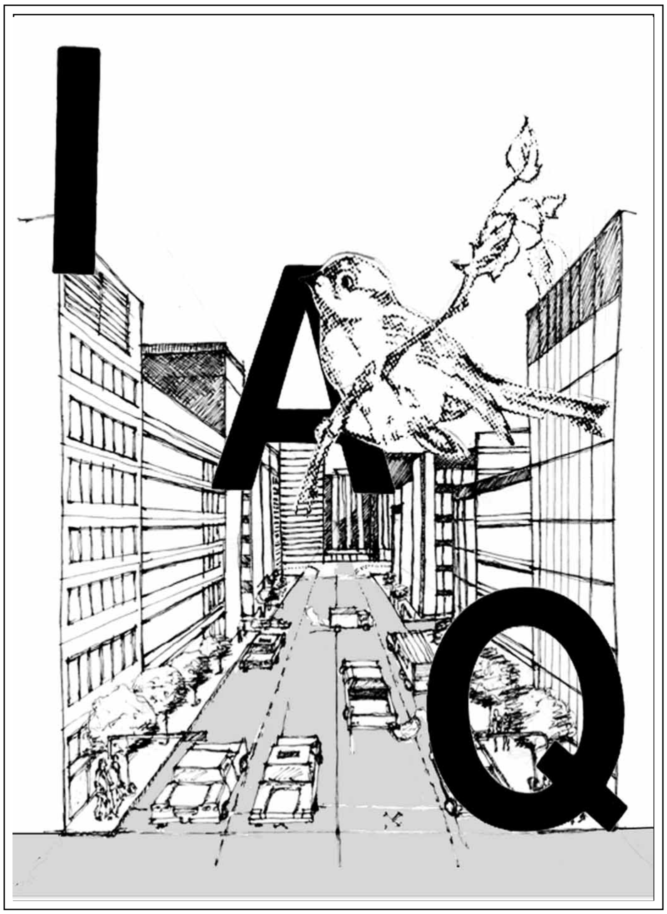
VITAL SIGNS

HEALTH AND THE BUILT ENVIRONMENT: INDOOR AIR QUALITY



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HEALTH AND THE BUILT ENVIRONMENT

A course on indoor air quality would not have been possible unless it can be proven that low levels of air contaminants can affect the health and well-being of building occupants. Against insurmountable odds, pioneers such as Drs. Theron Randolph, William Rea and Doris Rapp persisted in their belief to warn others about the potentially devastating effects of indoor air pollutants.

The effect of environmental stress on large mammals by Dr. Valerius Geist, at The University of Calgary, is also a good indicator for such stress on humans. His course called **Health, Lifestyle and Environmental Design**, addressed the interrelationship between biology and the environment. However, the need to effect change in the built environment requires an interdisciplinary approach to the topic. The short time that building designers spend on formulating a building can have long-term consequences on the health of all future occupants. In 1989, the course called **Health in the Built Environment** was offered to enable the next generation of scientists, planners and building designers, the tools to improve the built environment. Until his retirement in 1995, Dr. Geist co-taught this course which now forms the basis of this curriculum package.

The Vital Signs project is a series of courses dealing with building environment, specifically as it pertains to energy use. Professor Charles (Cris) Benton, University of California at Berkeley, had the foresight to include indoor air quality as part of these courses. The U.S. Energy Foundation, along with PG&E and others, helped fund part of the curriculum package development. Invaluable comments were received from Professor Benton, the Vital Signs staff, Professor Walter Grondzik at Florida A & M University, Professor Rick Diamond at Lawrence Berkeley National Laboratory and Professor John Reynolds at The University of Oregon. Dr. Dixon Thompson, an environmental scientist, gave valuable comments to this curriculum package and is currently co-teaching this course at The University of Calgary.

Development of the written materials and the illustrations for this curriculum package came from graduate students who took the course, Denise De Biasio, Antonio Santini, and Gregory Woods. It was Denise and Tony that wrote much of the material and brought this project to a successful conclusion. It is without a doubt that this package would not have the same quality without their help. In addition, Marino Vardabasso was instrumental in assisting with technical support.

Many guest lecturers contribute to the course on a regular basis including Jeff Bradshaw, Jackie Mack, Pat Lawrence and others. Donations of literature and monitoring instruments were received from SKC Inc., Gastec, Matheson Gas, The Allergy Shop and others.

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Objectives

The objectives of this Vital Signs Resource Package on indoor air quality are as follows:

1. To introduce architecture students to the problems associated with indoor environments, specifically indoor air quality;
2. To provide students with a fundamental knowledge of building related illnesses, their causes and effects;
3. To enable the students to develop the skills required to examine particular problems associated with indoor air quality, identify their causes and recommend mitigation strategies; and
4. To encourage students to adopt creative design and planning practices based on occupant health and well-being.

Overview

This Vital Signs Resource Package will identify the environmental factors that affect occupant comfort and health. Achieving healthy indoor air quality is a multifaceted problem which can only be arrived at by a comprehensive and interdisciplinary approach to the design, construction and operation of buildings.

The first portion of this Vital Signs Package will describe the importance of indoor air quality, through a discussion of its historical development and identifying why it is increasingly becoming an issue of concern. Furthermore, a discussion of human health and how it can be adversely affected by poor indoor air quality will emphasize the importance of the architect's role as a designer of buildings for human occupation.

The second portion of this Package will address the many sources of indoor pollution, such as building materials, finishes and furnishings that out-gas toxic fumes. Methods to control indoor pollution will also be discussed, such as source reduction and ventilation. Ventilation is recognized as the most effective means to remove airborne pollutants from buildings, assuming an effective airflow rate, filtration and airflow patterns. However, ventilation systems themselves may also be major contributors to indoor air quality problems, through inadequate distribution, filtration, system design, cross-contamination, etc.

The third and concluding portion of this Vital Signs Package on indoor air quality will present three levels of Field Protocols which will instruct the students as to how to conduct indoor air quality investigations. The three levels of Field Protocols increase in complexity and are designed to build upon one another. Students and the instructor must choose the appropriate level of investigation, depending on such factors as level of architectural education, available equipment and resources.

This Vital Signs Package is intended to deal specifically with indoor air quality, however, other environmental factors which affect occupant comfort, health and well-being will be briefly discussed. This is necessary due to the interdependent nature of such factors and their ability to influence human perception of indoor environmental quality.

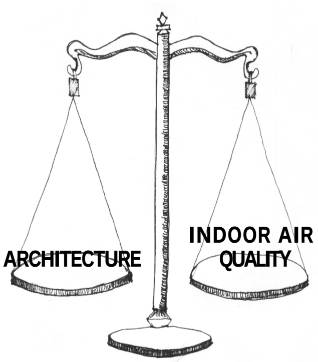


Figure 1: Balancing Architecture and Indoor Air Quality.

Indoor Air Quality and Architecture

The architectural design process is about the creation of beautiful and functional spaces. This point is undeniably true. However, the measure of "beauty" may be contemplated. Too often, success and beauty in architecture are solely determined by design aesthetics, yet the practice of architecture is a constant balancing act, involving numerous factors, aside from design aesthetics. Issues of functionality, practicality, building science, occupant comfort, safety and health, just to name a few, must be juggled in order to achieve a successful and beautiful building.

This approach to architecture is analogous to the functioning of the human body where all the organs, tissues and muscles are inter-related and co-dependent. Similarly, achieving healthy indoor air quality involves balancing factors, such as building finishes, furnishings, indoor vegetation, mechanical systems, building maintenance, energy efficiency and sustainability. This list illustrates how providing clean indoor air involves an interdisciplinary approach to building design and construction. In the past, indoor air quality has often been overlooked by design professionals - architects, engineers and interior designers. Team work, mutual respect and interdisciplinarity will ease the transition towards healthy and clean indoor environments. As a leader of the design process, architects are well-positioned to advance the need for maintaining occupant health and well-being.

2.0 HISTORIC OVERVIEW

... disease is a direct manifestation of an unhealthy site ...

Hippocrates

It is conceivable that health problems associated with the built environment began when cave dwellers struggled to vent fumes within their primitive shelters. Hippocrates, Greek philosopher and “father of medicine” was one of the first known individuals to rationally examine the nature of adverse health effects in relation to work and living spaces. In his treatise, **“On Air, Water and Places”**, Hippocrates proposed that disease is a direct manifestation of an “unhealthy site” rather than a form of punishment cast down by angry gods. The quality of the air, water, food and general living conditions, along with the climatic elements of wind, sun and rain all contributed, according to Hippocrates, to the well-being of persons (Lord, 1986).

The Industrial Revolution witnessed severe deterioration of human health within closed environments. Factory workers led a short and miserable existence in their harsh environments. Exposure to the mechanical and chemical industrial processes of the 18th and 19th centuries was often a deadly affair. In Sheffield, England, for instance, a condition described as “grinder’s asthma” plagued the unfortunate tradesmen who made cutlery for a living. On average, grinders had a life expectancy of 30 years. At the time, a grim joke circulated amongst the residents of Sheffield ... “Heavy drinking lets the grinder live longer because it keeps him away from work” (Lord, 1986).

Intolerance towards these kinds of conditions eventually brought about laws which sought to provide safer built environments. A similar evolution is now slowly occurring in home and work environments to improve health standards. Modern day health problems associated with indoor environments, in particular those related to indoor air quality can be traced to four fundamental developments in the last 45 years. They are as follows:

- the increase in the amount of time spent in indoor environments;
- the increased dependence on artificial products;
- energy conservation techniques; and
- advances in medicine.

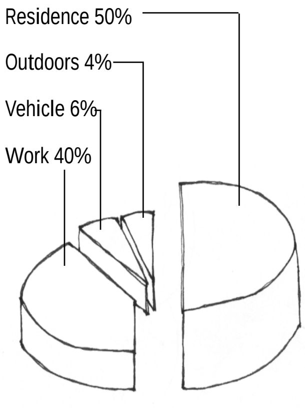


Figure 2: Average daily time allocation, where time spent outdoors is represented by a mere 4%.

2.0.1. Amount of Time Spent Indoors

The amount of time that the average person spends indoors has drastically increased due to a number of compounding factors. The postwar era witnessed a tremendous demographic shift from rural to urban lifestyles. This change resulted in an increase of indoor activities, for instance, work became a predominantly indoor activity housed within factories and offices. Also, activities such as sports and shopping shifted to being primarily indoor functions. These factors coupled with increased dependence on the automobile has lead to a point where the average person presently spends over 95% of their time indoors (note: this data is specific to cold climate lifestyles and may vary in warm climates).

2.0.2. Increasing Dependence on Artificial Products

The chemical industry has undergone widespread development since the late 1940s. This trend has resulted in a tremendous and continuous influx of synthetic chemical products into commercial and domestic environments, in the form of building materials, cosmetics, cleaners, solvents and clothing fabrics. Unfortunately, humans are being subjected to phenomenal chemical exposure at a rate which the human body must struggle to cope with. “Presently, there are 4 million chemicals recognized by the U.S.A. EPA ... 60,000 of which are manufactured commercially, and three new chemicals produced per day” (Rea, 1992, page 7).

2.0.3. Energy Conservation

The "oil crisis" in the early 1970s forced the development of energy conserving strategies in a variety of industries. For the building construction industry, emphasis was placed on energy efficiency through “air-tightness”. Although these designs successfully conserved energy, air-tight buildings have, in part, compromised the health of building occupants. Air-tight enclosures reduce the infiltration and exfiltration of fresh air which can lead to the build-up of indoor air contaminants. Sustainability and energy efficiency continue to be strong issues in this time of limited resources. Therefore, the implementation of energy conserving strategies in the built form must be balanced with occupant health.

2.0.4. Advances in Medicine

The medical field has undergone incredible technological advances over the past 45 years. These advances are enabling people to live longer and survive situations which in the past were un-survivable. It could be stated that these advances permit physically weaker people to cope in an increasingly hostile world. These people have been labeled "environmentally sensitive" because of their reduced ability to cope with polluted indoor environments created by the first three factors. The environmentally sensitive have difficulty coping with low levels of environmental contaminants. They are aptly referred to as "canaries". Historically, the canary bird was brought into coal mines as an early warning mechanism to detect the build-up of toxic gases. The canary was able to react to these gases earlier than humans because of their increased sensitivity to air contaminants. Individuals suffering from environmental sensitivities may be canaries of the 1990s, warning the general population about the increasingly polluted environment.

Figure 3: The canary is the symbol of the environmentally sensitive. Ironically, canaries are no longer permitted in coal mines, since it is considered to be a hazardous environment.

3.0 HUMAN HEALTH AND WELL-BEING

The concept of human health often remains unconsidered, until illness presents itself. The definition of human health as defined by the World Health Organization (WHO, 1946) is as follows:

> “Health is a state of complete physical, mental and social well-being, not merely the absence of disease or infirmity.”

Maintaining human health depends on a balanced interaction between a number of complex factors. As the definition implies, simply being free from physical disease or illness does not qualify "good health". The components of mental and psychological well-being are crucial to human health. Indeed the mind is powerful, individuals who perceive a physical threat to their health may incur a deterioration in their quality of life, perhaps temporarily, real or perceived. Similar to the notion of health is the notion of human comfort; it too is dependent on numerous variables.

3.1 Human Comfort

Achieving occupant comfort is the result of a collaborative effort of environmental conditions, such as:

- indoor air temperature;
- mean radiant temperature;
- relative humidity;
- air movement;
- illumination;
- sound;
- air quality; and
- other factors.

Environmental stressors can produce adverse health effects.

In order to discuss occupant comfort, these factors must be touched upon, since they affect the occupant's perception of his/her environment. Furthermore, environmental stressors, such as those listed above, can produce health symptoms similar to those associated with poor indoor air quality. Understanding these factors and their affect on human comfort will enable the indoor air investigator to determine whether or not air contaminants (or a combination of numerous factors) are responsible for occupant dissatisfaction.

The first four conditions determine thermal comfort, defined as "a balanced condition of thermal neutrality, under which the body need not strain to reduce or increase heat loss" which occurs through convection, radiation, perspiration and/or respiration (Stein and Reynolds, 1992). An imbalance between the body heat generated and the body heat lost produces a rise or fall in skin temperature. It is this change in temperature that is sensed as discomfort, which may cause physiological stress. For a more detailed description of the factors affecting thermal comfort, refer to the Vital Signs Resource Package entitled "HVAC Components and Systems" by Walter Grondzik, Florida A&M University.

3.1.1. Indoor air temperatures greatly affect occupant comfort and perception of the environment. If the ambient indoor air temperature is too warm, people perceive the environment to be stuffy with little airflow. This condition can often result in fatigue and lethargy. Furthermore, high temperatures may cause increased outgassing of toxins from furnishings, finishes, building materials, etc. Alternatively, ambient temperatures that are too cool can cause occupant discomfort such as shivering, inattentiveness, muscular and joint tension.

3.1.2. Mean radiant temperature or the radiant field is determined by surface temperatures, such as the temperature of walls, ceilings and windows. These surfaces radiate heat to, or extract heat from, surrounding surfaces, including the human body, potentially causing discomfort. For instance, a person near a cold glazing surface may feel cold and uncomfortable, since body heat is being lost to the glazing surface.

3.1.3. Relative humidity is a measure of water vapour content of the ambient air as a percentage of the air's capacity to absorb water vapour. Relative humidity is a factor dependent upon air temperature, that is, air at a higher temperature is capable of holding more water vapour than is cooler air. Irritation of the mucous membranes can result from relative humidity values which are too low.

3.1.4. Air movement may be caused by fans, furnaces, natural convection, air leakage, and the movement of people. Air motion increases the convective and evaporative heat losses from the body, which may create discomfort due to perceived drafts.

3.1.5. Proper illumination depends on the quality, quantity, and location of lights. Inadequate illumination can result in occupant discomfort in the form of eyestrain and/or headaches. Furthermore, the duration, intensity and wavelength of light can affect individuals with seasonal affective disorder (SAD). For more information on illumination, refer to the Vital Signs Resource Package entitled "Interior Illuminance, Daylight Control and Occupant Response" by Mark Schiler and Shweta Japee, University of Southern California, Los Angeles.

