot-water heating coils, fans and filters with water chilling, and heating plants that distribute water to the various air handlers and zones. Other stores, however, use large unitary units (ASHRAE, 2011). In either case, systems must have adequate zoning. Also the wide variations in occupant density may justify considering variable-volume air distribution systems (ASHRAE, 2011).

Forced air furnaces are found in commercial settings. Such furnaces should have both a fresh air intake and a combustion air intake; however, both may not always be found in older commercial and residential buildings.

- **Tall and multi-storey buildings**

The ventilation systems in tall and multi-storey buildings have evolved to meet the owners' goals, occupants' needs, energy costs and environmental concerns, including indoor air quality. Systems can range from small, unitary, decentralized cooling and heating systems to large centralized systems with chillers, cooling towers and boilers as well as large air-handling systems.

Centralized systems are usually composed of a primary and secondary system. In the primary system, the cooling and heating medium (typically water or brine) is cooled or heated and the distributed to the secondary system (ASHRAE, 2011). Centralized systems include the following systems:

- Secondary systems
 - ▶ Air handling and distribution
 - ▶ In-room terminal systems
 - ▶ Dedicated outdoor air systems (DOAS) with chilled water for cooling and hot water, steam, or electric heat for heating (for special areas when required)
- Primary systems
 - ▶ Central cooling and heating plant

Typical decentralized systems (dedicated systems serving a single zone, or packaged systems such as packaged variable air volume) include the following (ASHRAE 2011):

- ▶ Water-source heat pumps (WSHP), also known as water-loop heat pumps (WLHP)

- ▶ Geothermal heat pumps, such as groundwater heat pumps and ground-coupled heat pumps
- ▶ Hybrid geothermal heat pumps are a combination of groundwater heat pumps, ground-coupled heat pumps, and an additional heat rejection device for cases with a limited area for the ground-coupled heat exchanger or where it is economically justified
- ▶ Packaged single-zone and variable-volume units
- ▶ Light commercial split systems
- ▶ Mini-split and variable-refrigerant-flow (VRF) unit

Air distribution and conditioning in tall and multi-storey buildings can be met by one or more central mechanical equipment rooms serving multiple floors or by separate systems installed in local fan rooms on each floor to supply air only to that floor. (ASHRAE, 2011). Often, several types of systems can be applied to one building because of special requirements, such as continuous operation and supplementary cooling for certain sections of the structure. The systems likely to be encountered include (ASHRAE, 2011):

- **All-air variable-air-volume (VAV) systems**

Variable-air-volume (VAV) systems are the most common systems in tall buildings. They provide conditioned air from either a central fan room or from local floor-by-floor air conditioning units. In geographical locations requiring heat, the system must be designed with (a) an auxiliary means of heating, such as hot-water baseboards controlled either directly by thermostat or automatically by setting the hot-water temperature inversely to outdoor air temperature, (b) a thermostatically controlled exterior wall electric baseboard or either an electric or hot-water heating coils in the perimeter VAV boxes. VAV terminals or boxes are available in many configurations:

- ▶ A pinch-off box directly reduces supply air volume with a reduction of the cooling load. This system is the most common terminal in commercial applications and has the smallest height of any terminal used in office buildings.
- ▶ A series-flow fan-powered VAV terminal maintains constant air flow into a space by mixing cold supply air with return air from the space. This terminal contains a small fan to deliver constant air flow to the space when the building is occupied.
- ▶ A parallel-flow fan-powered VAV terminal maintains variable air flow into a space and mixes cold supply air at minimum flow requirements with return air from the space. This terminal contains a small fan that starts only in heating mode to deliver mixed primary and return air flow to the space when the building is occupied and operates only when heating is required to deliver warm return air, mixed with cool primary air. This option delivers increased air flow to the space during heating. Primary air can also be shut off and the terminal will operate only the fan to deliver return air during unoccupied periods. When heating requirements increase, a box-mounted heating coil (hot-water or electric) supplements the heat provided by return air. The parallel approach does not ensure constant air volume to the space, as can be

obtained with the series approach; however, it does provide a minimum air flow at significantly lower operating cost.

- ▶ An induction box reduces supply air volume inducing mixing of room air with supply air, maintaining constant supply air flow to the space. These units require higher inlet static pressure to achieve velocities necessary for induction, an increase in supply fan energy requirements and have been known to experience operational problems. As a result, these boxes are now seldom used in commercial projects.
- **Low-temperature air VAV systems**

These systems operate with low-temperature supply air between 8.9°C and 0°C which increases the temperature supply differential dramatically thereby reducing primary air quantities required. Fan-powered variable-air-volume terminals or induction-type air supply terminals are required to avert the problem of reduced air flow at less than design loads; which occurs particularly in the interior zone. The function of the air delivery terminals is to mix room air with cold supply air to deliver warmer air to the space to offset heat gain.
- **Air/water systems**

These systems historically included induction systems; however, modern systems use fan-coil units outside the building and typically supply interior spaces by an all-air variable-air-volume system. An advantage of this type of system is that it reduces the required capacity of the central supply and return air systems, the size of distribution air ducts, and the mechanical room space needs. However, these types of systems require space for heat exchangers and pumps to obtain the hot and cold secondary water needed by the fan-coil unit system.
- **Underfloor air distribution (UFAD) systems**

UFAD systems use the space beneath a raised floor is as a distribution plenum that delivers air to the space above. Traditionally these systems were in ceiling spaces and delivered air to the occupied space below. These systems use manually adjustable supply diffusers or automatically controlled terminal units beneath the floor to control the supply of air. UFAD systems can use central fan rooms or floor-by-floor fan units for conditioning and distributing air.
- **Large spaces or units**

The selection of ventilation and air conditioning equipment and systems depends on the type of facility. Some facilities might need only heating and cooling in administration areas while other facilities may need sophisticated ventilation and air conditioning systems to create special environmental conditions required for products, equipment or activities within the facility.

In warehouses, air distribution and conditioning systems can range from small, unitary, decentralized cooling and heating, such as unit heaters and unit ventilators, to large centralized systems with chillers, cooling towers and boilers as well as large air-handling systems. The large systems can be housed either in one or more central mechanical rooms serving multiple floors, or separately installed in local fan rooms. Each system supplies air only to the area where the system is installed as well as stockrooms, rest rooms, break rooms and offices. Special storage rooms designed for

perishable merchandise may require separate HVAC systems or refrigeration. Most warehouses are only heated and ventilated and are likely to use forced-flow unit heaters located near entrances and work areas or large central heating-and-ventilating units (ASHRAE, 2011).

In big-box stores and grocery stores, each specific area is typically treated as a traditional stand-alone facility.

H.4.4.3 Specialized facilities

- **Schools**

Air distribution and conditioning systems for K-12 schools may be centralized, decentralized, or a combination of both. In all cases, schools need outdoor air for ventilation and for removing indoor air pollutants generated by occupants and any other building-related sources.

Centralized systems typically incorporate treatment and distribution of air by secondary systems. In such systems, the cooling and heating medium is typically water or brine that is cooled and heated in a primary system and distributed to the secondary systems. Centralized systems include (ASHRAE, 2011):

- Secondary Systems
 - ▶ Air handling and distribution
 - ▶ In-room terminal systems
 - ▶ DOAS with chilled water for cooling and hot water, steam, or electric heat for heating. Typical DOAS units are air-handling units that cool, dehumidify, heat, humidify and filter the outdoor air before it is introduced to the conditioned space.
- Primary Systems
 - ▶ Central cooling and heating plants or rooms

Forced air furnaces are found in some school settings, such as older schools and portable school structures. Such furnaces should have both a fresh air intake and a combustion air intake. However, both may not always be found in older schools.

Typical decentralized systems (dedicated systems serving a single zone, or packaged systems such as packaged variable-air volume) include (ASHRAE, 2011):

- Water-source heat pumps (WSHPs), also known as water-loop heat pumps (WLHPs)
- Geothermal heat pumps (groundwater heat pumps, ground-coupled heat pumps) or hybrid geothermal heat pumps (combination of groundwater heat pumps, ground-coupled heat pumps and an additional heat rejection device), for cases with limited area for the ground-coupled heat exchanger or where it is economically justified
- Packaged single-zone and variable-volume units
- Light commercial split systems

- Mini-split and variable-refrigerant-flow (VRF) units

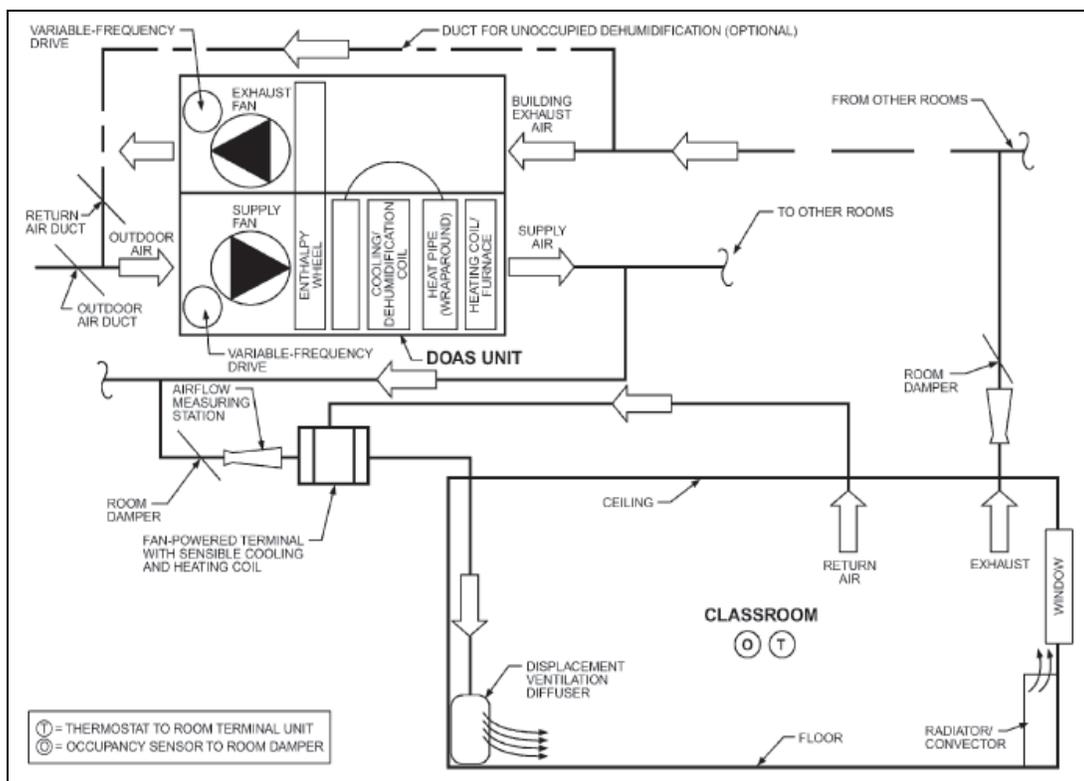
The use of displacement ventilation for classrooms, as opposed to the more traditional mixing ventilation, is better for maintaining IAQ. In displacement ventilation, colder fresh air is discharged to the space close to the floor level while warm air is exhausted from the ceiling or close to it. The colder air, discharged at the floor level, is gradually heated by people, computers and unit heaters, and then rises to the ceiling where it is exhausted. The rising air will entrain IAQ contaminants allowing them to be effectively removed. Figure H-19 is a schematic of a typical ventilation system layout.

- **Recreational facilities**

- **Ice arenas**

These facilities require special ventilation and air conditioning systems which must include dehumidification systems. The purpose of these special systems is to keep spectators comfortable, to prevent roof condensation and fog forming above the surface of the ice. The ice-rink facility must also be heated to keep the ice rink warm even in warm climates and to control air humidity control.

Figure H-18: Typical displacement ventilation system layout



Source: ©ASHRAE (2011 ASHRAE HANDBOOK – HVAC Application (SI Edition)), (Chapter 7- Educational Facilities), (2011).