3.1.6. The quality of the sound within an environment has tremendous potential to influence occupant perception of the environment. Loud or sudden noise has the ability to startle people potentially causing undue stress. Similarly, inadequate acoustical privacy may create occupant dissatisfaction with the environment, possibly creating psychological stress.

3.1.7. The air quality of the indoor environment is capable of affecting human comfort in a multitude of ways, depending on the contaminant. Airborne contaminants range from toxic substances such as carbon monoxide to nuisance matter such as large dust particles. There are literally thousands of air contaminants, each having varying effects on the human body. It is necessary to discuss how the body deals with pollutants before the contaminants themselves and the symptoms they inflict on the human body can be discussed.

There are literally thousands of air contaminants, each having varying effects on the human body.

3.1.8. Other factors which influence human comfort within the indoor environment are numerous, and can include such things as the quality and comfort of the furniture; the degree of occupant control over the environment (physically and psychologically); and the nature of the relationships among the occupants. For example, in an office setting, if staff members are not able to create harmonious relationships, they may potentially be subjected to undue psychological stress. All of the factors discussed above influence the occupant's perception of the environment. These issues are crucial to understanding the nature of occupant complaints. These factors may cause the occupants unnecessary stress and place them at a more vulnerable position, physically and psychologically, to cope with indoor air quality problems.

3.2 Toxins and the Body

The body is a complex interaction of numerous functions such as inhalation, digestion of food, and excretion of wastes. While all these functions are being performed, the human body fights off armies of pollutants through built-in defense mechanisms. Throughout this daily body functioning, the human body remains in a state of balance, known as homeostasis. Disease or illness occurs when the body's homeostasis is disrupted. Becoming ill is dependent on the interrelation of a variety of factors, such as the body's genetic makeup, the environment to which the body is exposed, and the degree of stress exerted on the body.

The human body fights off armies of pollutants through built-in defense mechanisms.

There are a variety of avenues for toxins to enter the body. The most significant paths, for air contaminants to enter the body are:

- inhalation;
- skin absorption; and
- ingestion.

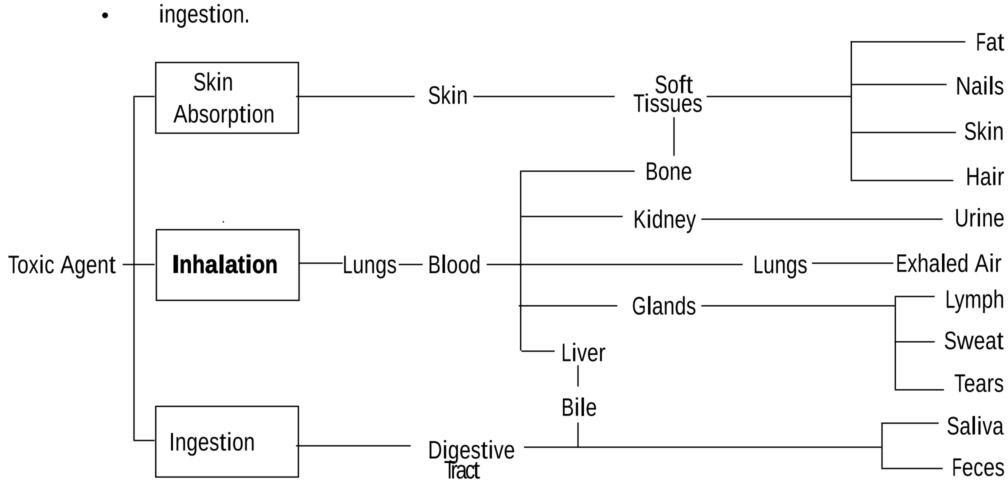


Figure 4: The pathways for toxic agents in the human body.

3.2.1. Most air contaminants enter the human body through the process of inhalation. The main function of inhalation is to provide oxygen to the body's cells and to remove excess carbon dioxide. The respiratory system consists of three main parts:

- the upper airway system (consisting of the nose, mouth, larynx and pharynx);
- the conducting zone (consisting of the trachea, bronchioles and terminal bronchioles); and
- the respiratory zone (consisting of the respiratory bronchioles, the alveolar ducts and the alveolar sacs).

Air enters the nose becoming warmed and moistened while passing through the conducting zone. The air then passes through the terminal and respiratory bronchioles, until it reaches the alveoli. It is in the alveoli where the exchange between oxygen and carbon dioxide occurs.

Air contaminants may cause respiratory, physical, neurological, mental and behavioural problems.

The human health effects of airborne contaminants vary greatly with the nature and type of contaminant. Gases which enter the body through the respiratory system are transferred into the blood stream by the alveoli and then carried throughout the body. Once inside the bloodstream, the contaminant(s) can be responsible for a variety of ailments, not just respiratory problems but physical, neurological, mental and behavioural problems (Rapp, 1985).

Fibres and particles greater than 5 μm (microns) in aerodynamic diameter which enter the respiratory system are generally intercepted by mucous, nose hair and cilia in the trachea. Once trapped by these mechanisms, the particles are expelled from the body by coughing and sneezing. Particle-laden sputum which fails to be excreted in this manner is expelled through the digestive system. However, some fibres and particles are too small to be filtered by the respiratory defense systems, such as those smaller than 5 μm in aerodynamic diameter. Particulate matter falling into this category are of concern due to their ability to by-pass the human defenses and enter the lungs. The smaller the particle, the easier the passage into the human respiratory system and the greater possibility to cause harm.

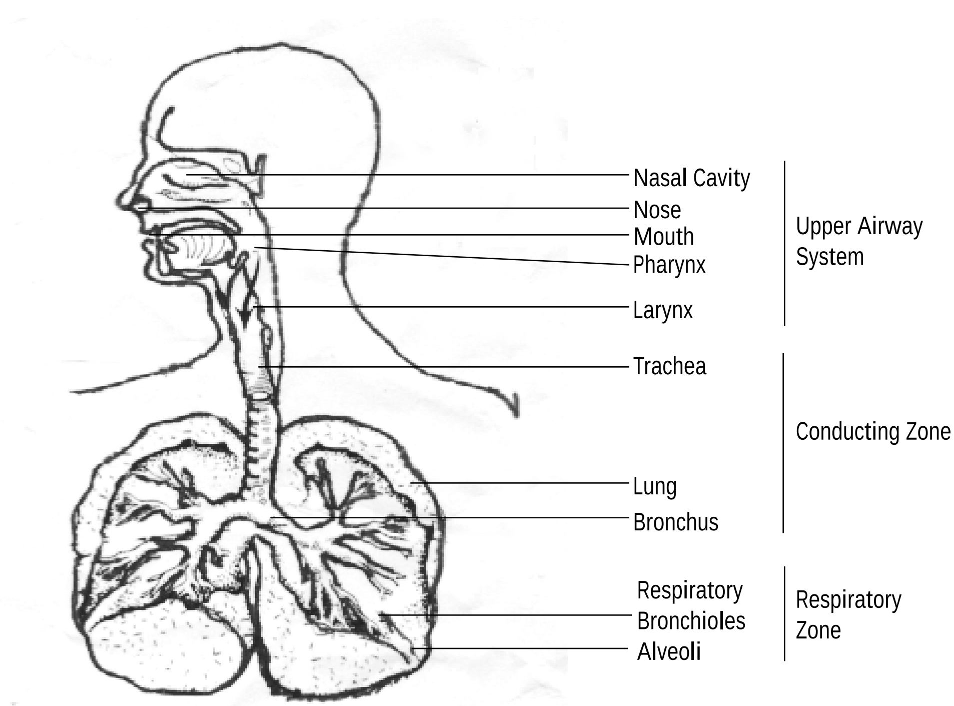


Figure 5: The Human Respiratory System.

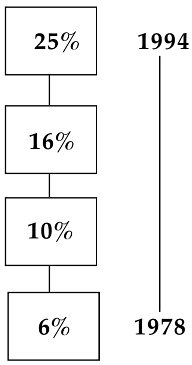


Figure 6: Estimation of respiratory illnesses and allergies amongst the Canadian population.

3.2.2. It is also possible for contaminants to enter the human body through skin absorption. Typically, the skin is an excellent protective barrier for the human body, however, it is capable of absorbing contaminants. Potentially, the contaminants may then enter the bloodstream, in turn affecting various organs throughout the body. This is the case with some pesticides. Other toxins, such as acids, alkalis, organic solvents, and bleaches, destroy the skin's barrier and cause harm at the site of contact. Some contaminants may pose a problem if brought into contact with the skin, these include cresol, and toxic metals, such as lead, mercury, zinc, and cadmium.

3.2.3. Chemicals may enter the body through the process of ingestion. Food and liquid exposed to a polluted environment may absorb airborne toxins. Upon consumption chemical laden food may release its burden into the body. Chemicals may also enter the body through the ingestion of chemically processed foods, however, this is beyond the scope of this Resource Package.

3.3 The Importance of Indoor Air Quality

Over fifteen years ago, Canada Mortgage and Housing Corporation (CMHC) estimated 6% of the Canadian population had severe respiratory problems. This estimate has risen to 25% of the population. These statistics may serve as an indication of the growing number of indoor air quality problems in recent years. In the United States, a 1991 federal estimate indicated that approximately 15% of Americans suffer from chemical sensitivities (Mathews, 1992, page 7).

The need and importance of creating and maintaining a clean and healthy indoor environment should be evident, given the human warning signals. Presently, indoor air quality is only a problem when building occupants report symptoms. However, waiting for occupant intolerance is not satisfactory. All buildings (new and old) should maintain a practical degree of healthy indoor air for its occupants.

3.4 Sick Building Syndrome and Building Related Illness

A variety of expressions have been associated with illnesses caused by poor indoor air quality, such as sick building syndrome (SBS), building related illness (BRI) and environmental sensitivity.

Sick building syndrome varies in a number of ways from building related illness. The symptoms of sick building syndrome are predominantly non-specific, that is they are not readily identifiable to one illness, or one contaminant source. The World Health Organization (WHO) listed the following symptoms as those most commonly attributed to sick building syndrome:

- eye, nose and throat irritation;
- sensation of dry mucous membranes and skin;
- erythema;
- mental fatigue;
- headaches;
- high frequency of airway infection and cough;
- hoarseness, wheezing, itching and unspecified hypersensitivity; and
- nausea and dizziness.

Sick Building Syndrome:
- predominantly non-specific,
- 20% or more affected, and
- symptoms relieved upon exit from the building.

Characteristically, the symptoms of sick building syndrome are prevalent in 20% or more of the building's occupant population, as opposed to building related illness which typically only afflicts a few occupants (Samet and Spengler, 1991, page 308). Another identifiable characteristic of sick building syndrome is that the symptoms are relieved upon exit from the building. Most occurrences of sick building syndrome are found in office buildings and can sometimes be mitigated by modification of the ventilation and mechanical systems.

Building related illnesses, as defined by the U.S.A. National Research Council (NRC) in 1987, are illnesses arising from exposure to indoor contaminants that cause a specific clinical syndrome (Samet and Spengler, 1991, page 307). The nature of the illness is dependent on the contaminant present within the building. For example, exposure to bio-aerosols can cause illnesses such as humidifier fever and hypersensitivity pneumonitis, whereas exposure to the legionella bacteria precipitates Legionnaires' disease. These symptoms are not alleviated by exit from the building. The most effective mitigation strategy for building related illness is to trace the illness to a specific contaminant and remove the source from the building.

Building Relate Illness:
- specific contaminant source,
- only afflicts a few, and
- not alleviated by exiting the building.

Identifying these two types of illnesses caused by indoor environments can sometimes create confusion when investigating an air quality problem. On occasions, both illnesses have been present in the same building, and on other occasions a building related illness may be mistaken for sick building syndrome, or vice versa. These definitions are useful tools in assisting to identify the problem, yet it is the alleviation of the health and indoor air problems which are the highest priority, above classification.

3.5 Environmental Sensitivity

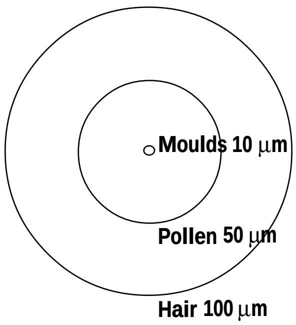
Environmental sensitivity describes a condition where the human body exhibits symptoms which indicate adversity to environmental pollution. People who have environmental sensitivities (a disorder otherwise known as environmental illness, or multiple chemical sensitivity, MCS) exhibit a heightened sensitivity when exposed to common environmental agents. Relatively low concentrations of indoor air contaminants which do not illicit serious health problems in the majority of the population have significant detrimental effects on people who are hypersensitive to them.

Environmental Sensitivity:
- individuals with acute sensitivity to low levels of air contaminants.

Different types of sensitivities exist and are formed from the complex interrelationships between biochemical individuality, the body's nutritional state and the total body burden. Biochemical individuality refers to the unique genetic make-up that characterizes every individual human being. The body's nutritional state has an important influence upon its many interdependent systems, most notably the endocrine, neurological and immune systems. The concept of total body burden represents all of the physical, psychological, chemical and biological stresses that the body must continuously confront and deal with to maintain itself.

Environmental sensitivities can be prompted by the presence of a single acute source, the experience of a high level exposure, repetitive or cumulative low level exposures, or combinations thereof. In addition, the inducing agent(s) may not be the same as the substance(s) that thereafter provoke negative responses. Pollutants have also been observed to work in a synergistic fashion as two or more substances may have a combined effect (Rea, 1994, page 842, and Samet and Spengler, 1991, page 337). The multiplicative effects of several different toxins consequently make the causation of many cases of environmental illness difficult to identify.

People afflicted with environmental sensitivity usually display a chronic polysymptomatic disorder which primarily affects one organ, and causes secondary effects in others. The disorder manifests itself through a multitude of often serious and debilitating symptoms, relief from which may be possible by avoidance of the instigating agent(s). Treatment of the environmentally sensitive is conducted by clinical ecologists who emphasize the uniqueness of the individual and direct their studies toward how the environment affects each individual in a different manner. Controversy within the medical community surrounds the definition, diagnosis and treatment of this disorder, as well as the population of the environmentally hypersensitive. These conflicts result in adverse consequences, emotionally and economically, for patients who are trying to cope with their debilitating illness and their lack of support in attempting to gain help.



Bacteria	**0.1 µm**
Virus	**0.012 µm**
Environmental Tobacco Smoke	**0.01 µm**

Figure 7: Diagram of particle sizes illustrating their scale in comparison to a magnified strand of human hair.

4.0 ENVIRONMENTAL CONTAMINANTS

The following section deals with the various types of pollutants, and their potential sources. Contaminants can be classified in four broad headings, each of which represents a wide variety of pollutants:

- Organic Compounds;
- Inorganic Compounds;
- Particulate Matter; and
- Biological Contaminants.

It must be understood that these classifications are intended for the ease of the indoor air quality investigator(s) to categorize certain contaminants for later research. Although the pollutants are classified into these categories, certain contaminants may belong to two or more classifications, depending upon their nature.

4.0.1. Organic Compounds

The classification of organic compounds represents chemical compounds that contain carbon-hydrogen bonds in their basic molecular structure. Their sources can be either natural products or synthetics, especially those derived from oil, gas, and coal. Organic contaminants may exist in the form of gas (vapour), liquid or as solid particles in the atmosphere, food and/or water (Rea, 1992, page 765).

4.0.2. Inorganic Compounds

Inorganic compounds are those which do not contain carbon-hydrogen bonds in their molecular structure. They include carbon dioxide, sulphur dioxide, nitrogen oxides, carbon monoxide, ozone, lead, sand, metal, ammonia and some particulate matter.

4.0.3. Particulate Matter

Particulate matter is formulated by a complex mixture of organic and inorganic substances, each with diverse physical and chemical properties. Furthermore, they represent a wide variety of substances ranging in size from 0.005 to 100 µm (microns) in aerodynamic diameter, including asbestos, dust, mould, pollen, and dander. The danger of particulate matter is their ability to become contaminated by other ambient sources, increasing health risks to individuals who are exposed to respirable suspended particles (RSP). Particles following into this category are less than 10 µm in aerodynamic diameter. As mentioned previously, particles smaller than 5 µm are capable of by-passing the respiratory defenses.