Mechanical ventilation is necessary to be able to control the indoor air quality, and thermal and humidity conditions inside the ice rink (USEPA, 2012).

Ventilation is needed both in the public spaces, such as dressing rooms, foyers, and cafeterias, as well as the main area. Inadequate ventilation can cause health problems within the facility.

The dehumidification plant is needed to dry the rink air. Excess moisture in indoor air will cause corrosion of metal structures, rotting of wooden structures, fungi and mould growth, increased energy consumption and ice quality problems (USEPA, 2012).

- **Swimming pool facilities or natatoriums**

Outdoor air ventilation must be sufficient to provide acceptable air quality conditions for the average pool using chlorine for primary disinfection. However, these ventilation requirements may be either excessive for pools with low occupancy or inadequate for high-occupancy pools (ASHRAE, 2011).

Proper duct design and installation is critical because failure to effectively deliver air where it is most needed can result in air quality problems, condensation, stratification and poor equipment performance (ASHRAE, 2011).

The following should be examined with respect to ductwork (ASHRAE, 2011):

- ▶ Duct materials and hardware must be resistant to chemical corrosion from the pool atmosphere. Galvanized steel and aluminum sheet metal may be used for exposed duct systems. Certain types of fabric duct (airtight) with appropriate grilles sewn in are also a good choice.
- ▶ Grills, registers and diffusers should be constructed from aluminum. They should be selected for low static-pressure loss and for proper air distribution.
- ▶ Supply air should be directed against envelope surfaces prone to condensation (glass and doors). Some supply air should be directed over the water surface to move contaminated air toward an exhaust point and control chloramines released at the water surface. Note: air movement over the pool surface must not exceed 15 m/s.
- ▶ Return air intakes should be located to recover warm, humid air and return it to the ventilation system for treatment. This is necessary to prevent supply air from short-circuiting and to minimize recirculation of chloramines.
- ▶ Exhaust air intakes should be located to maximize capture effectiveness and minimize recirculation of chloramines. Exhausting from directly above whirlpools is also desirable. Exhaust air should be taken directly to the outdoors, through heat recovery devices where provided.
- ▶ Filtration should be selected to provide 45% to 65% efficiencies and be located to prevent condensation in the filter bank. Filter media and support materials should be resistant to moisture degradation.
- ▶ Fibreglass duct liner should not be used and must be applied to the duct exterior where condensation may occur.

- **Personal- and social-care facilities and institutions**

Because of the varied nature of these facilities, a varied approach to ventilation and air conditioning is needed. As these facilities may be similar to a normal residential

buildings or have complex designs similar to the varied types of commercial structures the ventilation systems may also be similar. However, medical evidence has shown that proper air conditioning is helpful in preventing and treating many conditions. For this reason, ventilation requirements exist to protect occupants from harmful exposures (ASHRAE, 2011).

The basic differences between ventilation and air conditioning systems for hospitals (and related health facilities) and that for other buildings stem from (ASHRAE, 2011):

- The need to restrict air movement in and between the various departments
- Specific requirements for ventilation and filtration to dilute and remove contamination (odour, airborne microorganisms and viruses, and hazardous chemical and radioactive substances)
- Different temperature and humidity requirements for various areas
- Design sophistication needed to permit accurate control of environmental conditions

For the purposes of suppressing and preventing the spread of airborne diseases in health-care facilities, isolation rooms with appropriate ventilation pressure relationships are primarily used (ASHRAE, 2011). Such isolation areas are created by systems that generate negative air pressure by exhausting more air out of a room than is supplied to the room. In highly contaminated areas, such as autopsy, airborne infectious isolation rooms, laundry and bed-pan washing areas, negative air pressure ensures potentially contaminated air will not flow into nearby rooms, but instead be exhausted out of the existing room.

In other areas where airborne contaminants are undesired, such as operating rooms and sensitive patient rooms, positive air pressure prevents out-of-room air from leaking into the specialized rooms. Air supply to sensitive, ultraclean areas should be located on the ceiling, with perimeter exhaust outlets near the floor, providing downward movement of clean air through the breathing and working zones to the floor area for exhaust (ASHRAE, 2011).

Outdoor air is virtually free of infectious bacteria and viruses and; therefore, is a good source of make-up air, provided the air intakes are properly located, and areas adjacent to the intakes are properly maintained. Ventilation using outdoor air dilutes viral and bacterial contamination within a hospital. Such ventilation is important because infection control problems often involve a bacterial or viral source within the hospital. If ventilation systems are properly designed, constructed and maintained to preserve correct pressure relations between functional areas, they control the spread of airborne infectious agents and enable the proper containment and removal of harmful airborne agents (ASHRAE, 2011).

In general, ventilation system design should maintain air movement from clean to less clean areas. In critical-care areas, constant-volume systems should be used to ensure proper pressure relationships and ventilation; while in noncritical patient care areas and staff rooms, variable air volume (VAV) systems may be considered for energy conservation (ASHRAE, 2011).

There are seven principal divisions of an acute-care general hospital and the environmental requirements of each these divisions differ according to their function and procedures carried out in them. These divisions are (ASHRAE, 2011):

- Surgery and critical care
- Administration
- Nursing
- Diagnostic and treatment
- Ancillary
- Sterilizing and supply
- Services, such as food, mechanical and utility areas

In non-acute-care facilities, such daycare centres, group homes, treatment facilities, and old age homes, the divisions may be similar to those in acute-care hospitals but may lack some specific purpose divisions, such as diagnostic, surgery and critical care areas.

When central systems are used to condition patient rooms, each patient room should have individual temperature control. Also, air pressure should be neutral in relation to other areas. Where room unit systems are used, it is common practice to exhaust air through the adjoining toilet room equal to the amount of outdoor air brought in for ventilation (ASHRAE, 2011).

Ventilation requirements for this area depend on the type of food service adopted by the facility. Local exhaust to the outdoors should be provided for areas where bulk food is dispensed and dishwashing facilities are provided from a centralized food service area and small pantries used for between-meal feedings or ward distribution require no special ventilation (ASHRAE, 2011). The air pressure of the food service area and pantry should be in balance with that of adjoining areas to reduce the movement of air into or out of the area (ASHRAE, 2011).

Controlling bacteria levels in nursing homes is not as critical as it is in acute-care hospitals; however, the same general infection control considerations should be considered; that is, movement of air from clean to less clean areas. Ventilation and air conditioning will also need to provide sufficient ventilation to dilute and control odours and be designed and controlled to prevent drafts (ASHRAE, 2011).

Temperature control should be on an individual-room basis. In geographical areas with severe climates, it is likely that patients' rooms will have supplementary heat along exposed walls, such as unit heaters, electric heaters or radiators (ASHRAE, 2011).

- **Specialized medical facilities**

The ventilation systems for specialized medical facilities will have the same operating principles as hospitals in the areas of infection control, air quality, air movement, temperature and humidity, pressure relationships and ventilation. (ASHRAE, 2011). If the specialized medical facility is physically connected to a larger structure, such as an acute-care hospital or medical office building, the specialized medical facility may be served either its own system or by the adjacent building's ventilation and air conditioning unit (ASHRAE, 2011). In either case, the specialized medical facility's system will be similar to those found in acute-care hospitals. However, the size and

capacity of the system may vary (see *Section - Personal and social-care facilities and institutions* above).

Facilities may have local exhaust systems to focus on point sources of contamination, such as dental care where dental drilling uses nitrous oxide that should be vented to a treatment or capture facility before being exhausted to the outdoor environment.

H.4.5 Guidelines

H.4.5.1 Alberta Building Code (ABC)

The Alberta Building Code explicitly follows and acknowledges ASHRAE 62 guideline on “Ventilation for Acceptable Indoor Air Quality” and ASHRAE 55 “Thermal Environmental Conditions for Human Occupancy,” both of which are revised and updated regularly. The reader should refer to the ABC, ASHRAE 62 and ASHRAE 55 for detailed information on ventilation requirements for residential, institutional and commercial business indoor air requirements in Alberta.

H.4.5.2 American Society of Heating, Refrigerating and Air Conditioning Engineers

The leading organization for the development of ventilation standards has been ASHRAE. It has established standards for suggested air velocities and for the supply of outdoor air for institutions, commercial and residential premises. Table H-8 presents air movement standards suggested by ASHRAE.

Table H-6: Air motion

Operative temperature	Upper limit to air speed
> 25.5°C (77.9°F)	0.8 m/s (160 fpm)
22.5°C to 25.5°C (72.5°F to 77.9°F)	= 50.49 - 4.4047 ta + 0.096452(ta) ² (m/s, °C) = 31375.7 - 857.295 ta + 5.86288(ta) ² (fpm, °F)
< 22.5°C (72.5°F)	0.15 m/s (30fpm)

ta = air temperature

Source: Adapted from ASHRAE, *ASHRAE Standard 55-2010; Thermal Environmental Conditions for Human Occupancy*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, Georgia,

One of the most common complaints of building occupants is drafts or unwanted air motion which cools the body. Air motion occurs naturally as cool air sinks and warm air rises. However, fluctuating air velocities are more uncomfortable than a constant velocity and; therefore, efforts should be made to maintain a constant and moderate degree of air motion. Too much air motion leads to cooling and too little can lead to feelings of stuffiness.

Ventilation standards for residential buildings, commercial facilities, schools and other indoor facilities have been developed by ASHRAE. In the following pages, these standards have been presented in different tables (Table H-7 through Table H-10). The reader is also encouraged to refer to ASHRAE 62, “Ventilation for Acceptable Indoor Air Quality,” ASHRAE 170, “Ventilation of Health-Care Facilities,” and ASHRAE 55 “Thermal Environmental Conditions for Human Occupancy,” for further information and for updated information and values.

H.4.5.3 ASHRAE outdoor requirements for building and facilities

The following three tables (Table H-7 through Table H-9) prescribe supply rates of outdoor air required for acceptable indoor air quality in different buildings and facilities. These values have been chosen to control CO₂ and other contaminants with an adequate margin of safety and to account for health variations among people and varied activity levels.

NOTE: These values were current at the time this document was produced. Please refer to the ASHRAE Standard 55-2010; “Thermal Environmental Conditions for Human Occupancy.

Table H-7: Ventilation rates for public facilities

Application	Default occupant density #/1000 ft ² or #/100 m ²	Outdoor air requirements			
		Cfm/ person	L/s xperson	Cfm/ ft ²	L/s x m ²
Educational					
Classrooms (ages 5-8)	25	10	5	0.12	0.6
Classrooms (ages ≥ 9)	35	10	5	0.12	0.6
Laboratories	25	10	5	0.18	0.9
Wood/metal shop	20	10	5	0.18	0.9
Music rooms	35	10	5	0.06	0.3
Multi-use assembly	100	7.5	3.8	0.06	0.3
Computer lab	25	10	5	0.12	0.6
Daycare (ages ≤ 4)	25	10	5	0.18	0.9
Art classroom	20	10	5	0.18	0.9
Public assembly					
Auditorium seating area	150	5	205	0.06	0.3
Places of religious worship	120	5	2.5	0.06	0.3
Libraries	10	5	2.5	0.12	0.6
Lobbies	150	5	2.5	0.06	0.3
Museums (children's)	40	7.5	3.8	0.12	0.6
Museums/gallery	40	7.5	3.8	0.06	0.3
Sports and amusement					
Spectator areas	150	7.5	3.8	0.06	0.3
Gambling casino	120	7.5	3.8	0.18	0.9
Sports arenas (play area) ¹	-	-	-	0.30	1.3
Swimming (pool and deck) ²	-	-	-	0.48	2.4
Gym, Stadium (play area)	30	-	-	0.30	1.5
Ballrooms and discos	100	20	10	0.06	0.3
Bowling alleys (seating areas)	40	10	5	0.12	0.6

¹ When combustion equipment is intended to be used on playing surface, additional dilution ventilation and/or source control shall be provided

² Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.

Source: ASHRAE (2010). ASHRAE 62.1-2010, "Ventilation for Acceptable Indoor Air Quality". American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc. Atlanta, GA

Table H-8: Ventilation rates for residential facilities (single, multi-unit and private dwellings)^a

Applications	Outdoor air requirements				Comments
	Cfm/ Person	Cfm/ Person	Cfm/ Person	Cfm/ Person	
Dwelling Unit	5	2.5	0.06	0.3	Default occupancy = 2 for studio and 1 bedroom apartment + 1 for each additional bedroom Air from one dwelling shall not be recirculated or transferred to any other space outside that dwelling
Common Corridors	-	-	0.06	0.3	

^a In using this table, the outdoor air is assumed to be acceptable.
Note: x denotes multiplication.

Source: ASHRAE (2010). ASHRAE 62.1-2010, "Ventilation for Acceptable Indoor Air Quality". American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc. Atlanta, GA

Table H-9: Ventilation rates for commercial facilities (offices, stores, shops, hotels)

Application	Default occupant density #/1000 ft ² or #/100 m ²	Outdoor air requirements			
		Cfm/ person	L/s x person	Cfm/ft ²	L/s x m ²
Office buildings					
Breakroom	50	5	2.5	0.12	0.6
Office space	5	5	2.5	0.06	0.3
Reception	30	5	2.5	0.06	0.3
Main lobby	10	5	2.5	0.06	0.3
Restaurant dining rooms	70	7.5	3.8	0.18	0.9
Cafeteria/ fast-food dining	100	7.5	3.8	0.18	0.9
Bars	100	7.5	3.8	0.18	0.9
Kitchen (cooking)	20	7.5	3.8	0.12	0.6
Bedroom/living room	10	5	2.5	0.06	0.3
Barracks sleeping area	20	5	2.5	0.06	0.3
Laundry room	10	5	2.5	0.12	0.6
Lobbies/perfunction	30	7.5	3.8	0.06	0.3
Multipurpose assembly	120	5	2.5	0.06	0.3
Sales	15	7.5	3.8	0.12	0.6
Mall common areas	40	7.5	3.8	0.06	0.3
Barbershop	25	7.5	3.8	0.06	0.3
Beauty/nail salon	25	20	10	0.12	0.6
Pet shop (animal areas)	10	7.5	3.8	0.18	0.9
Supermarket	8	7.5	3.8	0.06	0.3
Coin-operated laundry	20	7.5	3.8	0.12	0.6

Source: ASHRAE (2010). ASHRAE 62.1-2010, "Ventilation for Acceptable Indoor Air Quality". American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc. Atlanta, GA

Table H-10: Health-care facilities

Application	Minimum outdoor ACH
Patient rooms	2
Newborn nursery suite	2
Treatment room	2
Operating rooms	4
Recovery and ICU	2
Autopsy rooms	2
Physical therapy	2

Source: ASHRAE (2008). ASHRAE 170-2008, "Ventilation of Health-Care Facilities". American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc. Atlanta, GA

H.4.6 Contamination of HVAC systems

The effectiveness of a ventilation system can be assessed by measuring different IAQ parameters, such as the distribution and concentrations of contaminants, air velocity, air temperature, relative humidity and turbulence intensity (Spengler & Chen, 2000).

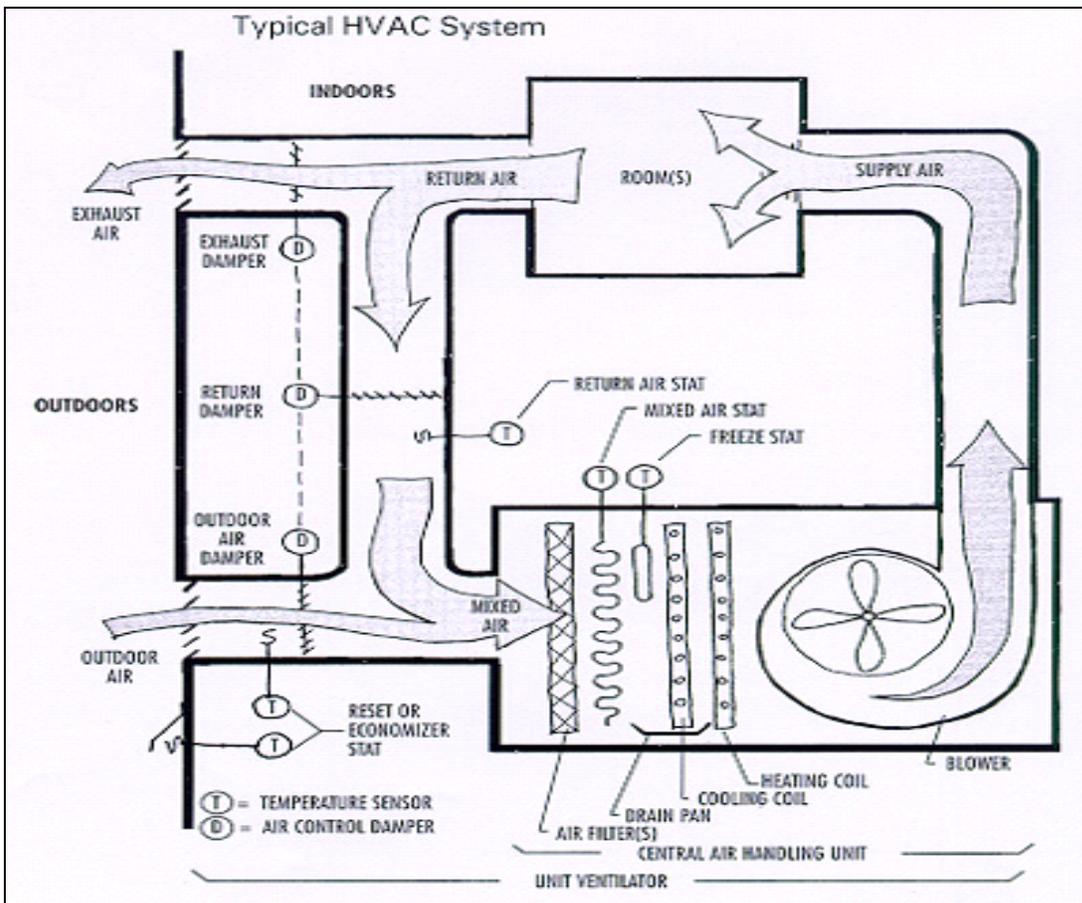
Dust or particulate matter is found in almost every building. HVAC systems can be contaminated with dust. Excessive dusts can accumulate on the filter surface because of infrequent replacement. The duct liner material, if not covered by a smooth impermeable membrane, can collect dusts because of the porosity of the duct surface (Godish, 2000). Figure H-20 shows a typical HVAC system and different components that can be contaminated with dusts and other contaminants. Dust can be generated either indoors or outdoors, and then drawn through ventilation systems or by infiltration.

The composition of house dusts may vary throughout a home as well as between homes, across seasons and in different geographic locations. A limited number of studies have characterized dusts in the indoor environment. Household dusts have been shown to contain synthetic and toxic chemicals (lead, pesticides, PAHs, phenols and phthalates), soil, plant parts, skin, insect and animal parts, and pollens (cited in Liroy *et. al.*, 2002). These dusts can potentially contaminate ventilation systems. Ventilation systems in homes and buildings where smoking is allowed can be severely contaminated with toxic ETS-deposited aerosols.

Contamination of HVAC systems by mould is also associated with dust accumulation and excess moisture. In the presence of moisture near the fan coil units, the liner materials can become contaminated because of mould growth (Godish, 2000).

The HVAC system is very similar to the respiratory system in a human body. It provides conditioned air, which is necessary for the health and comfort of building occupants. HVAC systems are also designed for cooling during warmer months and for heating during winter months. During the cooling cycle, warm air is cooled when it passes through the cooling coil. Excessive moisture in the warm air is condensed into liquid water that falls into a collection pan. HVAC components, such as cooling coils, condensate drainage pans, and adjacent areas are susceptible to moisture influences and hence prone to fungal and bacterial growth (Yang, 1999).

Figure H-20: Schematics of a typical HVAC system



Source: USEPA Indoor Air Quality website 2001 <http://www.epa.gov/iaq/schools/tfs/graphics/hvacsystem.jpg>
 Accessed June 17, 2002

The following moisture-loving species of fungi are common inhabitants of cooling coils and drain pans. Table H-10 presents a list of microbes and microbial materials found in dirty HVAC systems (Yang, 1999).

- *Acremonium spp.*
- *Aureobasidium pullulans*
- *Exophiala spp.*
- Yeasts
- *Phoma spp.*
- *Sporobolomyces spp.*
- *Rhodotorula spp.*

Table H-10: Microbes present in a dirty HVAC system

Microbes	Comments
Legionella pneumophila	A common waterborne bacterium, It can be detected in cooling towers water or the building water system (specifically, hot water). It is known to cause Legionnaire's disease and pontiac fever.
Pseudomonas aeruginosa	A common waterborne bacterium may cause opportunistic infection. It grows in water (both potable and stagnant water)
Cladosporium cladosporiodes	A common colonizer in a dirty HVAC system (downstream from cooling coils), associated with allergies and hypersensitive pneumonitis
Penicillium corylophilum	A common colonizer of a dirty HVAC system, potentially allergenic

Source: Biological Contamination of HVAC system, Yang (1999), P & K Microbiology Services, Inc. Cherry Hill, New Jersey

H.4.7 Maintenance of HVAC systems

The following steps can be taken to address potential and existing biological contamination problems in an HVAC system (Yang, 1999; Health Canada, 1995):

- Maintain and clean the cooling coil and ensure the condensate collection pan drains to a sewer.
- Minimize the conditions and amplifications of biological contaminants by maintaining impervious insulation coverings in the AHUs and the ductwork.
- Eliminate areas of dampness and moisture accumulation.
- Maintain and visually inspect the humidifier at regular intervals.
- Make sure that the outside air intake is placed away from any source of chemical and biological sources of contamination, such as accumulated debris, plumbing stack vents, washroom exhaust grilles, ponded water, street-level loading dock areas and cooling towers. Clean the air intakes at regular intervals to remove litter and dirt.
- Clean the HVAC system when there are signs of microbial growth and heavy dust accumulation. Control dust deposits effectively.
- Set up a preventive maintenance program for all components of the HVAC system.
- Increase the supply of fresh air to the building, if required.
- In case of industrial operations or problematic emissions, extend the stack height at least two metres above the highest level of the roof. Also, consider removing rain caps to improve dispersion.

H.5 Materials concerns

The information presented below is an overview of different building materials and health concerns associated with them. In the following section, a few examples will be discussed from an extensive list of building materials (see Table H-11). For a detailed description of each specific building materials, the reader should refer to the publication by Canada Mortgage and Housing Corporation (CMHC) entitled, *Building Materials for the Environmentally Hypersensitive* (1995, revised 2005). The book lists more than 180 building products and their associated health risks, especially for hypersensitive individuals.

Varying definitions of environmental hypersensitivity

Different organizations and regulatory agencies have provided definitions of “environmental hypersensitivity”. The Canada Mortgage and Housing Corporation’s (CMHC) working definition of “environmental hypersensitivity” is controversial and the subject of a great deal of debate.

As a result, CMHC’s definition of “environmental hypersensitivity” is not endorsed in this manual. The reader is advised to refer to other publications for additional information on “environmental hypersensitivity”

The following excerpt is a summary of CMHC’s (2005) definition of “environmental hypersensitivity”:

Environmental hypersensitivity is a chronic (> three months) multi-system disorder, usually involving the central nervous system and at least one other system.

Environmental Hypersensitivity occurs in a small population subgroup reacting to very low levels of indoor pollutants that normally do not affect the general population. It is characterized by multiple symptoms, which continues for more than three months.