Further dangers with particulate matter lie in their ability to become contaminanted by other sources.

4.0.4. Biological Contaminants

Biological contaminants are generally referred to as microbes or micro-organisms. Biological contaminants are minute particles of living matter produced from a variety of sources. For the most part, sources of biological contaminants are found outdoors, however, many occur both in outdoor and indoor environments. The variety of biological compounds that may be present in the ambient environment is immense. Therefore, exposure to an increased concentration creates a potential health risk to susceptible individuals. Contaminants of this source may come in one of the following three main forms:

• VIRUS **• BACTERIA** **• FUNGI**

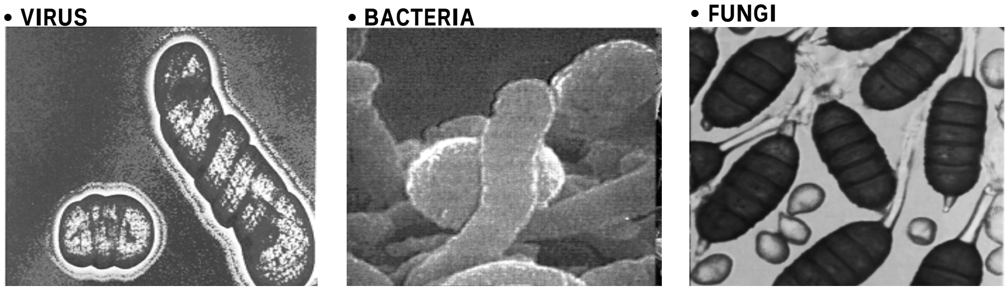


Figure 8: The three forms of Biological Contaminants

4.1 Sources of Indoor Contaminants

The indoor environment of any building is a result of the interaction between the site, building systems, construction techniques and building materials, as well as indoor pollutant sources and the building occupants. Each of these topics will be discussed along with examples. It is necessary to clarify that the sources of indoor contaminants listed in the following sections are intended as examples and are in no way an exhaustive list. Table A.1 in the Appendix is a comprehensive table outlining the most common indoor air contaminants, their characteristics, sources, health effects and current legislative standards.

Figure 9: Local geography may affect ambient environmental quality.

4.1.1. Site

A polluted outdoor environment may negatively affect the air quality within a building. Prevailing winds may carry pollutants from the surrounding site context, potentially enabling contaminants to be drawn into the building's mechanical system. Other geographical factors, such as inversions, may trap air pollution at low levels potentially increasing concentrations of contaminants in the ambient air. The quality of the outdoor environment is determined by the following conditions:

- local geography, such as mountains and bodies of water may affect wind patterns and local climate;
- the surrounding rural context may contribute to air contamination through:
  - agricultural activities which may be a source of pesticide pollution;
  - forests may be a source of pollution through the potential of forest fires;
  - arid lands pose the possibility of wind stirring up particulate matter;
  - pollen and spores may be a problem for those who suffer from hay fever and seasonal allergies;
- the surrounding urban context may affect air quality in the following ways:
  - buildings in dense urban cores may create Venturi effects, potentially depositing debris near building intakes;
  - re-entrainment of own or neighbouring building exhaust into air intakes;
- proximity to garbage dumpsters;
- transportation activities near a building may pollute the outdoor air with combustion by-products, from the following sources:
  - vehicle exhausts from roadways, parking garages, and/or loading docks;
  - railway lines; and
  - airports;
- industrial activities may pollute the air within the surrounding context from the following:
  - refineries;
  - heavy and/or light industry; and
  - factories;
- soil gases may enter the indoor environment, for instance,
  - radon;
  - leakage from underground nearby fuel tanks; and
  - previous use of the site may have resulted in soil contamination, for example, landfills, and battery storage sites;
- nearby construction activities, such as reroofing of buildings using bitumen.

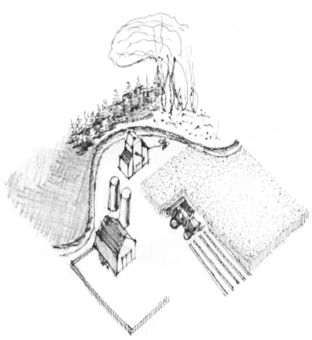


Figure 10: A rural context surrounding a site may be a source of outdoor pollution.

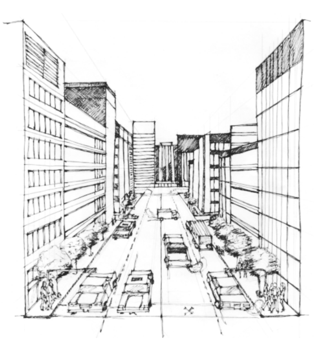


Figure 11: A dense urban context may cause the trapping of pollutants creating a risk of being drawn into the indoor environment.

Figure 12: Bird or animal fecal matter near an air intake poses a risk of unpleasant odours and biological contaminants entering the building.

Figure 13: Fresh air intakes inappropriately positioned in a loading dock, can draw toxic fumes into the building's HVAC system.

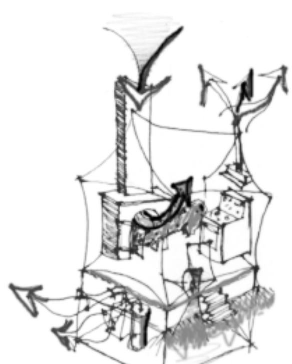


Figure 14: Negative pressure within a home.

4.1.2 Building Systems

Heating, ventilating and air conditioning (HVAC) systems play a crucial role in maintaining a clean indoor environment. These systems control the rates, airflow patterns and the degree of comfort required by the occupants. However, inadequate design and operation of the HVAC system(s) can have dramatic effects on the indoor air quality, as well as, the occupant's health. Common HVAC inadequacies which may effect the quality of the indoor air are listed below:

- contaminated outdoor air introduced into the system;
- inadequate filtration and filter housing systems (i.e., air allowed to by-pass the filter via gaps in the filter housing);
- poor maintenance of the HVAC system(s);
- incorrect aperture of damper opening, therefore, not enough outdoor air introduced to the system;
- improper pressure differences (negative pressures draw contaminants into other spaces);
- supply diffusers and return grilles placed inappropriately (e.g., too close together, obstructed by an object, or near a contaminated area causing the spread of contaminants). Short circuiting is the term applied when supply diffusers and return grilles are positioned too close together, causing the fresh supply air to be drawn into the exhaust without circulating throughout the space;
- outside air intake and exhaust grilles placed too close together allowing for the re-entrainment of stale air;
- outside air intakes which are located in or near:
  - areas of high contaminant concentration;
  - loading docks;
  - garbage areas;
  - high traffic corridors;
  - areas which have potential for animal habitats (e.g., ledges for birds, which may accumulate fecal matter)
  - areas near stagnant water sources;
  - close proximity to neighbouring building exhausts;
  - areas near fume hoods, chimneys and other building system exhausts;
  - areas of exposed soils and dense vegetation;
  - areas where prevailing winds blow contaminants towards the building from other potential sources;
- exhaust grilles located near operable windows;
- poorly maintained mechanical rooms which are used as plenum spaces;
- humidification systems with stagnant water located near other system(s), particularly the HVAC system;
- inadequate distribution of air;
- dirt and grease accumulation on grilles, diffusers and ductwork; and
- unbalanced comfort zones.

Another consideration when dealing with indoor air quality problems associated with mechanical systems is backdrafting. Backdrafting is the re-entrainment of combustion fumes into a space through de-pressurization. This de-pressurization causes naturally rising combustion fumes to be drawn down the chimney(s), in order to achieve an indoor/outdoor pressure equilibrium.

Negative pressure within a space or building maybe caused in several ways. For instance: an unbalanced ventilation system(s) where more air is exhausted than supplied. In addition, exhaust hoods, central vacuum cleaners, inadequate combustion air, odour exhaust fans, prevailing winds and stack effect are all potential causes of negative pressure within a building.

Figure 15: Evidence of backdrafting on a domestic hot water tank.

A carbon monoxide detector can detect increasing concentrations of carbon monoxide gas.

The sources prone to backdraft are naturally vented, fuel burning appliances and equipment, including:

- domestic hot water tanks;
- natural gas boilers;
- fuel-fired hot air furnaces; and
- wood burning fireplaces and stoves.

Evidence of backdrafting can be found on the mechanical equipment itself. It is distinguishable by a build-up of charred creosote contaminants at the bottom of the chimney. In naturally vented fireplaces, evidence of backdrafting is not visually detectable. However, odours associated with the burning of wood may provide an indication of chimney backdrafting.

Backdrafting is particularly dangerous, since many pollutants are generated from the combustion process, such as:

- carbon monoxide, CO;
- carbon dioxide, CO_2;
- nitrogen oxides, NO_x;
- sulphur dioxide, SO_2;
- volatile organic compounds, VOC;
- respirable suspended particles, RSP; and
- incompletely burned gases, also known as products-of-incomplete combustion (PIC).

4.1.3. Construction Techniques and Building Materials

The means by which a building is constructed may affect the quality of the indoor air. The choice of materials, component detailing and material installation play a role in potentially affecting the air quality. The following construction techniques may create air quality problems (this list is by no means exhaustive):

- the use of chemically based adhesives for fastening, as opposed to mechanical fastening;
- the use of asbestos;
- on-site floor finishing, such as hardwood flooring and moisture sealing of concrete floors;
- energy conservation techniques, specifically air-tightness when combined with inadequate HVAC systems;
- the use of pesticides for pest control, for instance termites;
- the use of oil coated concrete formwork;
- the use of ceiling plenums or crawl spaces as return air ducts;
- cost saving techniques, such as the placement of building intake and exhaust placed close together causing cross-contamination;
- material storage may cause building materials to absorb contaminants from other sources;
- the practice of building occupants moving in prior to construction completion;
- building cleanup prior to occupancy, generally includes the use of chemically based cleaners and solvents, as well as the stirring up of particles;
- the use of chemically impregnated building materials, such as preserved woods, particle boards, etc. ;
- the use of synthetic materials, such as plastics, rubber baseboard, etc.;
- the use of solvent based paints, lacquers and varnishes; and
- lead based paints which were commonly used in older buildings and may be a source of pollutant during refinishing activities such as sanding, stripping, etc.

Building materials may be sources of pollution within the indoor environment. Architects must realize the impact their material selections have on indoor air quality and occupant health. Table 4.1.3 is intended to illustrate commonly used building products and pollutants which they may potentially out-gas into the indoor environment.

TABLE 4.1.3 BUILDING MATERIALS

BUILDING MATERIAL	POSSIBLE POLLUTANTS
WOOD PRODUCTS	
Particle Board	Urea- and phenol-formaldehyde
Medium Density Fibre Board	Urea-formaldehyde
Plywood	Urea- and phenol-formaldehyde
Chipboard and Oriented Strand Board	Urea- and phenol-formaldehyde
INSULATION	
Batt	Particulate; resins; formaldehyde.
Rigid Board	Resins; polystyrene; hydrocarbons; polyurethane.
Foamed in Place	VOC; urea-formaldehyde; asbestos; benzene; benzaldehyde; acetaldehyde; cresol; methylnaphthalene; acrolein; anomia; phenol.
PAINTS	
Solvent-based	Lead; aromatic hydrocarbons; aliphatic hydrocarbons; VOC.
Water-based	Biocital additives; styrene; butylene; acrylics; vinyls.
CARPETING	Formaldehyde; VOC; synthetics fibers; nylon; latex rubber; polypropylene; polyester; use of carpet cleaners; carpets trap microorganisms, odours and particulate.
CONCRETE	Particulate, radon.
GYPSUM BOARD	Particulate, radon.
BRICK	Radon.
CAULKING AND SILICON	Synthetic polymers: pentane, hexane, octane, benzene.

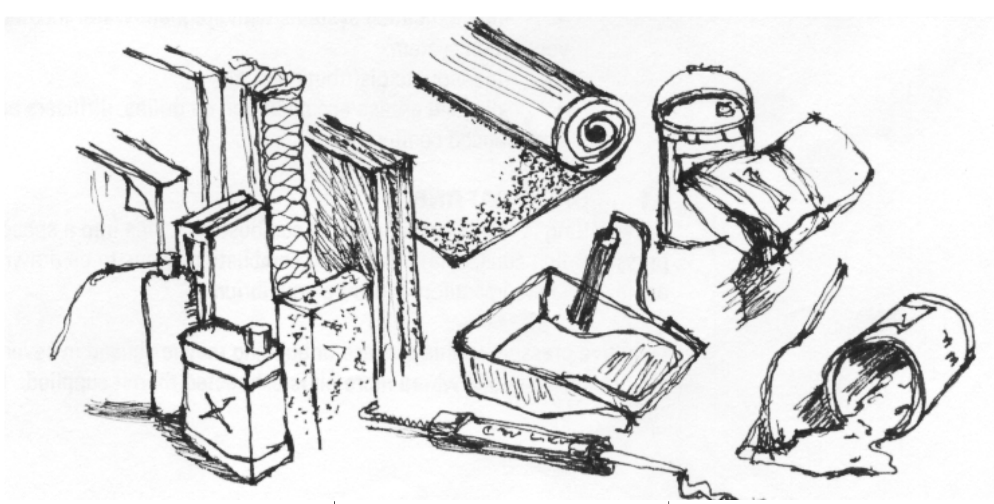


Figure 16: Potentially toxic building materials

4.1.4. Indoor Pollutant Sources and Building Occupants

An indoor environment is not complete until the building occupants have made it their own. Space personalization with interior furnishings and finishes may contribute to the level of air pollution within a building. Certain furnishings and finishes may act as breeding grounds or storage sinks for pollutants, which may later be released into the indoor environment. The building occupants and their activities may also contribute to air contamination. Examples of indoor pollutant sources and building occupant activities which may contribute to the level of air contaminants are as follows:

- human activities, such as,
  - cooking;
  - smoking;
  - exercising;
  - cleaning and maintenance activities, through the use of solvent or chemical based cleaning products, vacuuming, sweeping and also through the use of fragrances and deodorizers;
  - cosmetic odours from perfumes, body lotions, hair care products, etc.;
- clothing has the ability to trap and carry pollutants from other sources, such as animal dander, the odour of tobacco smoke and dry-cleaning chemicals;
- furnishings made from manufactured wood products that are not completely sealed;
- furniture which is made from fabrics and foams, which may act as storage sinks for contaminants, for instance sofas and chairs;
- fabrics coated with stain repellant, fire retardant and anit-static chemicals;
- furnishings such as oil paintings may continue to out-gas chemicals for long periods;
- fabrics used for furnishing, such as curtains;
- vinyl wallpaper;
- acoustical panels made of fabric and foam insulation;
- petroleum-based carpets and underpads,
- the process of steam cleaning carpets and rugs with chemicals;
- solvent based paints and lacquers;
- equipment emissions, for instance,
  - photocopiers, may release ozone into the air among other chemicals associated with the burning of toner onto paper;
  - fax machines;
  - computers;
  - motors and other mechanical systems;
  - clothes dryers;
- interior vegetation, such as,
  - plants, where the soil and drip pan may be a breeding ground for microbes;
- animals or pet dander and fecal matter;
- dry traps in plumbing fixtures which allow the passage of sewer gas into a space;
- standing water which has the potential to stagnate, for instance,
  - clogged or poorly designed drains and traps;
  - humidifier pans;
  - condensate pans;
  - leaking pipes;
  - condensation;
  - roof leaks and rain penetrations;
- HVAC systems, refer to 4.1.2.;
- pesticides from pest management;
- unvented crawl spaces with exposed earth; and
- attached parking garages.

Furnishings and finishes may act as storage sinks or breeding grounds for pollutants.

5.0 MITIGATION STRATEGIES FOR HEALTHY INDOOR AIR

The indoor air quality of a building is dependent on a variety of factors as outlined in the previous section. Mitigation strategies for achieving and maintaining a clean indoor air environment are essentially fourfold:

- education and awareness;
- source reduction;
- HVAC and ventilation strategies; and
- building maintenance.

5.1 Education

As a leader of the design team, the architect should adopt the role of educator, in order to successfully achieve a healthy level of indoor air quality. The architect should educate all those involved, including the client, property managers, building operators, construction trades, material suppliers and other consultants. The architect should point out the merits of maintaining a healthy indoor environment, as well as describing the methods by which to achieve such standards.

The degree of air quality varies depending on occupancy, ... For maximum human productivity and well-being higher air quality standards are strongly recommended.

Aside from defining the architectural programme, the architect and the client must also outline the required degree of indoor air quality to be achieved. Despite the desire for healthy air quality in all buildings, the degree of indoor air quality varies depending on the occupancy. For instance, the standard of indoor air quality required for a hospital operating room varies greatly with the tolerable air quality standard of an industrial building.

The client may not be conscious of indoor air quality issues, therefore, it is the architect's responsibility to design a clean indoor air environment. Educating the client in ways to provide and maintain indoor air quality, is the first and most crucial step towards a healthy indoor environment.

5.1.1. The Design Team and the Importance of Interdisciplinarity

By definition, interdisciplinarity implies that persons from different fields work together. The design and construction of any building is truly interdisciplinary. Similarly, team work is essential in achieving healthy indoor air quality. The architect must work closely and co-operatively with the mechanical/HVAC engineer in order to strike a balance between the aesthetics of the space and system component design. This effort includes ensuring adequate movement of air and ventilation within the space(s). In a similar fashion, the selection of interior finishes and furnishings with little or no outgassing properties, must be a collaborative effort between the architect and the interior designer. Together they must also ensure that the space layout, furniture arrangement and the positioning of vegetation (plants) and equipment, do not block the ventilation system or obstruct the flow of air within the space(s) in any way.

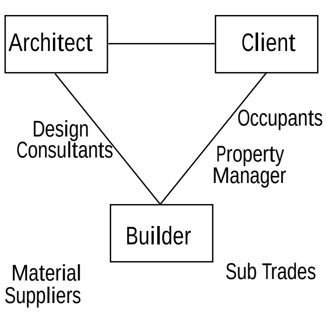


Figure 17: Design Team Relationships

5.2 Source Reduction

Eliminating sources of indoor airborne pollutants is obviously the most effective method to achieve indoor air quality. This type of strategy is most easily accommodated in the design phase of a new building. Applying these principles to an existing building may be difficult and expensive, and other mitigation strategies may be more appropriate.

The most effective methods in reducing pollutant sources within a building are through:

- the selection of building materials, finishes and furnishings; and
- construction techniques.

5.2.1. Selection of Building Materials, Finishes and Furnishings

The selection of building materials and finishes which minimize contamination of the indoor environment involves thorough research of materials and consultation with material suppliers. Table 4.1.3. illustrates a number of building materials currently being used and their potential negative effects. However, listing clean materials in a similar fashion is not so easy. There are numerous products on the market which are appropriate, and describing them here is beyond the scope of this Vital Signs Curriculum Materials Project. Environmental By Design by David Rousseau is a good reference in selecting and assessing clean materials.

A similar process of research and consultation with material suppliers is necessary for the selection of furnishings, so the building is not contaminated by their arrival. Research must also be conducted into the operation of equipment and appliances to ensure that they do not add contaminants to the environment.

5.2.2. Construction Techniques

It is important for all people involved with the project to have sufficient understanding of construction methods and their potential to contaminant the indoor environment. The method of component detailing can negate the effort spent in selecting the proper materials. For example, certain ceramic tiles are benign with no outgassing properties, however, if a petrochemical based glue and/or caulking is used, the advantage of selecting such a clean material is negated.

If using clean materials is not possible, encapsulation is recommended as a construction technique. Encapsulation is a technique which eliminates the outgassing of pollutants into the space. For example, coating particleboard with a non-toxic sealer will prevent formaldehyde outgassing. It is critical that the material be encapsulated from all sides for this method to be effective. Furthermore, any puncture through the encapsulated surface may release pollutants. In the particleboard example, holes drilled through the sealed surface will expose the interior of the particleboard, thus enabling the spread of formaldehyde into the air.

The release of contaminants from building materials and furnishings lessen with increased product age. Building bake-out is a method which has been used in an effort to accelerate the material aging process. The process involves raising ambient air temperatures while increasing ventilation rates for several days when the building is unoccupied. This technique works on the basis that heat increases the out-gassing of contaminants. The technique of building bake-out proves to be successful in decreasing the concentration of contaminants for a short period after the completion of the process. However, contaminant out-gassing resumes from the materials and furnishings soon after. Therefore, it is not recommended as an effective method for dealing with poor air quality, since it only provides temporary alleviation of the problem.

Baking out a new building before occupancy does not always reduce outgassing ... it is useful nevertheless to air out the building and its furnishings prior to occupancy.

5.3 HVAC and Ventilation Strategies

To ensure clean indoor air within a building, HVAC system(s) must expel stale air and replenish it with clean, fresh outdoor air. However, simple this may seem, it is not always the case. Varying climatic regions demand different thermal performance and conditioning within a space or building by the HVAC system(s). This situation requires a complex balance between supplying and exhausting air at rates that will ensure the required amounts and degree of fresh air.

Therefore, to ensure clean air several important objectives must be meet. Zone control is of great importance when dealing with indoor air quality. It allows for certain areas to be supplied with varying amounts of air, as well as providing separate circulation pathways. For instance, the perimeter of a building may not require the same amount of heating or cooling loads as does the inner portions of a building.

Variable air volume (VAV) systems must deliver a minimum amount of fresh and recirculating air to each room.

Variable air volume (VAV) systems were designed in this specific manner, allowing the building manager and/or occupants to set the required degree of thermal comfort. Automatic volume controls, linked to each thermostat, adjust the amount of air volume supplied to a space. However, this type of system is highly occupant dependent. For example, if the occupant does not adjust the thermostat, it is possible that no

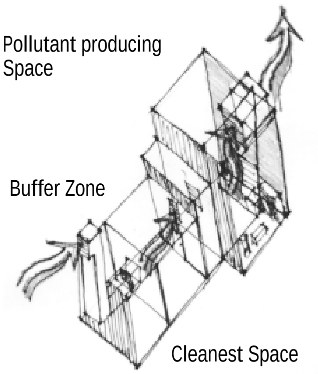


Figure 18: Supply of fresh air to the cleanest spaces within a building first.

demand for air will be made, thus no fresh air will be supplied to that space. VAV systems must be set-up so that a minimum degree of fresh air will always be supplied.

The placement of supply diffusers and exhaust grilles which allow for cross ventilation at the breathing level, is of critical importance. Diffusers and grilles should be placed at opposite ends of a space and free from any obstructions, which may block the airflow between them. A thorough understanding of the occupant's needs and space arrangements is required to ensure that the clean air supply does not become contaminated from other possible sources, which may be present within the room.

Ventilation should introduce clean, fresh outdoor air into a space at a percentage which provides the required degree of cleanliness. Forced ventilation system(s) introduce fresh air into the space after it is conditioned through the processes of filtration, heating or cooling, and humidification or dehumidification, as required. Once the air has been conditioned it should be supplied to the spaces in order of cleanliness; that is, supply the cleanest areas prior to supplying the areas which are potentially contaminated.

Task ventilation should be used in large open plan areas, or spaces which contain activities or equipment that may contaminant the air. This type of ventilation strategy removes pollutants from their source before they become circulated throughout the space. Task ventilation should be used in areas within a space that contain activities and equipment, such as smoking, photocopying, cooking, storage, and chemical experiments.

Natural ventilation requires that outdoor air be free of pollutants, unlike forced ventilation which may filter incoming air. This type of ventilation can be accommodated through strategically placed windows, doors, roof hatches, etc., as well as building stack effects. However, the incoming air is unconditioned and can pose problems with the air quality of a building or spaces. Thus, careful site analysis must be considered before this system is adopted.

Another system that must be considered is the design and placement of ductwork. Maintaining clean ductwork is as vital to clean indoor air as is the maintenance of the HVAC system(s). A variety of particulate matter may accumulate in ductwork, including microbial growth. Cleaning the ductwork on a regular basis can reduce the risk of contaminating supply air to the space.

The main HVAC system of a building is designed primarily to deal with heat losses and gains. In situations where buildings or spaces require large volume rates of exhausted air (most commonly in factories laboratories and assembly-type buildings), incorporating make-up air systems is a viable approach. Make-up air systems are designed to heat or cool incoming fresh air which replaces exhausted air. The system must be capable of supplying an equal amount of air to that being exhausted, thus preventing any pressure differences across the building envelope. To ensure proper operation, these systems require similar maintenance approaches as the main HVAC system.

Figure 19: Impingement type filters.

5.3.1 Air Filters

Ensuring clean indoor air quality requires the assistance of effective air filtration systems. Understanding how the different filtration systems perform is critical when designing for a certain degree of air cleanliness. Furthermore, it is also important to note that certain filters, specifically those greater than 30% efficiency, may increase static pressures causing problems to the blowers of the HVAC system. Essentially, there are three type of filter technologies: impingement, electronic and adsorption.

Impingement and electronic air filters are used to remove particulate concentrations from the air, whereas, adsorption type filters are used to eliminate (through adsorption) gases present in the air. In cases where occupants experience acute sensitivities to contaminants, it is recommended, if possible, to use filters that are not coated with fire-retardant materials. These fire-retardant chemicals can enter the air stream and be distributed throughout the building.

The variety of impingement and electronic air filters are as follows (this list is intended to illustrate the types of filters available and is by no means exhaustive):

- Dry Panel Filters - made of dry fibrous materials having an efficiency ranging from 5 to 30% atmospheric dust;
- Viscous Panel Filters - made of oily coated fibrous materials, with an efficiency of 10 to 35% atmospheric dust (not recommended because of their potential to contaminate air streams with oil);
- Extended-surface (dry) Filters - are a pleated type media commonly made of cellulose, bonded glass, wool felt and synthetics, with an efficiency range between 20 to 95% within the RSP range;
- High Efficiency Particulate Air Filter (HEPA) - is an extended surface type filter with an efficiency of 99.97% within the RSP range;
- Bag Filters - an enclosed sac type filter with efficiencies similar to those of HEPA filters;
- Electronic Filters - remove particulate matter by imposing a positive charge to airborne particles, which are later collected by negatively charged plates, 80-98% efficiency atmospheric dust. These efficiencies decrease dramatically when the filter is dirty, thus cleaning is suggested once per month. Also, electronic filters can produce ozone, which is itself an air contaminant; and
- Charged Media Filters - fibrous materials which are electrostatically charged, for example: glass fibres, cellulose; with an efficiency similar to that of dry panel filters.

Adsorption filters adsorb a variety of gases present in the air through activated carbons. The effectiveness of adsorption type filters rely upon the raw materials used and their processing techniques. A variety of materials may be used for the activated carbon (adsorption media), most commonly coal, peat, coconut and wood. The ability to absorb certain gases is dependent on the pore size of the material and the process of activation which the material is subjected to. Steam activation is a process which carbonizes the material, and then enlarges its pore structure through exposure to high temperature steam. The steam activation process allows a material's pore size to be readily altered, therefore carbons can be made to suit different purposes. The other process of activation is through chemical impregnation. Activated carbons impregnated in this manner utilize the combined effect of chemical reaction and adsorption to remove lighter-weight gases that are not readily adsorbed by activated carbons alone. For instance, the removal of formaldehyde gases require the use of chemically impregnated carbons. However, carbons activated through chemical impregnation may release chemical contamination into the air. Due to the complexity and variety of this type of filter media, consultation with filter experts is recommended, prior to their usage.

Certain degrees of air quality may warrant the combination of filter types, ensuring the removal of all contaminants present in the air. It is important, however, to understand that if this is the case, auxiliary fans may be required to compensate for increased static pressures caused by the filters. Furthermore, ensuring filters are properly placed and secured in their housing will prevent air from by-passing the filter. This effort will maintain the effectiveness of the filtration system.

Figure 20: Maintaining and replacing air filters on a regular basis, is crucial for healthy indoor air.

5.4 Building Maintenance

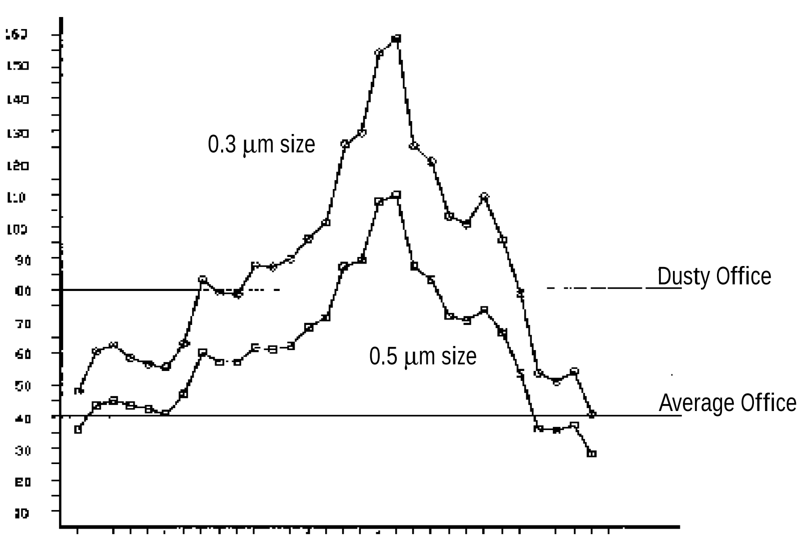
Maintaining building hygiene is important to ensure healthy indoor air quality. Regular cleaning of the building is necessary to avoid the accumulation of debris and particulate matter buildup. However, cleaning products may contribute to indoor air pollution, especially those which are chemically or solvent based. Where possible, it is recommended to use non-toxic cleaning solutions. In addition, the scheduling of maintenance activities should occur during periods when the building is unoccupied. For instance, cleaning in the evening is preferred in order that the cleaning odours and contaminants may be flushed out of the building, before the occupants arrive the next morning.

The maintenance of an HVAC system is of crucial importance, as a poorly maintained HVAC system may cause occupant discomfort and illnesses. Similar to maintaining an automobile engine for enhanced performance and better fuel consumption, HVAC systems require regular preventive maintenance and component changes. Air filters must be regularly checked. Furthermore, while changing filters, other component parts should be inspected, eliminating the possibility of problems which may affect the quality of air being supplied. If humidification systems are used, it is important to ensure that water, drains, drip pans, etc. do not permit standing water to become stagnant.

5.4.1. Vacuuming

Maintaining building hygiene is essential, however, the equipment used to do so may also contribute to the pollutant concentration. For instance, portable vacuum systems can potentially be the source of numerous airborne particulate matter. This type of vacuum system tends only to capture the large particle matter, which is not of risk to human health. The smaller, more dangerous particles simply pass through the system and remain suspended in the air for a period of time. Central vacuum systems which expel particulate matter to the exterior are the optimal alternative.

Figure 21: A portable vacuum system.



REFERENCE: Tang Lee, The University of Calgary, March 1, 1994

Figure 22: Graph of airborne particles during vacuuming.

6.0 FIELD PROTOCOLS

Preface

This portion of the indoor air quality Vital Signs Resource Package is intended to enable the student to receive 'hands-on' practical experience and knowledge of the problems associated with poor indoor air quality. It is essential that the investigator have sufficient knowledge of indoor air quality issues (i.e.: at a minimum, having taken this course, or thoroughly read this Resource Package), prior to attempting any of these protocols. These protocols are not meant to stand in isolation; their completion will require reference to this and/or other Vital Signs Resource Packages, and to external resources.

The three levels of field protocols presented are strongly interdependent; one level builds on the previous level. That is; the second protocol cannot be initiated without having completed the first. Similarly, the third protocol is an extension of the first and second field protocols.

In order to investigate the indoor air quality of any building, it is necessary to obtain permission from the building owner. Building owner(s) may have a negative response to an indoor air quality investigation, despite occupant complaints. It is prudent to always obtain permission from the building owner, and explain that the nature of the investigation is for academic purposes only. Furthermore, due to the sensitivity of the subject matter, and the potential for legal ramifications, all people contacted, especially the building occupants must be clearly told that the investigation is strictly an academic exercise. In addition, all people contacted should be reminded that the students are not professionals, and therefore, their conclusions cannot legally be used to resolve any indoor air quality problems. It is prudent for the student to include the following disclaimer on the title page of their final submission: (Refer to Appendix for sample sheet)

> "This report is submitted in accordance with the formal requirements for the course ...... the purpose of this report is strictly an academic exercise. As such neither the authors, the instructor(s), nor the University assume responsibility if the contents of this report are used for any other purpose."