Different building materials are characterized by having different chemical constituents, emissions rates and emission decay rates (CMHC, 2005). The emission rate from different building materials is dependent upon a number of factors including humidity, building temperature and the state of the building material. For example, paints and finishes are short-term emitters whereas particleboard or vinyl-sheet flooring are regarded as long-term emitters. Exposed surface area is also an important factor. Walls, floors and ceiling cover a significant portion of a building and low emissions from these materials can have significant effects on IAQ.

Table H-11: List of materials and their uses in building interiors and exteriors

Building components	Materials used in the interior and exterior environment of a building
Adhesives	Acrylic latex, casein glue, contact cement (solvent and water-based), plastic construction tape, polyvinyl acetate, starch based glue, thick-set mortar, thin-set mortar (acrylic-modified), vinyl tile adhesive, vinyl-sheet flooring adhesive
Barriers: air, vapour, weather and moisture	Airtight drywall, aluminum foil, building paper, plastic construction tape, polyethylene film, spunbonded polyolefin
Building Structure	Composite lumber, concrete, construction plywood panels, fabricated steel sections, fabricated wood trusses, recycled fibreboard, glue-laminated timbers, fibre gypsum board, lightweight galvanized steel studs, oriented strand board panels (waferboard), softwood lumber (S-grn), Primed steel
Cabinets and countertops	Acrylic sheet, formaldehyde free fibreboard, High pressure laminate, particle board and medium density fibreboard (MDF), hardwood plywood, softwood (sanded) plywood, polyester sheet, mineral filled polyester sheet, stainless steel
Caulking and filters	Acoustical sealant, acrylic latex caulking, butyl rubber caulking, dry-mix gypsum joint compound, pre-mix gypsum joint compound, oil and resin based caulking, polyurethane caulking, silicone caulking (acetic acid cure), silicone caulking (neutral cure), water-based caulking
Doors and Windows	Aluminum doors (baked-on enamel), unfinished aluminum doors, fibre-reinforced plastic, gas filled windows, clear and insulated glass, coated and tinted glass, insulated metal doors, polyvinyl chloride doors, screening, baked –on enamel steel, galvanized steel, window spacers, treated wood, untreated softwood, hollow-core wood doors, solid core wood doors
Electrical materials	PVC and steel electrical boxes, metal sheathed cable, vinyl sheathed cable, plastic and metal conduit
Exterior Wall	Clay bricks, high density hardboard, Metal lath, mortar, wood shingles, metal siding, vinyl siding, cement based stucco
Floor	Carpet, glazed ceramic tile, unglazed ceramic tile, concrete, construction plywood panels, dyed and sealed concrete systems, formaldehyde free fibreboard, recycled fibreboard, flagstone, slate, and stone, grout, parquet hardwood flooring, plank or strip hardwood flooring, linoleum, plank or strip softwood flooring, terrazzo, Portland cement system, vinyl composite tile, vinyl-sheet flooring
Foundation	Cement, concrete, concrete admixtures, concrete block, crushed rock, damp-proofing asphalt, damp-proofing cementitious, drain pipe foundation, drain tile, form-release oil, mortar, pressure treated lumber, pressure treated plywood, reinforcing steel
Gaskets and weatherstripping	Magnetic seals, neoprene rubber seals, plastic weatherstrip, PVC gasket, urethane gasket
Insulation	Cellulose fibres, expanded mineral, foamed silicate, Batt glass fibre, board glass fibre, loose glass fibre, mineral fibre, expanded polystyrene foam board, extruded polystyrene foam board, polyurethane foam board, one part polyurethane foam
Interior wall and ceiling	Acoustical ceiling tiles, cement backer board, cement bonded particle board, unglazed and glazed ceramic tile, gypsum board, fibre gypsum board, gypsum lath, gypsum veener plaster base, hardwood strip panelling, high-density hardboard, metal lath, mortar, lime and gypsum plaster, veener plaster, softwood strip panelling, baked-on enamel steel, wall coverings, wood lath
Miscellaneous mechanical Systems	Radiant heating system (electric and hot water tubing), galvanized steel
Paints, sealers, coatings	Water-based acrylic sealer, beeswax, carnauba wax, traditional solvent lacquer, European type (non-acid curing) oil finish, alkyd paint, latex paint, other environmental choice paint, low toxicity water-based paint, natural oil-based paint, solvent based sanding sealer, shellac, solvent type silicone sealer (5%), one part or two part water-based urethane
Plumbing	ABS pipe, acrylic bath fixtures, cast iron & steel plumbing fixtures, copper pipe, fibre-reinforced plastics, mineral-filled polyester fixtures,
Roof	Aluminum roofing, concrete tile, membrane roofing, modified asphalt torch-on roofing, asphalt shingles, glass fibre shingles, wood shingles, slate, baked-on enamel steel, galvanized steel, tar and gravel

Source: Canada Mortgage and Housing Corporation (CMHC). Building Materials For the Environmentally Hypersensitive, (1995, revised 2005). All rights reserved. Reproduced with the consent of CMHC. All other uses and reproductions of this material are expressly prohibited.

The following specific building materials will be discussed briefly. The reader should investigate further for additional information on these materials and other building materials.

- Carpets
- Vinyl flooring
 - Vinyl-sheet flooring
 - Vinyl tiles
- Hardwood flooring (parquet, and planks or strip)
- Paint
- Plywood
 - Softwood plywood
 - Hardwood plywood
- Particle board and medium density fibreboard (MDF)

H.5.1 Carpets

Carpet is a textile floor covering which woven, needle-punched, or felted from natural or synthetic fibres (CMHC, 2005). The health effects attributed to the emission of indoor air contaminants from newly installed carpets have been a public health concern for decades. As a consequence, carpets have been the focus of government and industry research, media attention, and the keen interest of the general consumer.

There are known to be a large number of chemical gases and vapours that can be emitted by carpets. Carpets emit a variety of volatile organic compounds (VOCs) including styrene, acetone, cyclopentadienes, methylcyclopentane, n-octane, n-undecane, n-dodecane, toluene, xylene, a variety of benzene derivatives and many others. The most noticeable VOC emitted by carpets is 4-phenylcyclohexene (4-PCH), which causes the “new carpet” smell. 4-PCH is a byproduct of the styrene-butadiene latex adhesive used to glue the tufted yarn onto a backing, which is either polypropylene or jute. The tufted yarn and the backing constitute “carpet” (cited in Calgary Health Region, 1993). The tufted yarn, carpet backing and adhesives used to glue the two items together are not the only sources of pollutants associated with carpets.

Other sources of pollutants include (Cutter Information Corporation, 1991):

- Carpet adhesives
- Carpet fibres
- Carpet dyes
- Topical treatments, such as:
 - Fire retardants
 - Fungicides
 - Soil-resistant chemicals

The products that are used to manufacture carpet may contain formaldehyde polymers (N.C. Department of Labor, 2009) and carpets may act as a “sink” for formaldehyde and other contaminants, both biological and chemical, such as VOCs and SVOCs. Carpets not only absorb contaminants from the air but also those that have been tracked into the home or spilled (Cutter Information Corporation, 1991; Godish, 2000). Biological and chemical pollutants found in carpets can include mites, fungi, bacteria (Godish, 2000; Cutter Information Corporation, 1991), lead and pesticides (DDT and chlordane (Cutter Information Corporation, 1991). The sorption of organic compounds in carpet fibres and subsequent re-emission can greatly affect the concentrations of indoor air contaminants. Research suggests that the VOCs sorbed and re-emitted from carpets can cause eye, nose and throat irritation, headache and lethargy, which are symptoms and characteristics of sick

building syndrome (SBS) (Cutter Information Corporation, 1991). Additional reported symptoms can include rashes, hives, itching and swelling of the skin. For a detailed discussion on sorption and desorption of VOCs, the reader should refer to *Appendix A.2 Vapours (volatiles and semi-volatiles)*.

Research shows that VOC emissions from carpet, glue and cushions can be affected by several variables, including (Cutter Information Corporation, 1991):

- Levels of VOCs within the adhesive
- VOC emission rate of adhesive and cushion following installation
- Emission rate decay curve over time
- Ambient temperature
- Permeability of the floor material to each of the VOCs present in, and released by the adhesive and cushion
- Relative humidity

The majority of carpet- and cushion-related health effects have been linked to styrene-butadiene latex backings and the adhesives used in the installation of carpets. Carpet adhesives are important sources of VOCs, specifically during and immediately following carpet installation (Cutter Information Corporation, 1991). Generally, new carpet "off-gases" within the first 48 hours to 72 hours following installation. Studies have found that there are a wide variety of SVOCs emitted from carpet and carpet-related products, including 4-phenylclohexene, dichlorobenzene, triethyl phosphate and bis(2-ethylhexyl)phthalate (Pleil & Whiton, 1990)

The Carpet and Rug Institute (CRI) has provided voluntary standards for carpet emissions. Carpet manufacturers can adopt these standards. Table H-12 presents emission criteria for carpets and its accessories (Coughlan, 2001).

Table H-13: Emission criteria for carpets and adhesives published by the Carpet and Rug Institute (CRI)

Target compounds	24 Hours	
	Maximum emission factor (EF) (µg/m ² -hr)	
	Carpet	Adhesive
Acetaldehyde	130	130
Benzene	55	-
Benzothiazole	-	30
Caprolactam	130	-
2-Ethyl-1-Hexanol	-	300
2-Ethylhexanoic Acid	46	-
Formaldehyde	16	16
Isooctylacrylate	-	690
Methyl biphenyl	-	95
1-Methyl-2-pyrrolidinone	300	300
Naphthalene	8.2	8.2
Nonanal	24	-
Octanal	13	-
Phenol	-	190
4-Phenylcyclohexene	50	50
Styrene	410	410
Toluene	280	280
Vinyl Acetate	190	190
Vinyl cyclohexene	-	85
Xylenes (m-, o-, p-)	-	650
TVOC	-	8000

Source: Carpet and Rug Institute (2012). "CRI Green Label Plus™ Carpet Program - CARPET EMISSIONS TEST CRITERIA". Carpet and Rug Institute website: <http://www.carpet-rug.org/commercial-customers/green-building-and-the-environment/green-label-plus/carpet-and-adhesive.cfm>

H.5.1.1 Recommendations for control measures

The following control measures can be put in place to reduce or eliminate emissions from carpet materials (cited in Calgary Health Region, 1993).

- Building ventilation rates should comply with ASHRAE guidelines. During the carpet installation process and for the following 48 to 72 hours, the ventilation system should be operated at maximum fan speed and optimized to exhaust as much return air as possible.
- Where possible, use woven area rugs that do not have a backing. Area rugs are generally made with wool or cotton using no adhesives and are regarded as being safer than wall-to-wall broadloom. However, area rugs are more expensive than broadloom.
- Remember the best time to buy and install wall-to-wall carpet for IAQ purposes is during the summer months when windows and doors can be opened.
- Try to purchase carpet that has already been aired for several weeks by having been unrolled in a well-ventilated area. In addition, during the installation process, keep

windows and doors open to air out the premises. For commercial buildings, ensure maximum operation of the ventilation system, with 100 per cent exhaust and no recirculation, if possible.

- People who suffer from “chemical sensitivity” or asthma should obtain a fresh sample of carpet from the carpet roll they intend to purchase. Then they should take it home and sleep near it for approximately one week. If there is a bothersome odour from the sample, the carpet should not be purchased.
- Avoid getting carpets wet for a maximum three days, as carpets can support bacterial and fungal growth.
- When carpet is initially installed in a residential premise, an individual, or family, may be plagued by a variety of upper respiratory symptoms. These symptoms can be expected to resolve themselves within three-to-six months, since the VOCs present in carpet decrease rapidly with time. Consequently, the best control measure for such a short time period is to provide increased air exchange rates by maintaining continuous ventilation by opening doors and windows, and through a ventilation system.
- The “environmentally hypersensitive” (sensitive or vulnerable) individuals should avoid using carpets. Alternative materials, such as area rugs, hard wood flooring, ceramic tile or stone, may be more appropriate. For area rugs, select natural fibres, if appropriate, without any chemical treatment and horizontally woven carpet, which are less tightly woven and less likely to hold dirt (CMHC, 2005).
- Use nail strips as an alternative to carpet glues (CMHC, 2005).
- Area rugs can be more easily cleaned than carpets (CMHC, 2005).

Source: A letter dated January 9, 1990, from Krista Keimel, CBC, “Market Place” to Pam Moore, Indoor Air Quality Consultant, Alberta health, filed in divisional records (cited in Calgary Health Region, 1993)

H.5.1.2 Recommendations from USEPA (1995)

When purchasing or installing a new carpet, take the following steps to ensure safe selection, handling and installation:

- Ask for information on carpet emissions when talking to the carpet dealer.
- Ask the retailer to unroll and expose the carpet to the air in a ventilated area.
- Use low toxicity adhesives, if required.
- If possible, leave the area during and after the installation of the carpet.
- Ask the installer to follow the Carpet and Rug Institute’s installation guidelines.
- Ventilate the indoor space where the new carpet is being installed.
- Contact the carpet dealer if you feel there is an objectionable odour from the carpet.
- Always follow manufacturer’s carpet maintenance instructions.

H.5.2 Vinyl flooring

In this sub section, the following two types of vinyl materials are discussed.

- Vinyl-sheet flooring
- Vinyl tiles

H.5.2.1 Vinyl-sheet flooring

Vinyl-sheet flooring is produced by layering PVC resin over a backing material. The backing materials can be paper or foamed plastics. To impart flexibility to these flooring materials, plasticizers are added to the resin. Other additives, such as fungicides, are also added to inhibit growth of fungus and other microbes. To maintain vinyl floors, various maintenance cleaners and waxes are used (CMHC, 2005). The following box lists the different components of vinyl-sheet flooring.

Components of vinyl-sheet Flooring

- Polyvinyl chloride
- Plasticizers
- Coatings (Urethanes)
- Backings (natural and synthetic textile fibres)
- Glues

• Source of emissions and health concerns associated with vinyl-sheet flooring

Several VOCs are emitted from vinyl flooring; primary emissions from vinyl flooring materials are n-tridecane and phenol. The associated materials of vinyl flooring, such as seam sealers, emit tetrahydrofuran and cyclohexanone. The adhesives used in the vinyl flooring materials emit toluene (Hodgson, 1998, cited in Wallace, 2001).

Vinyl-sheet flooring has significantly higher PVC content than vinyl tiles. The odours from older vinyl-sheet flooring may be a result of the slow degradation of the PVC polymer. Strong odours that are associated with new vinyl flooring sheets can affect various sensitive individuals. The slow degradation and off-gassing of PVC polymer can also affect the health of some individuals. As a consequence, Canada Mortgage Housing Corporation has not recommended using this product (CMHC, 2005).

H.5.2.2 Vinyl tiles

Vinyl tiles are made from PVC resins, generally by injection moulding or dispersion coating. There are two types of vinyl tiles:

- Homogenous vinyl tile
- Vinyl composition tile

Homogenous vinyl tile contains a higher proportion of PVC resins to fillers than vinyl composition tile (15% PVC + 85% calcium carbonate). Calcium carbonate acts as inert fillers for vinyl composition tiles. Usually, plasticizers are not needed for vinyl tiles.

However, in some instances, they are used in quantities much smaller than in homogenous vinyl tile or vinyl-sheet flooring. The adhesives that are used for installation of vinyl tiles may be a source of off-gassing VOCs.

CMHC recommends use of vinyl composition tiles with the lowest possible PVC content and odour. Vinyl composition tiles are less odourous than vinyl-sheet flooring (CMHC, 2005).

H.5.3 Hardwood flooring

There are various types of hardwood flooring available. In the following sub-sections, they are discussed under parquet, and plank or strip hardwood flooring.

H.5.3.1 Types of hardwood flooring

- **Parquet**

Parquet flooring is a composite or laminate of small hardwood strips that are typically glued together. Some parquet flooring consists of veneer hardwood bonded to a plywood base. This flooring material is available in both finished and unfinished forms. In case of unfinished products, sanding is required. For finished parquet flooring, urethane, acrylic or Swedish oil is used as a surface coating (CMHC, 2005).

- **Emission sources and health concerns associated with parquet flooring**

Volatile chemicals are emitted from various components, such as adhesives, sealers and finishes, that are associated with parquet flooring. With larger floor areas, the emissions of VOCs from these flooring materials will also increase. Sanding of unfinished parquet flooring can be an important source of dusts that may irritate individuals (CMHC, 2005).

- **Recommendations from CMHC**

Parquet is only one component of the whole flooring system to be considered.

- Test additional components, such as subflooring material, adhesives and different parquet suppliers including various wood types, glues and finishing products to determine individual tolerance levels before installation.
 - Use low-toxicity glues and adhesives.
 - Conduct personal exposure testing.

- **Plank or strip hardwood flooring**

Plank or strip hardwood flooring consists of ¾ in.-deep solid wood of varying widths. Laminated hardwood is a thinner flooring type with a thickness of 3/8 in., typically made of three layers of wood. Veneer hardwoods on a composite wood base have the appearance of plank flooring. Because of their laminated construction, veneer hardwood can off-gas VOCs and may be a significant concern. The use of solid wood floors avoids the off-gassing concerns of synthetic laminates.

All hardwood flooring, regardless of the type is usually nailed or glued onto the subfloor. Based on the recommendations of CMHC, hardwood flooring is considered a good floor system provided all the materials are chosen carefully. Additional verification should be completed to ensure that the plank flooring is not veneer. The following box presents a rule-of-thumb of the flooring system classification.



- **Particle board and medium density fibreboard (MDF)**

Particleboard and MDF are made from softwood. Particleboard is produced by using chips and shavings in a dry process, whereas, MDF is manufactured from milled fine particles using a wet process (CMHC, 2005).

- **Emission sources and health issues**

Urea formaldehyde (UF) resin is used in the manufacturing process of particleboard and MDF. UF resin is less stable to moisture and consequently, in the presence of water or high moisture, UF resin undergoes hydrolysis that results in the production of formaldehyde. However, even in normal dry use, particleboard and MDF can emit wood terpenes, formaldehyde and other VOCs. MDF and particleboard were shown to emit higher amount of formaldehyde than other building materials (Table H-13). During the manufacturing and installation process at construction sites, dusts and gases are also produced from cutting, shaping and sanding activities associated with these building materials.

There are several alternatives to particleboard and MDF. Solid hardwood is the best alternative. Softwood plywood is the second best option. Of course, formaldehyde-free fibre and particleboards are available; however, these products may contain isocyanates, which may also be a health concern.

CMHC has recommended sealing all the exposed surfaces and edges of particleboard by applying a water-based acrylic sealer. Acrylic sealers can be slightly odorous and irritating; however, they generally have very low emission rates and their application also reduce terpene emission from softwoods and formaldehyde emissions from other composite wood products (CMHC, 2005).

H.5.4 Plywood

H.5.4.1 Softwood plywood

Sanded softwood plywood is typically used for structural purposes, such as form a subfloor. It is also used as a base for high quality furniture and cabinets (CMHC, 2005). Currently, all sanded softwood plywood is made with phenol-formaldehyde resin adhesives is much more stable to moisture than urea formaldehyde resin-based products. In addition, phenol formaldehyde is a lower emitter of formaldehyde than urea formaldehyde when properly cured. Airborne dust generated from cutting plywood containing formaldehyde-based resin and adhesives can be a respiratory irritant (CMHC, 2005) but there are several formaldehyde-free and environmentally friendly alternatives to softwood plywood.

H.5.4.2 Hardwood plywood

Hardwood plywood comprises hardwood veneers that are bonded to a core consisting of cross-ply veneers, or a composite of particleboard or fibreboard. They are all glued together to form wooden panels. Hardwood plywood is used for cabinets, door frames and furniture. UF resin is most commonly used as the bonding adhesive (CMHC, 2005).

During cutting, the airborne dusts generated from hardwood plywood can act as respiratory irritants. Also, wood terpenes and emissions, such as formaldehyde from UF resin can be released during cutting. The excessive heat produced by the cutting process helps release these chemicals into the indoor air. The following box presents the different components of hardwood plywood.

Components of vinyl-sheet Flooring

- Oak, maple, birch for facings
- Veneer plywood
- Particle board or medium density fibreboard
- Solid wood for core
- Urea-formaldehyde resin

After installation, hardwood plywood can off-gas formaldehyde. The emission rate is dependent upon moisture content and relative humidity of the air. Because of the resin’s sensitivity to dampness or water contact, UF-bonded wood products are intended for use indoors. Historically, UF-based adhesives were formulated with high formaldehyde-to-urea ratios (Formaldehyde: Urea = 1.5:1). As a result, formaldehyde emissions from UF-based adhesives were 1000 times greater than PF-bonded products (Godish, 2000).

Table H-13 is a comparative account of formaldehyde emissions from construction materials and other products.

Table H-13: Formaldehyde emissions from different construction and consumer products

Product	Emission rate (ug/m2/day)
Hardwood plywood panelling	1500 – 34,000
Softwood plywood	240 – 720
Particle board	2000 – 25,000
Medium-density fibreboard	17,600 – 55,000
UFFI	1200 – 19,200
Fibreglass products	400 – 470
Paper products	260 – 280
Clothing	35 – 570

Source: Modified and adapted from Indoor Environmental Quality, Thad Godish (2000), Lewis Publishers, 2001. Original data extracted from: Pickerell, J.A., et al., Environ. Sci. Tech., 17, 753, 1983; Matthews, T.G., CPSC-LAG-84-1103, Consumer Products Safety Commission, Washington, D.C., 1984; and Grot, R.A. et al., NIBSIR 85-3225, National Bureau of Standards, Washington, D.C., 1985

The reader can compare the emission rates from different construction materials and consumer products. Because of various health issues associated with UF, they are no longer being used in high concentrations in wood products.

- **Emission sources and health issues**

The adhesives used in plywood have become a concern. Both urea formaldehyde and phenol formaldehyde can be used in the manufacture of the various types of plywood and have health concerns, such as being carcinogenic and being associated with their off-gassing. As a result, many manufacturers are turning to low formaldehyde-emitting glue systems denoted by an "E" rating; with "E0" meaning zero formaldehyde emissions (Engineered Wood Products Association of Australia, 2007).

- **Recommendations**

CMHC recommends consumers select composite wood products made with more stable glues. In addition, surface treatment of wood with water-based acrylic sealers can help reduce formaldehyde emission rates. Water-based sealers are also effective in reducing terpene emissions from softwoods as well as formaldehyde emissions from composite wood products (CMHC, 2005). Preferred alternatives to composite wood products include solid wood, ceramics and stone.

H.5.5 Paints

Although paint enhances building interior aesthetics and protects various surfaces from damage and chemicals such as VOCs, the particulates and dusts released from paint application, curing or removal can nevertheless contaminate indoor air and present a health concern. Indoor air quality concerns from paints primarily are related to VOC emissions. Even low VOC emissions from paints doesn't guarantee a safe indoor environment because some chemicals are toxic at very low levels. Various toxic ingredients in paint and other paint-related materials, such as paint strippers, primers and thinners, present health and comfort problems in indoor settings because of the aerosolization and volatilization during and sometimes after paint application. In addition, exposure to dusts and particulates generated from mechanical disturbances of the cured materials can be responsible for health complaints and compromised indoor air quality (Jacobs, 1994). Other paint-related products, such as sealers and coating agents, can also contribute to poor indoor air quality. Toxic solvent vapours and paint additives can also cause health problems.

On the other hand, paints can improve indoor air quality by inhibiting growth of certain microorganisms on unpainted surfaces. Paints and sealers can also be used to seal different building materials to reduce off-gassing of emissions (CMHC, 2005).