The student must be aware of interview ethics prior to commencing the protocols. It is their responsibility to explain to the interviewee that the contents of the interview will be kept in confidence; and that the interviewee has the right to refuse to answer any question and to terminate the interview at any time.

These protocols specifically emphasize indoor air quality as the main impetus for the investigation. Therefore, other factors which contribute to the overall comfort of the occupants, such as illumination and acoustics, will not be considered, despite their ability to influence the occupant's perception of their environment.

Operational procedure for instruments are not discussed here since they vary depending on the manufacturer and model, etc. Any questions regarding equipment operation should be referred to the instrument's manufacturer or accompanying instruction manual.

Furthermore, any quantification of levels, temperature, relative humidity, etc., taken indoors should also be taken outdoors to facilitate comparisons.

These protocols were designed to be applicable to a variety of building types, residential and non-residential. Therefore, not all questions are applicable to all building, as such the investigator(s) must use their discretion when following the guidelines and checklists.

6.1 FIELD PROTOCOL LEVEL I - INITIAL BUILDING WALK-THROUGH

The intent of this first level field protocol is to develop the student's ability to make visual observations and to discover clues within the indoor and outdoor environments which may potentially affect the building's indoor air quality. It also includes a preliminary discussion with the building operator/owner or occupant as to the reason for investigation.

The purpose of this protocol is for the student to familiarize themselves with the building and to begin to identify problems which may be the cause of indoor air quality problems. This field protocol will provide the student with the overall picture of how the building functions from a contextual viewpoint, as well as with respect to building occupancy and building system operation. A complete walk through the building is necessary in order to establish the relationships between interior spaces and the exterior. Sketches and photographs are encouraged at this stage. The organization of this protocols begins from the interior working its way out and utilizes the occupant's complaints as a basis for investigation.

This field investigation involves observing the building within it's broader contextual environment, including an investigation into the history of the site as obtained from the building department of the municipal office. This information may be useful to identify the construction date, the extent of renovations, previous occupancies (if any) and potential site contaminants. The age of the building will give clues as to it's construction method, i.e.: pre- or post-energy conservation.

Aside from these investigative inquires into the building's history, this initial walk-through involves identifying site characteristics with respect to potential pollutant sources. This would entail obtaining, or sketching a neighbourhood map and detecting possible pollutant sources, such as: transportation corridors, parking lots, adjacent building exhaust, chimneys, industrial effluent, or neighbouring building construction or renovation activities. Recognizing environmental factors which may impact the air quality of the indoor environment is also important, for instance: prevailing winds and orientation, etc. Bearing in mind that the wind may come from any direction.

This protocol enables the student(s) to become familiarized with the building and the nature of the indoor air quality problem in a broad sense. At the conclusion of this protocol, the student(s) may begin to hypothesize as to the potential cause of the problem. However, the second field protocol will allow the student(s) a more detailed investigation of the building enabling a precise hypothesis to be formulated.

Tools Required

Tools required for recording observations:

- Notepad,
- Camera,
- Neighbourhood plan and floor plans of the building, if available.

Building Identification

Date of Investigation:____________________ Time from: ________ to: ________

Building Name:____________________
Address: ____________________
Contact Person(s):____________________Telephone: __________

Basic Construction: ____________________

Number of Floors: ________ Area per floor:________Total Area: ________
Age of Building:____________________Type of Occupancy:________

The local weather office, airport, radio station or the newspaper may need to be consulted for some of this data.

Weather Conditions:
Outdoor Temperature and Relative Humidity: ____________________
Wind Direction and Speed: ____________________
General Description (sunny, cloudy, rain, etc.): ____________________

Observations

Interior
Obtain or sketch an interior floor plan of the building, to help establish room relationships.

What are the occupant complaints?

Where in the building is the air quality the worst?

Where is it the best?

What materials (furnishings, finishes, vegetation, etc.) in the building may be a source of contamination?

Contextual/Exterior
Sketch or obtain a contextual plan, identify neighbouring buildings, orientation and direction of prevailing winds.

Describe the relationship of the building to it's surrounding context.

How is the air quality affected by outdoor pollutant sources (e.g. high traffic areas, rural locations, urban cores, industrial sites, etc.)?

On the contextual plan locate the air intake and exhausts.

Are the air intakes at risk of contamination?

Overview
Do you feel that the building requires a more detailed investigation? Why?

How does the design of the building promote or hinder the health of the building occupants?

6.2 FIELD PROTOCOL LEVEL II - COLLECTING ADDITIONAL INFORMATION AND FORMING A HYPOTHESIS

The second field protocol can only be considered after completion of the first. It is recommended that the two protocols be undertaken on different days. Allowing a few days between visits to the building, enables the investigator(s) to reflect upon the nature of the problem. As well, observing the building under different climatic conditions is useful in understanding how the building functions under diverse conditions.

A discussion with the building occupants documenting their complaints will provide a basis for the investigation of air quality problems. From this discussion, the investigator(s) can begin to collect additional information in order to formulate a hypothesis as to the nature of the air quality problem.

A detailed checklist is provided as a basic structure for the collection of additional information. The checklist is intended to identify numerous areas of concern from which the investigator(s) may find clues as to the nature of the indoor air quality problem(s). This checklist has been constructed to address residential and non-residential buildings, and as such some questions may not be applicable to all building investigations. Throughout the checklist, information has been provided to assist the investigator(s) in synthesizing the data collected in order to formulate a hypothesis.

The checklist is broken down into the following main categories:

- Occupant Interview
- Interior Observations
- Mechanical System Observations
- Exterior Observations
- Contextual Observations

The assistance of the building operator may be required, since it is necessary to access non-public portions of the building, such as: mechanical rooms, filter banks, roof(s), etc. Examining the maintenance schedule is useful in order to determine upkeep of the mechanical system(s), for example: the frequency of filter and belts changes, etc. It is necessary to open and thoroughly inspect the mechanical system(s) to observe their general cleanliness.

It is critical that the investigator(s) document information thoroughly through the use of photographs, sketches and notes. In addition, any instrument readings should include location and time of the test. This will be extremely useful for subsequent analysis and developing mitigation measures.

By the conclusion of the second field protocol the investigator(s) should be able to formulate a hypothesis as to the cause of the indoor air quality complaints. The third protocol will test, and ideally support, the hypothesis through the use of more elaborate instrumentation.

Tools Required

Tools for recording observations:

- Camera (wide angle and macro lens)
- Notepad
- Neighbourhood Map
- Floor Plans and Sections

Tools for probing and collecting:

- Flashlight
- Tool Box, including screw drivers, wrenches, etc.
- Ladder, as appropriate
- Tape Measure

Instruments required:

- Temperature
- Relative Humidity
- Carbon Dioxide (CO_2) Monitor
- Airborne Particle Counter

Instrumentation

This level of protocol only requires that basic measurements be taken. These include: temperature, relative humidity, carbon dioxide and airborne particle count. Throughout the protocol reference will be made as to appropriate times to take such measurements. However, these are only guidelines and additional measurement may be warranted at the discretion of the investigator(s).

Temperature and relative humidity readings can be taken in two ways: (pictures and descriptions of the equipment can be seen in the appendix)

- with a hygrothermograph, which enables continuous reading over a period of time, it should be located in a central location at average height. The hygrothermograph can be suspended in front of air diffusers to indicate its on-off cycle;
- with hand held instruments; and

Carbon dioxide measurements should be taken during building occupancy and in areas where the occupants spend most of their time. Carbon dioxide can be measured in three ways:

- with a hand-held direct reading portable CO_2 monitor (preferably one with continuous data memory);
- with sorbent sample tubes; and
- short-term or long-term colour detection tubes.

The CO_2 monitor is recommended as the most accurate and quickest method for air sampling of the three listed above, however it is the most expensive. An indication of carbon dioxide levels exceeding 600 ppm, present in the air can indicates a potential fresh air/ventilation problem. Ideally, CO_2 levels should be taken throughout the building for a 24 hour period or longer. This enables investigator(s) to assess the affect of occupancy and ventilation rates on the amount of CO_2 present in the air. If unable to acquire long-term monitoring equipment, then one sample per hour for an eight period will suffice . It is also important to measure the carbon dioxide level outdoors for comparison and analysis.

Particulate should be measured with an airborne particle counter. Particulate measurements should be taken throughout the building, and in particular, upstream and downstream of the filter inside the ductwork. Further, it is interesting to test the particle count during vacuuming and near other machines that may be operating within the space, such as photocopiers, wood saws, etc.

Particles can be counted either by mass or number. Mass count determines the weight of suspended particles, whereas, particle count determines the number of suspended particles present in the air, ranging from 0.3µm to 5µm. Mass count does not indicate the predominant size present within the air, therefore making it difficult to assess the health risk.

General Information

Date of Investigation:________________________ Time from: ________ to: ________

Building Name:____
Address: ____
Contact Person(s):________________________ Telephone:________________

Basic Construction: ____
____
Number of Floors: ________ Area per floor:________ Total Area: ________
Age of Building:________________________ Type of Occupancy:________________

Weather Conditions:
Outdoor Temperature and Relative Humidity: ________________________
Wind Direction and Speed: ________________________
General Description (sunny, cloudy, rain, etc.): ________________________

Occupant Interview

It is important that the interview ethics explained in the preface are adhered to. Ensure that the interviewee is not mislead by the questions. It is recommended that a random sampling of the occupant population be obtained, generally 6 to 7 people is sufficient. A general interview form is provided in this section as a guide for the investigator(s) to ensure that important issues are not overlooked. The interviewer should enquire into the nature, range and frequency of occupant symptoms and whether the symptoms subside upon exit from the building. It is necessary to ask about the interviewee's past health and general medical history to indicate any allergy related symptoms a person may have. Refer to Table 6.1 in order to interpret the occupant symptoms and to co-relate them to an airborne contaminant.

Prior to conducting the interview, the interviewer should observe the occupants and answer the following questions:

How do the occupants appear as a group? Look for a trend, not just one individual. For instance, is the majority wearing sweaters? t-shirts? These observations may indicate a potential thermal comfort problem that may be the basis for occupant complaints.

Do they appear energetic? lethargic? alert?

Occupant Interview Form

Occupant Name: ______________________________ Date: ______________

Symptoms
What kind of symptoms or discomfort are you experiencing?

Are you aware of other people with similar symptoms or concerns?

How would you rate your general health?

1	2	3	4	5	6	7	8	9	10
poor									excellent

Do you have any health conditions that may make you particularly susceptible to environmental problems, possibly including but not limited to:

- ☐ contact lenses
- ☐ allergies
- ☐ cardiovascular disease
- ☐ neurological problems
- ☐ undergoing radiation or chemotherapy treatment
- ☐ immune system suppressed by disease or other causes
- ☐ respiratory illnesses
- ☐ dermal (skin) problems

Timing
When did your symptoms start?

When are they generally worse?
Do they go away? If so, when?

Have you noticed any other events (such as weather events, temperature or humidity changes, or activities in the building) that tend to correspond to the timing of your symptoms?

Spatial Observations
Where are you when you experience symptoms or discomfort?

Is any one area of the building particularly worse than other areas?

Where do you spend most of your time in the building?

Additional Information
Did you experience these symptoms prior to moving into this building?

Have you sought medical attention for your symptoms?

What is your overall perception of the space?

Do you have any additional comments?

Possible Symptoms

Listed below are possible symptoms which occupants may experience due to indoor air quality problems (Note: this list is in no way exhaustive). The investigator(s) may choose to use this quick reference list during the interview to record symptoms described by the occupant.

Eye Irritation
Watering Eyes
Dry Throat
Cough
Wheezing
Sore Throat
Chapped Lips
Shortness of Breath
Headaches
Cold or Flu-like symptoms
Sleepiness, tiredness
Abdominal Pain
Nausea
Fatigue
Diarrhea
Irritability
Skin rash or itch
Weight loss
Dizziness
Runny nose
Respiratory tract irritation
Stuffy feeling
Difficulty sleeping at night
Nasal irritation
Bleeding nose
Vomiting
Menstrual problems
Dry skin
Sinus congestion
General muscle-ache
Joint pain

Interpreting Interview Data

Essentially the data collected during the interview deals with three areas: symptoms, occurrence, and spatial observations. Finding patterns in the data can provide clues as to possible indoor air quality problems.

Symptoms

Table 6.1 co-relates occupant symptoms to possible pollutant sources, as well environmental parameters that have the potential to cause similar problems are listed. This table is not exhaustive and is only intended as a quick reference guide to the possible pollutant sources. These must be verified through further testing and investigation.

TABLE 6.1 Health Symptoms Caused by Air Pollutants

SYMPTOM COMPLEX	POSSIBLE POLLUTANT	POSSIBLE ENVIRONMENTAL PARAMETERS
HEADACHES, FATIGUE Drowsiness, Dizziness, Shortness of Breath, Stuffiness	Carbon Dioxide	Ventilation Problems; insufficient fresh air
Nausea, Vomitting, Impaired Vision	Carbon Monoxide	
Incoordination, Stupor, Respiratory Irritation	VOC	
SKIN PROBLEMS Dryness, Itching, Irritation	Glass Fibers (MMMF)	Low relative humidity, warm temperatures, air movement
DELAYED ADVERSE HEALTH EFFECTS Neurological Damage	Lead	
	Asbestos	
ALLERGIC TYPE SYMPTOMS Rhinitis	Biological Agents, ETS, Formalde-hyde, Particulate	
Rashes which improve when away from the building	Formaldehyde, Glass Fibers MMMF, Allergens	
Watery Eyes	Formaldehyde, VOC, Particulate, Bioaerosols, Hydrogen Sulphide	Artificial Lights (UV)
EYE, NOSE AND THROAT IRRITATION Burning, Dry, Gritty Eye	Nitrogen oxides, Formaldehyde	Artificial Lights (UV)
Coughs	Ozone, Sulphur Dioxide, ETS, VOC	
Respiratory Irritation	VOC	
Bleeding Nose	Formaldehyde	

TABLE 6.1 Continued

SYMPTOM COMPLEX	POSSIBLE POLLUTANT	POSSIBLE ENVIRONMENTAL PARAMETERS
DIFFICULTY SLEEPING	Formaldehyde, Hydrogen Sulphide, Lead	
SYMPTOMS THAT MIMIC 'COLD' AND MENSTRUAL PROBLEMS	Formaldehyde	
IRRITABILITY, ABDOMINAL PAIN, ANEMIA, LACK OF APPETITE	Lead	
FEVERS, CHILLS, AND COUGHS Headaches, Respiratory Infection	Biological Agents, such as: Viruses, Moulds, Spores, Saprohpytic fungi	
Headaches, Malaise, Shortness of Breath, Lung Disorders	Organic Aerosols (dusts of animals and vegetative origins)	
Lethargy, Breathlessness, Weight Loss, Polyuria, Joint Pain, Muscle Aches	Biological Agents (Humidifier Fever)	
Vomitting, Diarrhea, Abdominal Pain, Pneumonia, Shortness of Breath	Biological Agents (Legionnaires' Disease)	

Occurrence Patterns

Occurrence patterns may give indications as to the indoor air quality problem. The following examples are provided to assist in developing a hypothesis.

Pattern	**Possible Problem**
Symptoms worse at the beginning of the day	• HVAC shut-off overnight • Cleaning and maintenance activities • In a residential situation, look for pollutant sources in the bedroom area
Symtpoms worse at the end of the day	• Check ventilation • Check for activities which may cause pollutant build-up without proper ventilation, such as photocopiers in unventilated spaces • Check for inadequate HVAC system design, such as VAV which shut off when the temperature is warm at the end of the day
Intermittent Symptoms	• Check cycles within the building, such as delivery vehicles in loading docks which are near air intake • Cleaning cycles • Weather conditions
Recent Onset	• Check recent renovations or redecoration • Check recent HVAC adjustments • Check new equipment

Spatial Patterns

Defining the location of where there are clusters of symptom complaints may enable the investigator(s) to concentrate on a specific area within the larger building. The following examples are provided to assist in developing a hypothesis.