There are different categories of paint based on the solvent system used to suspend pigments and additives (Pergament, 1995). In this subsection, a brief discussion is provided for latex and alkyd paints only. Generally, latex-based paints have lower VOC contents than alkyd.

- Latex paints contain emulsions of polyvinyl acetate or acrylic resins thinned by water.
- Alkyd or oil-based paint contains an alkyd resin or oil varnishes thinned by mineral spirits

H.5.5.1 Latex paint

Water-based or latex paints consist of a variety of chemicals, such as glycols dispersed in water (Murray, 2000). However, sometimes organic solvents are added in small quantities to improve the overall quality of the paint. Glycol ether solvents are commonly used in latex paints. Ethylene glycol ethers are toxic and are gradually being substituted for less toxic solvents, such as propylene glycol ethers. The concentration of organic solvents is significantly less in latex paints than alkyd or oil-based paints. Therefore, latex paint is the paint of choice and the paint most used in homes.

Conventional organic solvent-based paints can contain up to 50% of petroleum based solvents, whereas, conventional water-based paints contain only 7% (Dulux, 1997, cited in Murray, 2000). Murray (2000) reported the indoor TVOC concentrations for six water soluble paints including: pure acrylic paint, acrylic undercoat, interior wall paint, satin acrylic, low sheen acrylic and primer sealer undercoat increased to a maximum value within three hours of application and then decreased to 3.6% to 49% of the maximum within 24 hours. The maximum TVOC concentrations ranged from 1.06 mg/m³ (interior wall paint) to 3.32 mg/m³ (satin acrylic paint). Emission rates of these six water-soluble paints decreased by 60% to 100% of their peak values within 24 hours of application. Maximum emission rates ranged from 3.9 mg/m²h. to 136 mg/m²h. Although the interior wall paint had the highest maximum emission rate at the beginning, the emission rate decreased to 0.09% from the peak value within 24 hours of the paint application (Murray, 2000). Two different air exchange rates (0.885 and 4.42 air exchange per hour) were used in the measurement of TVOCs concentrations from water-soluble paints.

Latex paint may also contain mercury which because of its high toxicity to bacteria and fungi, is added as a preservative during the production process. The mercurial compound most commonly found in paints is phenyl mercuric acetate (PMA). The presence of mercury compounds in water-based paint is not always shown on the label of the paint container. The following chemicals are less often used in paints as mercurial additives (Etzel & Agocs 1990); however, under federal government regulations, the Canadian Surface Coating Materials Regulations (SOR/2005-109), surface coatings including paints must not contain more than 10 mg/kg total mercury.

- Di(phenylmercuric)dodeceny succinate
- Phenylmercuric oleate
- Phenyl mercuric benzoate
- Phenylmercuric propionate

H.5.5.2 Alkyd or oil-based paint

Alkyd or oil-based paints contain fungicides, pesticides, preservatives, foam-control agents, acrylic resins, isocyanates and formaldehyde, which can evaporate over time into the air (Livos, 1996, cited in Murray, 2000). Solvents and driers in alkyd paint can be highly irritating and neurotoxic. Therefore, good ventilation is necessary when alkyd paint is applied on building interiors. The curing process of alkyd paint is slow but the paint is very stable when cured (CMHC, 2005).

In an experimental chamber study, Murray (2000) measured indoor TVOC concentrations and emission rates of different alkyd (oil-based) paints and compared them with natural oil-based and water-based paints. Two different air exchange rates (0.885 and 4.42 air changes per hour) were used in the measurement of TVOCs concentrations. The TVOC concentration for an organic solvent soluble paint, such as enamel undercoat, decreased with

an increase in the air exchange rate. The organic solvent-based paints, such as satin enamel, gloss enamel and enamel undercoat, had indoor TVOC concentrations that increased to a maximum value within two hours of application and then decreased rapidly to less than one per cent of the maximum value within 24 hours. The maximum indoor TVOC concentrations for organic solvent paints ranged from 104 mg/m³ to 262 mg/m³. For natural oil-based paints (natural oil paint, natural oil pre-coat and natural oil wall paint), the TVOC concentrations increased to a maximum value within three hours of application and then decreased to 7.4% to 22% of the maximum within 24 hours. The maximum TVOC concentrations for natural oil-based paint ranged from 0.17 mg/m³ to 109 mg/m³. For the synthetic organic solvent paints, the gloss enamel had the highest maximum TVOC concentration (262 mg/m³) and natural oil solvent paints had the lowest (0.17 mg/m³). As expected, the TVOC concentration for all paints decreased with an increase in the air exchange rate.

The emission rates for the six organic solvent paints reached their peak soon after application and then decreased rapidly and approached the non-detectable range. Maximum emission rates ranged from 1.38 mg/m²h. to 3,663 mg/m²h. The satin enamel had the highest maximum emission rate (3,663 mg/m²/h), whereas, the natural oil wall paint had the lowest rate. Emission rates for the six organic solvent-soluble paints decreased from 84.2% to about 100% within 24 hours after application (Murray, 2000).

Alkyd paints contain an alkyd resin or oil varnishes. Varnishes, which are commonly used for kitchen cabinets contain cross-linking agents, such as formaldehyde and other VOCs. In one experimental chamber test, the bulk of VOCs, such as xylene, were emitted from oil varnishes within a few hours after application. However, the formaldehyde decayed at a much slower rate, with a concentration of 0.3 mg/m³ measured at 2,800 hours after application. The exposure chamber was operating at 0.5 air changes per hour. The slow emission of formaldehyde can be a concern since kitchen cabinets are typically installed in homes towards the end of the home building project at least 30 days after manufacture (McCrillis *et al.*, 1999). Other researchers involved in chamber tests have reported that the free formaldehyde in conversion varnishes is responsible for just a fraction of the total amount of airborne formaldehyde. Howard *et al.* (1998) reported that formaldehyde was formed as a result of unidentified curing reactions. In that chamber test, an emission rate of 0.17 mg/m²/hour at 115th day was recorded for formaldehyde. Such long-term emissions have the potential to create elevated concentrations of formaldehyde in indoor environments (Howard *et al.*, 1998).

In another study, Fortmann *et al.* (1998) reported that over 90 per cent of the VOCs in interior alkyd paint were emitted during the first 10 hours following application of paints. The peak concentration of TVOCs was reported at 10,000 mg/m³ at 0.5 air exchanges per hour (ACH). They also reported that nearly all the VOCs were recovered during a two week emissions test. This finding was in sharp contrast to a previous study on latex paints, where it was reported that during a two-week period following application to gypsum board, only approximately 20 per cent of the oxygenated solvents were recovered, suggesting a potential for exposure over an extended period of time.

Jacobs (1994) compared emission rates, over time, of TVOCs from interior latex wall paints to that of interior alkyd wall paints. Generally, TVOC emissions from alkyd paints were much higher than latex paints. The TVOC emission rates from the alkyd paints decreased from 600 mg/m².hr (approximate peak concentration) to less than 5 mg/m².hr within 24

hours of the initial application, whereas, the rates for the latex paints decreased from 95 mg/m².hour (approximate peak concentration) to less than 1 mg/m².hr (Jacobs, 1994).

H.5.5.3 Paint alternatives

Several manufacturers are now providing alternatives to conventional paints. They generally fall into one of four categories:

- **Low VOC:**

To qualify for low-VOC status, paints and stains must be below the criteria set out in the Canadian Volatile Organic Compound (VOC) Concentration Limits for Architectural Coatings Regulations (SOR/2009-197). It is easier to achieve these VOC concentrations with latex paints than oil-based paints. Because low-VOC paints may still emit an odour until they dry, particularly sensitive individuals may wish to consider zero VOC or natural paints. Additionally, it is important to note that VOC levels vary considerably among low-VOC paints, because pigments add some VOCs and toxins to the base paint.

- **Zero VOC**

Considered the most appropriate paint for people with chemical sensitivities, children and those with compromised immune systems, zero-VOC paints are not allowed to contain more than five grams of VOCs per litre. Limited to latex paints, some manufacturers may claim "Zero-VOC" status for their base paints, but still use colourants, biocides and fungicides that contain VOCs. Like low VOCs, adding pigment will generally raise VOC levels.

- **Natural-made**

These paints are made primarily from renewable or abundantly occurring natural materials, such as citrus oil, lime, clay, linseed oil and even powdered casein (milk protein). Natural paints are considered the healthiest and most environmentally sound. Because natural paints do not contain petroleum products, they emit few, if any, of the VOCs regulated by current paint standards. While generally well tolerated, some natural oil-based products contain significant amounts of other VOCs from ingredients, such as citrus-based solvents.

- **Recycled**

While unlikely to be low VOC paints, recycled latex paint has its appeal for those who are not bothered by conventional paints, but rather want to make environmentally friendlier choices.

H.5.5.4 Health effects

High-level exposure to organic solvents in paints has been associated with an increased rate of miscarriage. Several studies have reported an association between exposure to paint during pregnancy and an increased risk for birth defects (Pergament, 1995; Canadian Centre for Occupational Health and Safety, 2008).

Paint solvents can affect people with heart conditions and individuals who wear contact lenses. Certain paint solvents, such as methanol, can stress the heart. Contact lenses can absorb solvent vapours from paints and hold them against the eye, resulting in irritation or eye damage (Faelten, 1988, cited in Calgary Health Region, 1993). For more information on the health effects of specific VOCs, refer to *Appendix A.2 – Vapours (volatiles and semi-volatiles)*.

H.5.5.5 Recommendations for control measures

- Ensure that the lids and caps of all paint cans and solvent containers are tightly sealed. If possible, store them in a paint cabinet with exhaust ventilation to control VOCs (Calgary Health Region, 1993).
- Avoid spray painting, if possible.
- As some latex paints also contain solvents, read labels or obtain information regarding the solvent content and make use of products that with low VOC contents (Calgary Health Region, 1993).
- Ventilate thoroughly during painting and, if required, during the primary curing period. If necessary, use portable exhaust fans with flex ducting to carry exhaust to an outside location (Calgary Health Region, 1993).
- Many latex paints appear to be dry after several hours, but most paints may continue to release harmful vapours for several days after application. Therefore, ventilation should continue for at least 48 hours, and preferably 72 hours (Montgomery County Department of Environmental Protection, 2002).
- Several VOCs from alkyd paints can be released through off-gassing. Vapour concentrations in a painted room can be reduced by setting box fans in a window blowing outward (Montgomery County Department of Environmental Protection, 2002). Ventilation will help painted surfaces dry faster (Montgomery County Department of Environmental Protection, 2002).
- Proper ventilation also prevents solvent vapours from settling into clothes, carpets, ceiling tiles, upholstery and other surfaces (Montgomery County Department of Environmental Protection, 2002).
- To reduce risks to a developing fetus, pregnant women should take following precautions:
 - Keep away from all areas being painting. But if exposure is unavoidable, keep it to a minimum.
 - If paint exposure is unavoidable, wear protective clothing, including gloves and masks
 - Effectively ventilate the workplace to reduce exposure to paint vapours.

- Complete home painting projects before conception.
- If removing old paint, determine ahead of time if the paint is lead-free or not.
- Avoid paints containing solvents, such as ethylene glycol ethers and biocides.

H.5.5.5.1 Recommendations from United States Environmental Protection Agency (USEPA, 2000)

- Schedule painting in the dry, warm months of the summer, fall or spring when windows can be left open for ventilation.
- Keep windows wide open for about two to three days after painting so that building occupants can avoid unnecessary exposures to paint vapours.
- Use window-mounted box fans to exhaust out vapours from indoor areas. If a fan is not available, make sure the areas have necessary cross ventilation. Use portable exhaust fans with flex ducting as required.
- Some chemicals from paints have been reported to cause cancer or reproductive and developmental effects in laboratory animals. Because of these concerns, susceptible individuals including young children, pregnant women and individuals with breathing problems should avoid exposure to paint vapors.
- Pregnant women should avoid undertaking painting projects and should limit their time in freshly painted rooms to avoid any health risks for themselves and their unborn babies, especially when oil-based paints are being used.