Pattern	Possible Problem
Widespread, no apparent pattern	• Check the quality of the outdoor air • Check the ventilation system • Check materials that are present or distributed throughout the building, such as cleaning products and equipment
Localized	• Check localized ventilation • Check activities within the area • Check materials, finishes and furnishings within the area

Interior Observations

These observations may be conducted for each individual room within the building, or for the building as a whole, dependent on the size and complexity of the building.

During the interior observation, it is important that the investigator(s) try to detect the first odour he/she senses upon entering the building. This first scent is impressionable, and the investigator(s) should try to identify and describe the nature of the odour, as it may indicate the type of contaminants present within the building. For instance, a pungent odour may indicate the presence of formaldehyde. It is necessary to detect and record the first scent observation before olfactory de-sensitization sets in. This procedure can be repeated by going outside for approximately 15 minutes or so, to re-sensitize the sense of smell and then re-enter the building.

The investigator(s) should take a thorough walk-through the building to carefully observe and record potential air contaminants. It is useful to obtain or sketch the floor plans of the building and annotate them indicating where possible problems may be located.

Building Hygiene and Maintenance

Describe the first odour.

Assess the building hygiene by:

Checking for dust build-up on horizontal surfaces in obscure locations, i.e.: tops of shelves, etc. Describe the nature of the dust (i.e.: oily, greasy, dry, etc.):

Checking for debris behind and under cabinets, refrigerator or furniture.

Rate the building hygiene:

1	2	3	4	5	6	7	8	9	10
poor									sterile

Is there any evidence of rodents? Check for droppings, rat poisons or mouse traps.

Are any pets or animals kept within the space?

Identify the cleaning solvents used in the building and their frequency of use. (This may require consulting the custodian).

Where are the cleaning solutions stored?

Chemicals continue to outgas and should be placed in an airtight cabinet or room with an exhaust, in order not to contaminate other occupied spaces.

Identify type of cleaning equipment, such as vacuum cleaner (i.e.: portable or central) and floor polisher.

Is there any deterioration of the finishings on the interior walls (for example: paint or wallpaper peeling, cracks, etc.) ? If so, identify on the plan and photograph.

Observing building hygiene will give the investigator(s) an indication as to the attitude of the occupants and the maintenance staff towards the building. Poor building hygiene indicates the possibility of poor building maintenance which can lead to the accumulation of particulate matter and/or mould growth. Furthermore, animals or rodents present within the space may lead to health problems associated with animal dander and fecal matter. Poor building hygiene is also a clue to a poorly maintained HVAC system. Check the particulate count within the space and compare it to outdoor values.

A well maintained building generally reflects pride of the building operator and their eagerness to resolve problems. However, there is a potential for cleaning solutions to be pollutant sources, especially those with a solvent or chemical base.

Biological Contaminants

Is there any evidence of water staining due to condensation or leakage (possibly from plumbing or roof leaks)? Check for water stains on the carpet, ceiling tiles and walls. Describe pattern, size and colour of the discolouration:

Is there any evidence of mould growth? Where, to what extent, pattern, colour, etc.? Check areas such as window frames, ceilings, and walls.

Are there any dust marks?

Dust marks are the accumulation of airborne dust particles on damp surfaces.

Is there any standing water. Check to see if there is algae in the water. Use the slippery water test. Ensure that water in floor drains is replaced regularly.

Are there any plants or vegetation within the space? Is there standing water on the drip plate?

The presence of interior biological contaminant growth may be a source of sensitivity for the building occupants. Biological contaminants require four basic elements for growth - a food source, moisture, oxygen and warmth. Elimination of any one of these will suppress the growth of biological contaminants. Check relative humidity and temperature levels. If mould growth is present these values may need adjustment to satisfy occupant needs while hindering biological growth. A relative humidity value of 70% is optimal for mould growth, however, in a space with a relative humidity value below 30% little mould growth occurs, with the exception of standing water and wet surfaces (Samet and Spengler, 1991, page 293).

Figure 23: The slippery water test. Rubbing fingers in water or against the container to feel if it is 'slippery'. If so, this may indicate the presence of algae.

Occupant Activities

Evaluate the human activities within the space, are there any which produce pollutants, such as cooking, exercising, smoking, etc.? If so, how are they vented?

Are there any activities which use chemicals, such as painting, photo development? If so, is there any storage of these chemicals within the space? They should be stored in air tight cabinets and directly vented to the outdoors in order to prevent their release into the indoor air.

Describe any renovations (major or decorative) or operating changes.

The occupants themselves may be unknowingly polluting the spaces through their activities. If there are pollutant producing activities within the space ensure that task ventilation is provided to prevent pollution from entering other occupied spaces.

Other Contaminant Sources -

Equipment

Identify any machines or equipment operating within the space that may be a pollutant source (for example: photocopiers, printers, other electronic equipment, heaters, fans, etc.). Locate them on the plan, and check to see if and how they are vented.

Are there any unvented appliances in the space, for example: gas stoves, kerosene/gas space heaters, kilns, dryers, or any indoor combustion equipment, such as ice resurfacing equipment, forklifts, etc.?

Furnishings and Finishes

Evaluate the finishing and furnishings within the space.

Are they potential pollutant sources? Refer to Table 4.1.3.

Other Contaminant Sources

Is there an attached parking garage? If so, where is it located?

How is it exhausted?

Are there fans activated by a carbon monoxide detector?

Is there an effective airlock between the building and the parking garage?

Does the garage have an odour of vehicle exhaust?

There may be numerous contaminant sources within a building. The equipment, furnishings and finishes can outgas a variety of air pollutants. Evaluating these may indicate air contaminants, for example, an unvented photocopier may release ozone into the space. Similarly, an attached parking garage that is not well vented and/or sealed from the occupied spaces may cause the accumulation of carbon monoxide and associated combustion fumes.

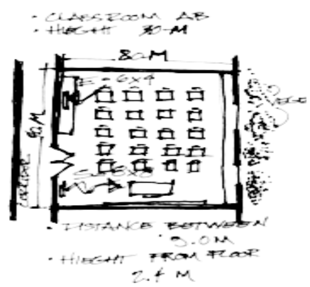


Figure 24: Sample annotated floor plan of air flow within a room.

Mechanical Observations (within the space)

Locate air diffusers and grilles within the space. Sketch floor plan and identify the location and size (measure them with a tape measure) of diffusers and grilles on the drawing. Be sure to include all of them.

Is there any blockage of the air supply diffusers by books, furniture, plants or other obstructions?

Have the occupants modified (for example: closed or taped up, etc.) any of the air supply diffusers?

Hold a piece of paper to the grille to determine if it is supplying or exhausting air.

Remove the grille and shine a flashlight to see the condition of the ductwork and/or plenum space (a ladder may be required here). The condition of the grille (dusty, dirty, greasy, etc.) will give an indication of the condition of the ducts and/or plenum.

Check for exhausts in pollution producing rooms such as the bathroom(s), kitchen, storage, etc. Trace their paths, are they exhausted directly outdoors or are they recirculated within the HVAC system?

The mechanical system components (grilles and diffusers) within the space must be checked to identify whether the space is receiving sufficient ventilation. The location of supply grilles and exhaust diffusers will indicate the potential for short-circuiting. Carbon dioxide levels should be taken in the space as an indicator of ventilation. High carbon dioxide levels may be due to poor ventilation. Furthermore, the condition of the ductwork and grilles will give a clue as to the quality of the air being delivered to the space. For example, the accumulation of dirt on the ducts or grilles may indicate a high particle count.

Mechanical System Observations (in the mechanical room)

Inspect the mechanical room and assess its level of cleanliness. The cleanliness of the mechanical room reflects the general attitude towards building hygiene.

1	2	3	4	5	6	7	8	9	10
poor									sterile

Is the mechanical room(s) used for storage, aside from that necessary for the operation of HVAC system(s)?

Identify the type of:

- Heating (forced air furnace, boiler system, solar systems, etc.):
- Cooling (central air conditioner, window unit, cooling tower, evaporative, etc.):
- Ventilation (variable air volume ventilator, make-up air units, etc.):
- Humidification (portable units: ultrasonic, cold mist, hot air vapourized; units attached to furnace:roller drum, plate unit, spray; heated water pan type, steam grid type, jacketed dry steam type, etc.):
- Filtration (electronic air cleaners, fibre furnace filters, HEPA filter, etc.):

Describe the general condition of each system.

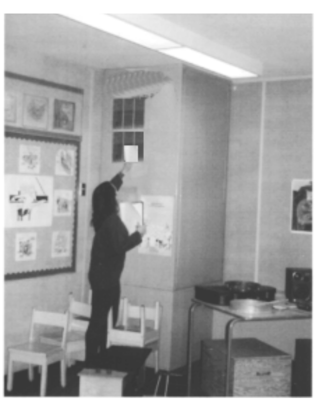


Figure 25: Paper test to determine whether a grille is a supply or an exhaust. If the paper is held to the grille, then it is an exhaust grille. If it is blown air, then it is a supply.

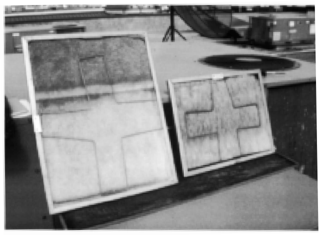


Figure 26: Evidence of particle build-up on filters in an unusual pattern.

Identify the type of energy used to operate the mechanical system(s). If fuel, are there any fuel odours present in the mechanical room.

Is the filtration system utilized appropriate for the building? That is, is its efficiency sufficient?

Describe the condition of the filters (are they dirty? wet?). Indicate any unusual dirt patterns on the filter. Unusual dirt patterns may indicate improper placement of the filters.

How do the filters fit in their holder (is it a tight seal, or can air bypass the filter)?

Check the maintenance schedule in order to see how often the filters are changed.

Indicate the amount and percentage of fresh air to recirculated air. Estimate the position of the dampers and how are they operated?

Are there any units where the condensate pan does not drain properly? Check for stagnant water using the slippery water test. Are there visible signes of mineral deposits and rust?

If system(s) require combustion air, how is it introduced into the system(s)? If mechanical systems utilize combustion air from the space there is a possibility of creating a negative pressure thus increasing the possibility for back-drafting of other HVAC equipment.

Is there any evidence of back-drafting on any of the units?

The mechanical system is the backbone of the air quality in a building. If it is poorly maintained it may cause the distribution of contaminants throughout the building. For instance, problems may arise when the mechanical room is being used both as a storage area and as a mixing plenum. In addition, standing water in the mechanical system can be a breeding ground for biological contaminants which can then be circulated throughout the building. For instance, Legionnaires' disease is associated with the presence of bacteria in the mechanical system. The introduction of outdoor filtered air into the airstream is important in maintaining a fresh supply of air to the spaces.

Exterior Observations

The nature of these observations entail a closer examination of the building itself. A careful and deliberate walk around the building will identify possible source of pollutants and their relationship to the building air intakes. Be sure to record all the information through sketches, photographs and notes.

Building Envelope

Rate the general condition of cladding system(s).

1	2	3	4	5	6	7	8	9	10
poor									excellent

Is there any evidence of envelope failures (i.e.: cracks)?

Are there any signs of water damage? (i.e.: efflorescence, staining, material deterioration, etc.)

Describe the types of fenestration: (i.e.: operable or not, double glazed, single glazed, etc.)

If operable windows, observe whether the occupants keep them open.

Figure 27: Observe the condition of roof-top mechanical units.

Roof
Describe the general condition of the roof.

1	2	3	4	5	6	7	8	9	10
poor									excellent

Is there any evidence of water ponding (look for dirt accumulation in low areas)? If so, is it near a mechanical air intake(s)?

Sketch the locations of penetrations, chimneys, drains, plumbing vents, etc. What is their relationship to the mechanical air intake(s)? Assess whether they pose a risk?

Are there any rooftop mechanical units? If so, identify the number and type, and locate on a roof plan. Observe the condition of the rooftop mechanical systems as per mechanical room observations.

The building envelope may provide clues as to the sources of indoor air problems, for instance: envelope cracks can allow water penetration, possibly resulting in mould and bacterial growth. Building envelopes which contain operable windows, if observed to be opened may indicate the occupant's need for fresh air.

Figure 28: Extension of air intake to minimize cross contamination by building exhaust.

The general condition of the roof may indicate the possibility of roof leaks which, on the interior, may be places for growth of biological contaminant. Furthermore, poorly drained flat roofs may result in water ponding near air intakes, thus increasing the potential for drawing microorganisms into the building's HVAC system.

Air Intakes

Identify the building's fresh air intakes. Locate them on the site plan.

Note the location of intakes, are they near:
- parking or major transportation corridors?
- loading docks?
- cooling towers?
- building exhaust(s), HVAC or other (e.g.: chimneys, plumbing stack vents, etc.)?
- any garbage containers?
- any exhausts of neighbouring buildings?
- any standing water?
- other pollution sources?

Is there potential for contamination of the air intake by any of the above listed sources?

Are there any risks or signs of blockage of the air intakes? (e.g.: snow, leaves or dust)

Is there potential for any bird/animal fecal matter build up in the vicinity of the air intake?

Figure 29: Stagnant water near building air intake.

Careful observation of air intakes from the exterior may indicate the potential for contaminants to be drawn into the building's mechanical system. For example, air intakes near loading docks risk drawing in air that is laden with combustion by-products.

Contextual Observations

Describe the type of neighbourhood, in which the building is situated (i.e.: mixed use, residential, industrial, etc.):

Are there any conflicting activities in the neighbourhood, which may pose a threat to the indoor air quality of the building under investigation?

Contextual observations are intended to identify anything that may pose a threat to the outdoor air quality that may in turn be drawn into the building primarily through the HVAC system. Therefore, it is important to bear in mind the location of the intakes and exhausts identified in the previous sections.

Formulating a Hypothesis

The information collected (data, notes, photos, and sketches) in this field protocol should enable the investigator(s) to formulate a hypothesis as to the cause of the air quality complaints. Due to the complexity of air quality problems, the hypothesis may encompass a number of issues. For example, the hypothesis may indicate a problem with standing water, ventilation and poorly locates air intakes.

The key to generating a hypothesis is to co-relate the data observed with the occupant's complaints. Once the hypothesis is formed it can be tested in the third protocol with instrumentation.

6.3 FIELD PROTOCOL LEVEL III - TESTING THE HYPOTHESIS

The third protocol is a series of experiments testing the hypothesis determined in protocol II. The first and second protocols are mandatory prerequisites for the third. The third protocol employs testing methods with increased accuracy, some of which may require laboratory analysis. The feasibility of such analysis is left to the discretion of the instructor and university.

Essentially protocol III is intended to verify the hypothesis formulated in protocol II. If, however, upon testing the hypothesis is not confirmed a re-evaluation of the hypothesis should be considered and further testing undertaken for its confirmation.

Field protocol III is less structured than the previous two protocols. This enables the investigator(s) to conduct experiments in areas where there is concern. A description of testing instruments is provided to assist the investigator(s) in selecting the appropriate instrument for their experiments. In addition, it is important for the investigator to take both indoor and outdoor measurements for comparisons. The third protocol is organized into three sections: air sampling for gases, microbial testing and the determination of air flow characteristics. A guideline is provided to assist the investigator(s) in determining air flow rates for individual spaces.

Upon completion of protocol III it is expected that the investigator(s) has discovered and confirmed the air quality problem. The investigator(s) should then be capable of recommending mitigation strategies for the alleviation of indoor air quality problems.

Tools Required

Tools required for recording observations:

- Camera
- Notepad
- Neighborhood Map
- Floor Plans and Sections
- Meteorological Data

Tools required for probing and collecting:

- Ladder (if not available on site)
- Tape Measure
- Flashlight
- Extension Mirror (to view around corners in ductwork)
- Smoke Tubes or Incense Sticks and matches
- Tool Box, with screw driver and pliers

Instruments required (In addition to those from Protocol II)

- Carbon Monoxide (CO) monitor, badge or detector tubes
- Ozone (O_3) monitor, badge or detector tubes
- Formaldehyde (HCHO) monitor, badge or detector tubes
- VOC monitor, badge or detector tubes
- Balometer or Anemometer
- Microscope (not required on site)

Air Sampling for Gases

The three types of air sampling processes are:

- CONTINUOUS MEASUREMENTS: this process requires equipment capable of recording pollutant concentration levels continuously over a specified period of time. This type of measurement is most useful to identify the peak and fluctuating periods of concentration;
- TIME AVERAGE MEASUREMENTS: this process involves averaging the concentration of the pollutant over a specified time period; and
- SNAPSHOT MEASUREMENTS: this instantaneous type of sampling is performed over a short period of time and only indicates the level of a contaminant for a specific moment.