For a detailed list of recommendations from USEPA on healthy painting practices, the reader should refer to the following website: <http://www.epa.gov/iaq/homes/hip-painting.html>.

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Appendix I

IAQ questionnaires

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I. IAQ investigation questionnaires

I.1 Introduction

This chapter includes three questionnaires that can assist the public health officer investigating an indoor air quality problem.

- IAQ telephone interview questionnaire
- The IAQ investigation onsite occupant interview questionnaire
- The IAQ investigation onsite walk-through questionnaire

I.2 IAQ Investigation telephone Interview questionnaire

The purpose of the telephone interview questionnaire is to gather information about the IAQ problem facing the complainant, and about the building and environment that the complainant is concerned about. The content of this questionnaire is based on ASTM D7297-06- Standard Practice for Evaluating Residential Indoor Air Quality (2006), and AHS-EPH DSOP IAQ - Indoor Air Quality (2012 in development).

Some or all of the questionnaires and questions for interviewing and onsite investigation may be completed based on the assessment and judgment of the investigating public health inspector.

If during the course of the investigation, a hypothesis is developed or source or cause is identified, then the interview can be terminated. If the problem remains following remedial actions, then the interview can resume.

I.2.1 Address and contact information

Questionnaire #: _____ Date: _____ Time: _____ a.m./p.m.

Name of occupant(s): _____

Address: _____

City or town _____ Postal code: _____

Home phone #: _____ Work phone:: _____

Recorder's name _____

I.2.2 Nature and history of problem

1. Please describe the problem you are experiencing.

2. When did you first notice the problem?

3. Is the problem specific to one area of the building? If so, where?

4. Are there any noticeable odours? If so, describe them.

5. Is the problem constant or intermittent?

I.2.3 Health status

1. Please describe any background medical conditions (e.g. asthma, respiratory disease, etc)?
Are there any sensitive/vulnerable individuals?

2. Who is affected? What symptoms? Onset of symptoms?

3. Is anyone in the premise unaffected?

4. Has a physician been consulted about the symptoms of the affected individuals?

Yes No

5. If yes, please provide the physician's contact info.

I.2.4 Building or facility characteristics

1. Number of users of the building? _____ Number of occupants in the suite? _____

Provide *the* exact number if possible:

2 or less 2 to 5 5 to 10 10 to 15 15 to 20 20 or more

2. Ages of occupants

Provide exact ages if possible:

Infants (0 to 6 months), toddlers (7 months to 4 years),
 child (5 years to 11 years), teen (12 – 19 years)
 adults (20 years to 65 years) senior (65+ years)

I.2.5 Possible contaminant sources

1. Has the premise been renovated or remodeled?

Yes No

2. If yes, please indicate:

When? _____

What was done? _____

-

- Did you notice
the problems prior? _____
3. Describe outdoor influences nearby:

4. Describe indoor activities:

5. Has any new furniture been introduced to the affected area?
 Yes No,
6. If yes, please indicate:
When? _____
What was introduced? _____
Did you notice the problems prior? _____
7. Has the premise been redecorated?
 Yes No
8. If yes, please indicate:
When? _____
What was done? _____
Did you notice the problems prior? _____
9. Please describe the nature, frequency and duration of any odours and if they coincide with symptoms:

10. Do signs and symptoms disappear when you leave your premise?
 Yes No

I.2.6 Building information

1. Which of the following best describes the building?

- Single-family house (number of bedrooms): _____
- Duplex or row-house (number of bedrooms): _____
- High-rise apartment complex (number of stories): _____
- Low-rise apartment complex (number of stories): _____
- Mobile/modular home or trailer (number of bedrooms): _____
- Office building (number of stories): _____
- Public facility (indicate type of facility)

- Institution (indicate type of institution)

- Commercial facility (indicate type of facility)

- School (indicate primary, junior high, high school, college or university)
- a recreational facility (indicate type of facility)

- Personal social care facility (indicate type of facility)

- Specialized medical facility (indicate type of facility)

2. When was the building constructed?

Indicate year if known _____

- 2010 or newer 2009 to 2000 1999 to 1990
- 1989 to 1980 1979 to 1970 1969 to 1960
- 1959 to 1950 1949 or older

3. Is this your home or a rental?

- I/ we own and occupy
- I/ we rent
- Other (specify)

4. How long have you occupied the premise?

5. Has there been any investigation of the problem?

- Yes No

If yes, please indicate:

Conducted by? _____

When? _____

What was done? _____

Findings? _____

6. Please describe the type of major appliances (e.g., gas, electric, etc.)

7. Please describe the type of heating, ventilation and air conditioning system (e.g. gas/oil furnace, forced air heating, HRV, exhaust vents, etc):

8. Please describe the physical or thermal comfort factors (relative humidity and temperature):

1.2.7 Other

1. Any additional comments provided by contact:

As per the investigation process, if the IAQ issue is not resolved at the end of the telephone interview, a site visit is necessary to gather more information for the purposes of resolving the complainants concerns.

If necessary, schedule a site visit:

2. What days of the week and times would be most convenient?

Day

Monday Tuesday Wednesday Thursday Friday

Time

9am to 10am 10am to 11am 11am to noon 1 pm to 2 pm 3pm to 4pm

I.3 IAQ Investigation onsite occupant Interview questionnaire

The purpose of the onsite occupant interview questionnaire is to gather more specific information about the IAQ problem. Interaction with the occupant is an important part of the site investigation process. Information from the occupant(s) helps the investigator to further develop the hypotheses. Talk to different occupants, the building manager and owner, if applicable, to gather as much information as possible. Try to interview identified sensitive or vulnerable individuals among building occupants. When talking to different occupants, differentiate them according to their age, sex and health status. These interactions will identify particular areas of concern in the building where emphasis is needed during the building assessment. The content of this questionnaire is based on ASTM D7297-06- *Standard Practice for Evaluating Residential Indoor Air Quality* (2006), and AHS-EPH DSOP IAQ - *Indoor Air Quality* (2012 in development).

I.3.1 Address and contact information

Questionnaire #:	_____	_____	_____
Name of interviewee:	_____		
Facility type:	_____		
Associated facility:	_____		
Address:	_____		
City/town:	_____	Postal Code:	_____
Recorder's name:	_____		

I.3.2 Problem information

1. Describe the problem being experienced in your own words:

2. When did you first notice this?

3. Can you describe the area of the building where you experience the problem?

4. Can you think of any possible causes of the problem? (e.g., renos, new furniture, etc.)

5. Describe any renovations/remodeling at the premise and note approx. when conducted:

6. Who did that work?

- Yourself Other building user Contractor Other, specify

7. Have you noticed any other events (such as weather events, temperature or humidity changes, or activities in the building) that tend to occur around the same time as your symptoms?

8. Have you noticed any specific incident or event that can be linked with the initial onset of symptoms (e.g., building renovations, new fans, layout changes, the installation of partitions/dividers, new lighting, furniture, carpeting, roof leaks, dampness in the wall, new paint etc.)?

9. Do you have any observations about building conditions that might need attention or might help explain your symptoms (e.g. temperature, humidity, drafts, stagnant air, odors)

10. Please describe the type of heating, ventilation and air conditioning system (e.g. gas/oil furnace, forced air heating, HRV, exhaust vents, etc):

11. Indicate the location of systems used (if applicable):

Heating:

Cooling:

Filtration:

Humidification:

Exhaust Fans:

12. Have any of the following been replaced, and if so, approximately when?

- | | | |
|------------------|--|-----------------------------|
| Furnace | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Air conditioning | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Ductwork | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Water heater | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |

- | | | |
|----------------|--|-----------------------------|
| Range/oven | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Dishwasher | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Clothes washer | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Clothes dryer | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Windows | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |
| Doors | <input type="checkbox"/> Yes, when _____ | <input type="checkbox"/> No |

13. How long have you lived/worked/used this building?

14. Where do you spend most of your time in the building/suite/room?

15. When do you notice the problem? Is it constant or intermittent? When does it recur?

16. What have you tried to address the problem?

17. Who did that work?

- Yourself Other building user Contractor Other, specify

18. Have visitors to the premises complained of symptoms?

- Yes No

If yes, please specify:

I.3.3 Potential sources:

1. Are any pets living on the premises?

Yes No

If yes, please specify:

2. Do you smoke?

Yes No,

If yes, please specify:

Average number of cigarettes/cigars smoked _____

Is there a designated smoking area? _____

Where? _____

Indoors or outdoors? _____

Do others smoke? _____

3. Do you use any of the following indoors and how often?

Candles Yes, frequency _____ No

Oil lamps Yes, frequency _____ No

Printers Yes, frequency _____ No

Copiers Yes, frequency _____ No

Hair spray Yes, frequency _____ No

Oven cleaner Yes, frequency _____ No

4. Do you start your car in the garage?

Yes, No

If yes describe frequency of occurrences and duration of idling in the garage:

5. Have you experienced any flooding or water damage associated with any of the following and approx. when?

Burst pipes Yes, when _____ No

Type: Sewerage Potable water

Flooding Yes, when _____ No

Type: surface water flow Groundwater rise

Roof leaks Yes, when _____ No

6. Have you experienced any condensation or rain/snow penetration or leakage at any of the following and approx. when?

Windows Yes, when _____ No

Doors Yes, when _____ No

7. In response to answers of “yes” to questions 5 and 6 what was done (remedial action(s)) and how much time elapsed between the “event” and the remedial action?

8. Do you use a humidifier and how often?

Yes No

9. If yes, describe use frequency and the kind of humidifier?

10. Describe how the humidifier is maintained (cleaned and sanitized?) and the frequency of maintenance:

11. Do you use any of the following for supplemental heat and how often?

Fireplace?

Wood Yes, frequency _____ No

Gas Yes, frequency _____ No

Woodstove?

Yes, frequency _____ No

Space heater?

Kerosene Yes, frequency _____ No

Unvented Yes, frequency _____ No

Electric Yes, frequency _____ No

12. If you use any of the above, do you notice a smell from them?

Fireplace?

Wood Yes, frequency _____ No

Gas Yes, frequency _____ No

Woodstove?

Yes, frequency _____ No

Space heater?

Kerosene Yes, frequency _____ No

Unvented Yes, frequency _____ No

Electric Yes, frequency _____ No

13. Do you notice drafts at any of the following and how often?

Doors Yes, frequency _____ No

Windows Yes, frequency _____ No

Wall outlets Yes, frequency _____ No

Exhaust vents Yes, frequency _____ No

14. Do you notice condensation on any of the following in winter?

Doors Yes No

Windows Yes No

If yes describe frequency and where:

15. Are windows and doors kept mostly: open closed

16. What cleaning products are used and where are they kept?

17. What pesticides and fertilizers are used and where are they kept?

18. Have any new furnishings been brought into the building?

Yes No

If yes, describe when and what furnishings:

19. Has there been any painting recently?

Yes No

If yes, what kind of paint? Oil Latex Low VOC

Describe when and where:

20. Are any of the following activities completed indoors?

Woodworking Yes, frequency _____ No

Photo processing Yes, frequency _____ No

Artwork Yes, frequency _____ No

Floral care & arrangement Yes, frequency _____ No

Growing & plant care Yes, frequency _____ No

Other chemical use Yes, frequency _____ No

Specify chemicals used:

I.3.4 Health status

1. Please describe any background medical conditions (e.g. asthma, respiratory disease, etc)?
Are you sensitive/vulnerable to anything specific?

2. What symptoms? Onset of symptoms?

3. Have you consulted a physician about your symptoms?

Yes No

4. If yes, please explain what the doctor said and provide the contact info.

5. Did the doctor give you any medication? Please specify:

How old are you? _____

I.3.5 Symptom Info

1. Where are you when you experience health concerns or discomfort?

2. Where do you experience these health concerns?

only at home at home and work all the time

Do the symptoms become less severe when away from the premises for a period of time?