The various types of air sampling equipment are:

- DIRECT READING MONITORS: these monitors are available for a variety of contaminants, they are convenient, portable and relatively accurate;
- COLOUR BADGES: the passive colour badges work by diffusion, the reaction between the badge and the air causes the badge to change colour; the level of concentration is then noted by comparison to a colour chart provided by the manufacturer, the badges are useful since they measure the level of air pollutant over a period of time (usually eight hours), however, this requires the investigator(s) to return after the required period of time has lapsed to retrieve the badge (accuracy +/-30%); and
- COLOUR DETECTION TUBES: colour detection tubes involve the passing of air through a tube by a pump, the reagent in the tube changes colour as it reacts with the air, and the concentration of the contaminant within the air can be measured on the side of the tube; this method is not very accurate (+/- 30%).

The four gases (CO, O_3, HCHO, VOC's) can be measured by any one of the three methods previously discussed. These gases should be measured for in a variety of locations where potential sources have been identified, and also in areas where occupants spend their time. For instance: carbon monoxide should be measured in parking garages, smoking rooms, near combustion sources, etc. Similarly, ozone levels should be measured near photocopiers. Formaldehyde and VOC's have a more ubiquitous presence than the previous mentioned gases, and therefore, they should be measured at random throughout the building and specifically in areas of concern.

This level of protocol may require sampling techniques which require laboratory analysis. Typically, only one gas is tested since these testing methods are costly. Therefore, it is expected that the protocol investigator(s) have a thorough understanding of the contaminant to be tested for. The four different techniques are:

- SORBENT SAMPLE TUBES: air is pulled through these tubes by a pump, and airborne chemicals are trapped within the tube. After sampling, the tube is sent to a laboratory for analysis by gas chromatography.
- IMPINGERS: these 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. The liquid can be analyzed to determine the level of concentration of a given contaminant;
- SAMPLE BAGS: these are used to collect airborne pollutants, which are then analyzed by a laboratory in order to determine the level of concentration for a given contami nant;
- FILTERS: these are used to collect indoor air contaminants in aerosol form (that is, particulate, dust, fumes, and mist) by pulling air through an air filter of specific type and pore size with a sample pump, the sample must be sent to a laboratory for analysis.

Microbials

Biological contaminants can be tested for under a microscope. Samples can be taken from areas containing mould and mildew and also from areas of particle concentration, such as horizontal surfaces, ductwork, vacuum bags, etc. When examining these samples under the microscope, try to identify their nature; that is: fibrous, insects, soot, etc. Identification of these samples may require help from other departments within the university, external consultants, or references. Be careful not to contaminant the samples during collection and transportation. A resealable plastic bag is best to collect samples.

Biological contaminants can also be tested for by using a petri dish containing agar, with a pump attachment. This type of test yields a colony count of the microbial in the air. The petri dish is then sent to a laboratory for analysis. Moulds and fungi on building materials, finishes and furnishings can be determined by using a swab test kit, and sending it to a laboratory for analysis.

Air Flow

In order to quantify the amount of air supplied and exhausted from a room, one of three methods can be selected:

- BALOMETER: this instrument measures the airflow rate accurately, when placed tightly over any grilles and diffusers. This one step method eliminates the need for multiple readings, and it outputs the rate of airflow in cubic feet per minute (CFM), cubic meters per hour (m^3/hr) or liters per second (l/s);
- ANEMOMETER: this instrument gives readings of air velocity in meters per second (m/s) or feet per minute (FPM). The anemometer is used to manually calculate the volume flow rate by multiplying the average velocity (therefore take readings at numerous locations across the grille) in a opening by the area of the opening;
- 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;

CAUTION: using smoke sticks or incense may cause irritation to the occupants, always obtain permission prior to their usage.

Smoke tubes are an effective way to monitor the direction of air flow, identifying dead air spaces, identifying the movement of air from a source. These contain chemicals that produce fumes (e.g. titanium tetrachloride) when air is passed through the tube by a rubber squeeze ball. In a similar fashion, incense sticks can indicate airflow direction.

Guidelines for Determining Air Flow for Individual Spaces

Locate the position of all air grilles, indicate on plans and sections.

Determine the airflow rate using the balometer or anemometer.

Trace the airflow pattern throughout the space: (place smoke tubes or incense sticks in front of supply air diffusers and observe the flow of air.)

Indicate the path of air on the section.

Access the ductwork in the space (this will require a flashlight and possibly a ladder).

State the condition of the grille(s):

1	2	3	4	5	6	7	8	9	10
poor									excellent

Figure 30: Measuring the airflow rate within ductwork.

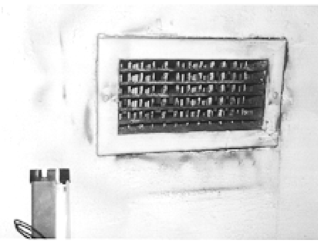


Figure 31: Dirt build-up on supply diffuser.

Remove the grille to inspect the condition of the grille and the duct.

Calculate the flow rate using the balometer or anemometer, a second time. Compare values to those values taken with the grill in place.

Compare the total air supply to exhaust from the room. What causes the difference, if any?

State the condition of the ductwork:

1	2	3	4	5	6	7	8	9	10
poor									excellent

Does it requires cleaning?

Collect samples from the duct in a plastic bag or container for microscopic analysis. Be careful not to contaminant the sample.

6.4 CONCLUSIONS AND MITIGATION STRATEGIES

The purpose of these indoor air quality investigations is to determine the level and sources of pollutants within a specific building and their health effects on the occupants. Once the hypothesis has been confirmed, the investigator(s) must develop reasonable mitigation measures with the assistance of the information provided in this Resource Package, by the instructor and external references. In order to assist the students reaching their conclusions, the following list of examples of common mitigation strategies is included.

Operation of Mechanical Systems:

- Ensure the operation of all mechanical systems at all times when the building is occupied;
- Turn on the ventilation system several hours prior to occupancy;
- Increase the amount of make-up air supplied to each room;
- Increase the amount of fresh air supply to the building by adjusting the dampers;
- Ensure that the air intake is free from potential contaminants;
- Add supply diffusers or return grilles;
- Revise layout of supply and return grilles to ensure short circuiting does not occur;
- Ensure adequate ventilation standards, according to Table 6.4; and
- Balance mechanical system.

TABLE 6.4 Minimum Ventilation Air for Various Activities From: Parmley, 1988.

Type of Occupancy	Ventilation Air Rate (cfm/ person)
Inactive, e.g.: theaters	5
Light activity, e.g.: offices	10
Light activity with some odour generation, e.g.: restaurant	15
Light activity with moderate odour generation, e.g.: bars	20
Active work, e.g.: shipping rooms	30
Very active work, e.g.: gymnasiums	50

It is important to note that the ventilation rates supplied in Table 6.4 are minimum values.

Mechanical Exhausts:

- Increase exhaust from pollution producing areas, such as kitchens, photocopy rooms, bathrooms, paint rooms, etc.

Fuel Emissions:

- Repair any fuel leaks; and
- Increase combustion air to the mechanical room in order to prevent backdrafting.

Air Filters:

- Add or replace air filters, ensuring they are the proper size and efficiency;
- Add or replace air filter housing to ensure air is not allowed to by-pass the filter;
- Institute regular filter maintenance; and
- Install or replace gas adsorption media to the air filtration unit.

Cleaning of Mechanical Components:

- Clean all ductwork and furnaces;
- Institute regular vacuuming of ducts and grilles; and
- Do not use space above suspended ceiling as an air plenum, it is difficult to clean and maintain.

Building Hygiene:

- Thorough cleaning of entire building, in particulate those places which harbour dust, moulds and micro-organisms;
- Thoroughly vacuum all areas;
- Install a central vacuum systems, or at a minimum use a high filtering portable vacuum cleaner, with a HEPA filter;
- Use a vacuum integrated floor polisher, with HEPA filter; and
- Replace cleaning chemicals with those which are unscented, non-toxic and environmen tally friendly.

Building Envelope:

- Ensure the roof is drains properly;
- Repair any cracks; and
- Ensure penetrations are well air-sealed.

Miscellaneous:

- Remove carpeting;
- Wrap insulation around cold pipes to prevent condensation and mould growth;
- Install a humidifier, and ensure that it drains properly to prevent mould growth;
- Reset thermostats and humidistats; and
- Ensure that hazardous materials are properly stored and vented, e.g.: paints.

7.0 CONCLUSION

It is the intention of this Vital Signs Resource Package to introduce architecture students to the topic of indoor air quality. Health in the built environment is a complex issue that must be balanced with numerous others issues during the design and construction of a building. Architects are well positioned to advance the quality of indoor environments through their selection of building materials, finishes and furnishings. As well as through the design of the building's HVAC systems.

It is hoped that this Resource Package will illuminate the topic of air quality and provide a point of departure for further investigation and exploration within the field of indoor air quality. This Resource Package has presented the fundamentals of indoor air quality and methods to conduct investigations. This package can serve as a foundation for architecture students in their future designs of healthy indoor environments.

8.0 GLOSSARY

Absorption - The procedure by which one substance enters the inner structure of another.

Acrylic - A term given to a group of synthetic resins made by polymerizing esters of acrylic acids.

Acute symptoms - Severe symptoms over a brief period of time, which occurs soon after a short period of exposure.

Adsorption - When liquids, dissolved substances or gases, condense and adhere to the molecular surface of solids.

Aero-dynamic diameter - The effective diameter of a particle (generally referred to as a sphere) of unity density based on its aerodynamic properties.

Aerosol - Liquid droplet or solid particle dispersed in a gas.

Aliphatic - A term used to describe open-chain carbon compounds (e.g.: methane and ethane).

Allergen - An antigen that causes an allergy.

Allergy - An unusual sensitivity to a particular food, particle, irritant, etc. (i.e.: reaction to chemical and physical stimuli).

ALTER - Acceptable long-term exposure range as defined by Health and Welfare Canada. It represents a concentration range to which it is assumed a person may be exposed over their lifetime without a deleterious risk to their health, based on existing information.

Alveoli - Terminal air sacs of the lung respiratory tree.

Ambient air - Outside air.

Anemia - A deficiency of hemoglobin and red blood cells.

Anemometer - An instrument used to measure air speed.

Antigen - A substance which stimulates the production of an antibody after entering the human body, after which the individual may elicit a specific immune response upon later exposure.

Aromatic - A group of hydrocarbons and their derivatives having physical and chemical properties resembling those of benzene (i.e.: aromatic compounds are distinguished by the presence of benzene nucleus).

Arthralgia - Pain in joints.

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASTER - Acceptable short-term exposure range as defined by Health and Welfare Canada. It represents a concentration range to which it is assumed a person may be exposed over a specific time period without a deleterious risk to their health, based on existing information.

Asthma - Inflammation of the airways, causing obstruction. The condition is reversible.

Atmospheric Dust Spot Efficiency Test - The atmospheric dust spot efficiency test is usually used to rate medium efficiency air cleaners and is based on the filter's ability to reduce soiling of a clean paper target. Although the test is useful for comparative purposes, the removal of small respirable particles may be lower than indicated.

BTU - British Thermal Unit.

Carcinogen - Cancer-causing substance.

CFM - Cubic feet per minute.

Chronic symptoms - Symptoms which persists for a long period of time.

Cilia - Short hair lining the trachea.

CMHC - Canada Mortgage and Housing

Commissioning - the process of verifying and documenting the performance of HVAC systems to ensure that their operation is in accordance with their design specifications.

Conjunctiva - Mucous membrane that lines the eyelids and covers the surface of the eyeballs.

Creosote - bituminous build-up in chimneys

CSA - Canadian Standards Association

Dampers - Devices that are used to control and vary airflow through air ducts, intakes or outlets.

Dermatitis - Inflammation of the skin.

Diffusers and grilles - Diffusers supply air and grilles return air.

Dyspnea - Shortness of breath.

Edema - A local or generalized condition in which the body tissues contain an excessive amount of tissue fluid.

Efflorescence - Refers to the formation of a fine (mould-like) whitish crystal crust on surfaces. The crystals are generally sodium salts which have diffused from a specific surface (e.g.: basement cement floors).

Emphysema - A lung disease associated with the thinning and breakdown of the alveoli.

EPA - Environmental Protection Agency.

Epistaxis - Nose bleed.

Erythema - Reddening of the skin.

Exfiltration - Air leakage outward.

Exhaust air - Air that is removed from rooms and/or additional spaces within a building and is exhausted.

Fungi - Eukaryotic organisms which lack chlorophyll and are formed by hyphae with rigid cell walls.

HEPA - High efficiency particulate absolute filter.

Hypersensitivity - Similar to an allergic reaction. Someone who is hypersensitive will experience an increased sensitivity to a previously encountered antigen.

Infiltration - Air leakage inward.

Inversion - Thermal atmospheric inversions are atmospheric conditions in which a mass of cold air is trapped by a mass of warm air above it. The warm air acts as a lid and prevents the cold air from rising (i.e.: pollutants cannot escape upwards). If sufficient wind is not present to disperse pollutants, they will remain in the area, near ground level, until the inversion ends.

Ischaemia - A reduction in blood supply to specific parts of the body.

Make-up air - Outdoor air supplied to a building to replace the air removed by exhaust ventilation.

Malaise - Obscure feeling of discomfort.

Micrometer (mm) - A unit of length equal to one millionth of a meter, 10-4 of a centimeter, or approximately 1/25,000 of an inch.

Myalgia - Pain in the muscles.

NAAQS - National Ambient Air Quality Standards, United States Environmental Protection Agency.

NRC - National Research Council.

Outgassing - A form of evaporation occurring with solid materials; the slow release of chemicals that are not perfectly stable within the structure of the material.

Pathogen - An agent capable of causing disease.

Pharyngitis - Inflammation of the phayrnx.

Pharynx - Passageway for air from the nasal cavity to the larynx and food from the mouth to esophagus.

Photo-chemical oxidants - Air pollutants that are formed by the action of light (or other forms of radiant energy) on hydrocarbons and the oxides of nitrogen.

PIC - Products of Incomplete Combustion.

Pneumonitis - Inflammation of the lungs.

Pulmonary - Relating to the lungs.

Recirculated air - Air that is removed from within the structure and is intended for reuse as supply air.

Return air - Air that is removed from rooms and/or additional spaces within a building and is exhausted or recirculated.

Rhinitis - Inflammation of the mucosa lining in the nose.

RSP - Respirable Suspended Particles defined by a size of less than 10 µm.

Seasonal Affective Disorder (SAD) - A depression that tends to recur as the daylight hours shorten in the fall and winter.

Sensitization - Exposure to a specific antigen, causing an individual to experience a heightened response when re-exposure to the same antigen occurs. The heightened response is a secondary immune response.

Short-circuiting - When supply air flows toward the exhaust grilles without entering the breathing zone.

Spectroscopy - Light is absorbed or emitted by various elements and compounds at specific and well-defined wavelengths. Consequently, spectroscopy involves the observation of the wavelength and intensity of light absorbed or emitted by various materials.

Spore - An environmentally resistant, dormant, reproductive cell body formed by specific microorganisms.

Supply air - Air that is supplied to rooms and/or additional spaces within a building.

Thermal comfort - Relates to the unique individual perspective of what constitutes an acceptable thermal environment.

Thermal environment - Includes variables within the environment (e.g.: temperature, water vapour, etc.) which affect a person's heat loss (comfort).

Threshold limit value (TLV) - Refers to an established value (i.e.: concentration) for a specific contaminant to which the majority of workers can be continuously exposed with no harmful effects. TLV's are time-weighted concentrations, usually based on eight hours of exposure per day.