Yes No

If yes, please describe any changes:

3. When do they generally start in the day?

mornings afternoons all day long

no noticeable patterns

4. When are they generally worst? (e.g. spring summer autumn winter)

5. Has the symptom severity increased?	Yes	No	Don't know	N/A
During warm, humid weather	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
During rainy weather	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
During the air conditioning season	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
At the beginning of the heating season	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Is the symptom severity decreased?	Yes	No	Don't know	N/A
When the humidifier is used	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
On very cold days	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
When windows are open	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

I.3.6 Information on occupation

1. Complainant's occupation:

2. Relevant information and work activities (e.g., is your job stressful, work related disease, or work with VDTs (video display terminals?), solvents, etc.)

3. How would the complainant classify their occupation?

- highly stressful moderately stressful low stress

4. What type of work do you do?

- volunteer part time full time

5. Work and Exposure history (if any)

Company Name and Work Location	From (mm/year)	To (mm/year)	Job title and description	Exposures ¹	PPE/Protective measure ²
1					
2					
3					

¹List significant chemicals, dusts, fibres, radiation, biologic agents, (bacteria, mould, etc.) and physical agents (heat, cold, noise, vibration, etc.) that you were exposed

²List protective measures taken in order to avoid exposure.

I.3.7 Other

Any additional comments provided by the contact:

I.4 IAQ Investigation onsite walk-through questionnaire

The onsite walk-through investigation may not be necessary if during the previous investigation steps, a source or cause has been confirmed and corrective actions have rectified the problem.

The purpose of the onsite walk-through survey is to identify and assess different sources of contaminants and their pathways. Identify different factors including physical, chemical and biological that may be responsible for health symptoms reported by different occupants. Perform a thorough walk-through survey of different parts of the building and—the building HVAC system if necessary. The content of this questionnaire is based on ASTM D7297-06- *Standard Practice for Evaluating Residential Indoor Air Quality* (2006), and AHS-EPH DSOP IAQ - *Indoor Air Quality* (2012 in development).

Some or all of the questionnaires and questions for interviewing and onsite investigation may be completed based on the assessment and judgment of the investigating Health Inspector. If during the course of the investigation, a source or cause is identified or hypothesis developed, then further work is not needed. If the hypothesis is not confirmed; that is, corrective measures were taken but the problem remains, investigation and use of the questionnaire may continue.

Some or all of the questionnaires and questions for interviewing and onsite investigation may be completed based on the assessment and judgment of the investigating public health inspector.

If during the course of the investigation, a source or cause is identified or hypothesis developed, then further work is not needed. If the hypothesis is not confirmed, ie corrective measures are taken but the problem remains, investigation and use of the questionnaire may continue.

Note: use a separate form for each person interviewed.

I.4.1 Address and contact information

Questionnaire #: _____ Date: _____ Time: a.m./p.m. _____
Name of interviewee: _____
Facility type: _____
Associated facility: _____
Address: _____
City/town: _____ Postal Code: _____
Recorder's name _____

I.4.2 General

1. When was the building constructed? Year built: _____ Approximate age: _____
2. Which of the following best describes the building?
 Slab on grade Full basement Finished Unfinished

- Foundation type Concrete Preserved wood
3. Floor type
- Earthen floor Earth floor without vapour barrier
- Earth floor without vapour barrier Concrete Preserved wood
- Crawlspace Concrete floor
4. Construction material (e.g., brick, wood frame, concrete, cinder blocks, etc.):
- _____
- _____
5. Thermal insulation type? (e.g., sprayed, foam, fiberglass, etc.)
- _____
- _____
6. Location(s)? (e.g., walls, attic, floors, etc.)
- _____
- _____
7. Number of users of the building?
- Provide exact number if possible: _____
- 2 or less 2 to 5 5 to 10 10 to 15 15 to 20 plus 20
- Designed occupancy limit (if specified): _____
8. Number of floors (count attic or basement if it has any finished rooms): _____
9. Square footage/floor: _____ Total square footage: _____
- Ages of occupants
- Provide exact ages if possible: _____
- Infant (0 to 6 months) Toddlers (7 months to 4 years)
- Child (5 years to 11 years) Teen (12 – 19 years)
- Adults (20 years to 65 years) Senior (65+ years)
10. Does the building have a garage?
- Yes No
- If yes, parking Attached Detached Carport Parkade Surface
11. Do any occupants smoke?
- Yes No Don't know
12. Pets in residence?
- Yes No Don't know

I.4.3 Exterior walk-through

Complete schematic of exterior of building noting all areas of concern

1. Neighbourhood:

Rural Commercial Industrial Urban Agricultural

2. Describe outdoor influences nearby:

3. Heavy traffic: Yes No Don't know

4. Describe the traffic situation:

5. Traffic density near premise:

High Moderate Low

Vehicle idling area: Yes No Don't know

Dump site: Yes No Don't know

Farms(s): Yes No Don't know

Industrial plant(s): Yes No Don't know

Radiation source: Yes No Don't know

Polluted lake/stream: Yes No Don't know

Other hazards: Yes No Don't know

Specify: _____

6. Possible contaminant source located near building fresh air intake(s)

Yes No

If yes, specify type of source: _____

Specify approx. distance and direction: _____

7. Use of pesticides or fertilizers: Yes No Don't know

If yes, specify type(s):

Specify location(s) used:

Construction and condition

1. Chimneys/flues:

Number: _____

Type/construction material:

Location(s):

Potential for water penetration:

2. Roof:

Flat Sloped, specify approximate slope: _____

Type/construction material:

Condition:

Potential for water penetration:

3. Gutters/downspouts:

Condition: _____ Splashblocks: _____

Blockages: Yes No Don't know

Directed away from house

Connected to weeping tile/below grade

4. Drainage:

Ground graded/slopes away from building Yes Not

If yes, specify approx. slope: _____

Ground condition: Wet Spongy Solid/dry Standing water

Note potential for water accumulation:

5. Exterior condition:

Locations of vest (mechanical, plumbing, appliance, etc.)

Staining

Locations of construction flaws/repairs

Siding/sheathing

Cracks/gaps/penetrations, specify location(s)

I.4.4 Interior walk-through

Complete schematic of each interior floor of building noting all areas of concern

I.4.4.1 Problem Description

1. Is the problem specific to one area of the building? If so, where?

2. Are there any noticeable odours? If so, describe them.

3. Please describe the physical or thermal comfort factors (relative humidity and temperature):

4. Describe if there appears to be a connection from the garage into the building (i.e. air flows from garage into building)?

5. Describe any evidence of (note locations, remedial actions, response time and type of water or pipe involved):

Burst pipes:

Floods:

Roof leaks:

Leaks/condensation at windows (air/drafts or water):

Leaks/condensation at doors (air/drafts or water):

I.4.5 HVAC systems

1. Please describe the type of heating, ventilation and air conditioning system (e.g. gas/oil furnace, forced air heating, HRV, exhaust vents, etc):

2. Indicate the location of systems used, if applicable.

Heating:

Cooling:

Filtration:

Humidification:

Exhaust Fans:

3. Approx. age of systems used (if applicable):

Heating:

Cooling:

Filtration:

Humidification:

Exhaust Fans:

4. Indicate the frequency of cleaning for each system (e.g., monthly, yearly, etc.). Inspect to assess the cleanliness of each system:

Heating system: _____ Clean Dirty

Cooling system: _____ Clean Dirty

Filtration system: _____ Clean Dirty

Humidification system: _____ Clean Dirty

Exhaust fans: _____ Clean Dirty

What is the main type of fuel used to heat the building?

Gas Wood Electricity Fuel oil Kerosene

Other, specify: _____

5. Does the building have a heat recovery ventilator (HRV)?

- Yes No,

If yes, please describe the HRV.

6. Systems condition (inspect to assess condition):

- Filters Clean Dirty
 Ducting Clean Dirty

7. Supplemental heating sources:

- Fireplace Wood Gas Wood burning stove
 Unvented gas or kerosene space heater
 Other, specify: _____

8. Air conditioning system:

- Central air Window unit
 Humidifier Through-wall unit

Alterations to the system? Yes No Don't Know

If yes, please describe the system and any alterations:

I.4.5.1 Alterations to the building

1. Describe any evidence of major renovations or operating changes to the building:

2. Describe any evidence of improvement to the degree of thermal insulation in the building in the recent past? (Include the addition or replacement of roof insulation, wall insulation, storm windows or doors, or double-glazing.)

Yes No Don't know

3. Type and year of improvement:

4. Describe any evidence of new carpets, furniture, or cabinets recently been installed?

Yes No Don't know

If yes, please specify what, and when:

5. Conditions of fixtures

Plumbing fixtures – sinks, faucets, drains, pipes

Kitchen: Leaks Water stains

Bathroom: Leaks Water stains

Toilet: Good repair Water stains Leaks

Shower/bathtub: Good repair Water stains Leaks

Laundry: Good repair Water stains Leaks

Other, specify: _____

6. Living areas

General: Temperature/RH Odours Vermin

Describe any problem:

7. Sanitation: Sanitary Unsanitary

Describe the situation:

8. Finishes:

Walls/ceilings

Good condition Stained/soiled Mould

- Flaking paints Recent renovations/painting
9. Flooring
- Good condition Stained/soiled Mould
 Water stains Wet/damp Recent renovations/painting
10. Area carpets
- Good condition Stained/soiled Mould
 Water stains Wet/damp Other, specify: _____
- Windows/Doors: Insect screens General condition/operable
11. Furnishings - upholstered furniture
- Sofa Chairs Other,
specify: _____
 New Good condition Stained/soiled
12. Sleeping arrangements
- Mattress with box spring:
 Good condition Elevated off floor Mattress cover
 Mattress without box spring:
 Good condition Elevated off floor Mattress cover
 Other, specify: _____
- Bedding/Linen: Clean Soiled
Stuffed toys: Clean Soiled
13. Basement
- Condition of foundation walls: Staining Efflorescence/white crystals
Gaps at penetrations in: Slab Walls
- Note possible areas/points for soil gas and/or water intrusion:

14. Appliances
- Cooking:
 Gas Stove Electric Stove Vented Clean Dirty
- Laundry
- Washer: Properly drains Standing water Leaks
Dryer: Vented to outside Dryer lint visible
- Cleaning
- Dishwasher: Properly drains Standing water Leaks
Vacuum: Central Portable HEPA filter Bagless
15. Water heater fuel:
 Gas Electric Vented Clean Dirty
Approx. age of water heater: _____ Rust colour stains on exhaust ducts

16. Activities/uses

Indicate any processes or activities in the building that may serve as contaminant sources:

Please describe the type of major appliances (e.g., gas, electric, etc.)

17. What type of fuel is used for cooking?

Gas Electricity Fuel oil

Other, specify: _____

18. Consumer products used in premise:

Chemicals Paints Cleaners Pesticides

Adhesives Cosmetics Air fresheners

Other, specify: _____

19. Appropriate storage

Yes No Don't know

Please describe any storage concerns:

I.4.6 Investigation/remediation/mitigation

1. Has there been any investigation of the problem?

- Yes No

If yes, please indicate:

Conducted by? _____

When? _____

What was done? _____

What were the findings? _____

2. How have you tried to address the problem?

3. Who did that work?

- Building owner Building user Contractor
 Other, specify _____

Other

4. Any additional comments:

Schematic Diagram – Exterior

Indicate North

○

Front of Property

Floor: _____

This template will allow you to sketch the floor plan of the location of concerns. Copy page as necessary to accommodate each floor of the investigation.

Schematic Diagram – Exterior

Indicate North

○

Front of Property

Floor: _____

This template will allow you to sketch the floor plan of the location of concerns. Copy page as necessary to accommodate each floor of premise/area under investigation.