Trachea - A cylindrical, cartilaginous tube which extends from the larynx to the bronchial tubes.

Toxicity - Refers to the harmful effect that a substance can have on a particular biological system or mechanism, and the conditions necessary for a harmful effect to occur.

WHO - World Health Organization

9.0 ANNOTATED BIBLIOGRAPHY

BOWER, JOHN. THE HEALTHY HOUSE, NEW YORK: CAROL COMMUNICATIONS, 1989.

This reference details issues such as: How to find, buy or build a healthy house; How to "cure" a sick house; Why materials are toxic. It also provides a description of indoor air contaminants, and alternative building techniques.

CANADIAN STANDARDS ASSOCIATION

This association has a number of relevant publications, including: CSA 2204-94 Guidelines for Managing Indoor Air Quality in Office Buildings: Occupational Health and Safety, June 1994.

DUNLOP, MARILYN. BODY DEFENSES, TORONTO: IRWIN PUBLISHERS, CO., 1987.

This document describes the immune system and how it can work both for and against the body. The role of stress in the immune system, and system malfunctions are described. This reference also provides information regarding current research in the field.

ENVIRONMENTAL PROTECTION AGENCY, U.S. ; INDOOR AIR DIVISION (6607J), OFFICE OF AIR AND RADIATION, 401 M STREET, S.W., WASHINGTON, D.C., 20460

This agency has a variety of informative and exceptional publications covering a wide range of issues concerning indoor air quality, such as:
Building Indoor Air Quality: A Guide for Facility Managers,
Indoor Air Pollution: An Introduction for Health Professionals,
The Inside Story: A Guide to Indoor Air Quality, Sept. 1993,
Residential Air Cleaning Devices, Feb. 1990,
Indoor Air Quality in Public Buildings, Volume I and II, Sep. 1988,
Ventilation in Office Buildings, July 1990,
Carpet and Indoor Air Quality, October 1992.

GODISH, THAD. INDOOR AIR POLLUTION CONTROL, MICHIGAN: LEWIS PUBLISHERS, INC., 1989.

A valuable book to a wide audience, which includes: clinical ecologists, architects, consultants, public health professionals and environmental professionals. It defines indoor air pollution in terms of the scope, sources and the health effects of many contaminants, such as asbestos, combustion pollutants, radon, formaldehyde, volatile organic compounds, pesticides and biogenic particles. Each topic is the discussed in great length and includes details on mitigation practices. This book references regulatory policies and standards within the United States. Godish provides useful diagnostic procedures for indoor air quality investigations and mitigation practices.

HANSEN, DOAN J, EDITOR. THE WORK ENVIRONMENT, VOLUME THREE: INDOOR HEALTH HAZARDS, BOCA RATON: LEWIS PUBLISHERS,1994.

This book focuses on health problems associated with indoor contaminants in the workplace. It provides a detailed summary for conducting indoor air quality investigations within the work environment.

HARRIS, MARJORIE. BETTER HOUSE AND PLANET, TORONTO: KEY PORTER BOOKS, 1991.

This book is in the form of an alphabetical dictionary from adhesives to zippers, providing over 500 tips for healthy housekeeping.

KAY, JACK G., GEORGE E. KELLER AND JAY F. MILLER. INDOOR AIR POLLUTION: RADON, BIOAEROSOLS AND VOC'S, CHELSEA, MICHIGAN: LEWIS PUBLISHERS, 1991.

Focuses specifically on the contaminants of radon, bioaerosols and VOC's, with brief information on other contaminants.

LESLIE, G.B. AND F.W. LUNAU. INDOOR AIR POLLUTION: PROBLEMS AND PRIORITIES, CAMBRIDGE: CAMBRIDGE UNIVERSITY PRESS, 1992.

This book addresses the common pollutants in the indoor environment, their health symptoms, control measures and regulatory guidelines.

LINIES, LTD. CMHC GUIDE TO VENTILATION SYSTEMS, OTTAWA: CANADA MORTGAGE AND HOUSING CORPORATION, MARCH 1988.

This publication discusses ventilation systems in the home with respect to their potential to remove concentrations of air pollutants. It describes ventilation problems during the winter months, indicating that indoor pollutant concentrations are at their highest during this time of year. This reference provides a detailed explanation of various ventilation systems: exhaust systems; supply air systems; and balanced supply and exhaust.

MATHEWS, BONNYE L. CHEMICAL SENSITIVITY, JEFFERSON, NORTH CAROLINA: MCFARLAND AND COMPANY, INC., PUBLISHERS, 1992.

Mathews has recovered from chemical sensitivity. This book describes the illness, what it is like to suffer from this disease and provides a guide for the patient as to how to cope with hypersensitivity, sick building syndrome and other environmental illnesses.

MEYER, BEAT. INDOOR AIR QUALITY, MASSACHUSETTS: ADDISON-WESLEY PUBLISHINGS COMPANY INC., 1983.

This reference serves as a detailed scientific report of air quality, including air impurities/monitoring/analysis; exposure levels and effects; control measures; and legislation.

OFFICE OF TECHNOLOGY ASSESSMENT WORK FORCE. REPRODUCTIVE HAZARDS IN THE WORKPLACE, PHILADELPHIA: SCIENCE INFORMATION RESOURCE CENTER, J.B. LIPPINCOTT COMPANY, 1988.

This reference provides a detailed report of reproductive health hazards, both for men and women. The focus for this document is the workplace. Reproductive health is to be safeguarded for the health of future generations, and for individual well-being. A discussion of these issues occurs at a biological level, as well at a human rights and government legislative level.

PILATOWICZ, GRAZYNA. ECO-INTERIORS, NEW YORK: JOHN WILEY AND SONS, 1995.

This book covers a wide range of environmental issues, including a discussion of indoor air quality. This reference is useful for the selection of non-toxic interior finishes and furnishings.

REA, WILLIAM J. CHEMICAL SENSITIVITY, VOLUME 1. BOCA RATON: LEWIS PUBLISHERS, 1992.

This is the first volume in a four volume set on chemical sensitivity. It deals with the nature of the illness, diagnosis, and treatment from the perspective of Dr. Rea of the Environmental Health Center in Dallas, Texas. This reference emphasizes the effect of environmental pollution of the human body, through a variety of case studies. It adopts a medical perspective of the subject.

REA, WILLIAM J. CHEMICAL SENSITIVITY, VOLUME 2. BOCA RATON: LEWIS PUBLISHERS, 1994.

The second volumes deals with sources of total body load. It identifies various pollutants, their impact on the total body load, and how the body deals with these pollutants while attempting to maintain homeostasis. Awaiting Volumes 3 and 4.

ROGERS, SHERRY. THE ENVIRONMENTAL ILLNESS SYNDROME: A PRESCRIPTION FOR ENVIRONMENTAL ILLNESS, NEW YORK: PRESTIGE PUBLISHING, 1986.

Rogers is a doctor who has recovered from environmental illness. The focus of this book is on maintaining optimum health, specifically the immune system, and preventing disease, through food allergies and rotation diet.

ROUSSEAU, DAVID WITH W.J. REA AND JEAN ENWRIGHT. YOUR HOME, YOUR HEALTH AND WELL-BEING, VANCOUVER: CLOUDBURST PRESS BOOKS, HARTLEY AND MARKS PUBLISHERS, 1988.

This book covers an introduction to outdoor and indoor pollutants within a home or apartment. It provides design ideas and detailed diagrams for construction. Enwright provides advice for living with environmental illness.

ROUSSEAU, DAVID. ENVIRONMENTAL BY DESIGN, POINT ROBERTS, WASHINGTON: H & M PUBLISHERS, 1992.

An excellent reference for the selection of non-toxic building materials. It examines tradition materials, and assesses numerous of products currently on the market.

RYLANDER, RAGNAR AND ROBERT JACOBS. ORGANIC DUSTS: EXPOSURE, EFFECTS AND PREVENTION, BOCA RATON: LEWIS PUBLISHERS, 1994.

This book discusses organic compounds and their effects on human health. It details the sources, composition and prevention measures.

SAMET, JONATHAN AND JOHN SPENGLER, EDITORS. INDOOR AIR POLLUTION: A HEALTH PERSPECTIVE, BALTIMORE: THE JOHN HOPKINS UNIVERSITY PRESS, 1991.

An excellent course textbook. It examines indoor air pollutants and assesses their health effects, as well as providing regulations on the various contaminants. It discusses current research issues, from a variety of contributors, including: epidemiologists, clinicians, risk assessors, microbiologists and engineers.

TATE, NICHOLAS. THE SICK BUILDING SYNDROME, FAR HILLS, NEW JERSEY: NEW HORIZON PRESS, 1994.

A good, introductory reference. Covers issues and key factors of sick building syndrome both within home and work environments. Provides case examples of sick buildings. Awaiting final publication.

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PARMLEY, ROBERT O. HVAC FIELD MANUAL, NEW YORK: MCGRAW-HILL BOOK COMPANY, 1988.

RAPP, DORIS. ALLERGIES AND THE HYPERACTIVE CHILD, NEW YORK: SIMON AND SCHUSTER, INC., 1985.

STEIN, BENJAMIN AND J.S. REYNOLDS. MECHANICAL AND ELECTRICAL EQUIPMENT FOR BUILDINGS, 8TH EDITION, NEW YORK: JOHN WILEY AND SONS, 1992.

WORLD HEALTH ORGANIZATION (1946) FROM THE PREAMBLE TO THE CONSTITUTION OF WORLD HEALTH ORGANIZATION, ADOPTED 22 JULY 1946. IN T.L. BEAUCHAMP AND L. WALTERS (EDS) CONTEMPORARY ISSUES IN BIOETHICS, THIRD EDITION, BELMONT CA: WADSWORTH PUBLISHING.

**TABLE A.1:
TABLE OF CONTAMINANTS**

CONTAMINANTS	CHARACTERISTICS	SOURCES
Carbon dioxide **CO_2**	Colourless, odourless, non flammable gas.	Combustion products of substances containing carbon (natural gas); human and animal respiration.
Carbon monoxide **CO**	Colourless, odourless, non irritating toxic gas	Combustion by-product; HVAC systems; backdrafting; petroleum driven appliances; clothes dryers; tobacco smoke; combustion of wood and coal; fireplaces; kerosene space heaters; parking garages; etc.
Nitrogen Oxide **NOx**	Reddish-brown in colour, water soluble, strong oxidant.	Outdoor infiltration; combustion processes; vehicle fumes; gas appliances and heaters; industrial furnances; hospital operating rooms.
Formaldehyde **HCHO**	Colourless, irritating, pungent odour, water soluble.	Vehicle exhaust fumes; industrial manufacturing processes; adhesives, building materials; tobacco smoke; Urea-formaldehyde foam insulation (UFFI); furnishings; textiles and new fabrics; aerosol products; embalming and anatomy pathology; fireplaces; fertilizers; pesticides; etc.
Radon	Colourless, odourless,tasteless, radioactive, water soluble gas, occurs naturally	Building materials; masonry, drywall, soils, water spray; dishwashers; washing machines; showers; well water.
Ozone **O_3**	Bluish in colour, odourous, high reactive gas.	Photochemical reactions involving sunlight with hydrocarbons and nitrogen oxides; photocopy machines; electronic air cleaners; aerosol sprays; and electronic equipment.

ASHRAE = American Society of Heating Refrigeration and Air Conditioning Engineers, ASTER = Acceptable short-term exposure range,

CONTAMINANTS	SYMPTOMS AND HEALTH EFFECTS	STANDARDS
Carbon dioxide **CO_2**	Fatigue; headaches; perception of warmth; sleepliness; dizziness; shortness of breath; and general feeling of stuffiness. Chronic exposure: bone demineralization	ASHRAE 1800 mg/m^3 (contin.) ALTER < 6300 mg/m^3
Carbon monoxide **CO**	Vomitting; impaired vision; headaches; nausea; confusion; drowsiness; bluing of finger nails in the cutical regions; fatigue; shortness of breath; and chest pains. Chronic exposure: heart arythmia; heart attack; impairment of mental functions; convulsions; coma and possibly death. For effects on pregnant women, please refer to appendix.	WHO 10 mg/m^3 (8 hr.), 30 (1 hr.) WHO 60 mg/m^3 (30 min.) WHO 100 mg/m^3 (15 min.) ASHRAE 10 mg/m^3 (8 hr), 40 (1hr) NAAQS 10 mg/m^3 (8 hr), 40 (1hr) ASTER <9.9 mg/m^3 (8 hr.) ASTER <29ppm (1 hr.)
Nitrogen Oxide **NOx**	Eye, nose and throat irritation; changes in sensory preceptions; pneumonia; and bronchitis. Chronic exposure: respiratory illness and pulmonary disfunction.	WHO 0.15 mg/m^3 (24 hr.) WHO 0.4 mg/m^3 (1hr.)
Formaldehyde **HCHO**	Watery eyes; skin rashes; coughing; asthma; burning sensation in the throat; runny and bleeding nose; sinus congestion; vomitting; diarrhea; headaches; blurred vision; dizziness; difficulty sleeping; and lethargy. Chronic exposure: reproductive and menstrual problems; chronic respiratory disease; and cancer.	WHO 0.1 mg/m^3 (30 min.) ASHRAE 0.1 mg/m^3 (ceiling) ALTER Action level 0.12 mg/m^3 (5min.) ALTER Target level 0.06 mg/m^3 (5min.)
Radon	Known carcinogen. Chronic exposure: Lung cancer	Action levels: WHO 100 Bq/m^3 (annual average) ASHRAE 0.027 WL (ann average) NAAQS 148 Bq/m^3 (ann. average) ALTER 800 Bq/m^3 (ann average)
Ozone **O_3**	Nose, throat and trachea irritant; coughing; chest discomfort; headaches; sensory irritations; inflammation of the airways and alveoli; and lung dis-function.	WHO 0.1-0.12 mg/m^3 (8 hr) WHO 0.15-0.2 mg/m^3 (1 hr) ASHRAE 0.1 mg/m^3 (contin) NAAQS 0.235 mg/m^3 (1 hr) ASTER <0.24 mg/m^3 (1 hr)

ALTER = Acceptable long-term exposure range, NAAQS = National Ambient Air Quality Standards, WHO = World Health Organization, Bq = Becquerel (a unit of radioactivity), WL = working level is a unit for measuring exposure to radon gas

**TABLE A.1:
TABLE OF CONTAMINANTS
CONT'D**

CONTAMINANTS	CHARACTERISTICS	SOURCES
Sulphur Dioxide SO_2	Colourless, reactive gas with a suffocating odour, it's vapour density is heavier than air; water soluble.	Combustion of sulphur containing fuels and industrial processes, such as: ore smelting; kerosene heaters; HVAC systems; wood and coal burning stoves; sewer gas leaks.
Hydrogen Sulphide H_2S	Colourless gas, with a pungent rotten egg odour, it's vapour density is heavier than air.	Natural gas extraction; livestock ranches; sewer gas; decomposition of organic matter in septic tanks; manure piles.
Fibrous Materials	Man-made mineral fibers; ceramic fibers; fiberglass; possible carcinogen (i.e.: asbestos).	Fireproofing; additives to floor tiles; brake liners; laboratory and electrical equipment; insulation.
Particulate	Inorganic and organic substances; able to remain suspended for long periods; respirable by individuals	Dust; aerosols; animal and human dander; ETS; building materials; fly ash; combustion by-product; microorganisms; outdoor environments; vegetation; automobiles; industrial and commercial processes.
Biological Contaminants	Minute particles of living matter (fungus, moulds, etc).	Humans; microorganisms; vegetation; insects; water; pollens; spores; fungus; molds; pets.
Environmental Tobacco Smoke ETS	Visible white smoke, lighter than air, contains up to 2000 compounds, 12 known and suspected carcinogens.	Cigarettes, pipes, cigars and any other sources of tobacco smoke.
Volatile Organic Compounds VOC	Collective name given to a diverse group of carbon based vapours and gases, which may exist in the form of a gas, liquid or solid particle in the atmosphere, food, and/or water.	Synthetically produced by chemical reactions; carpet; petroleum products; latex paint; pesticides; cleaning products; air fresheners and deodorizers; furniture polish; polyurethane; floor finishes; ETS; plastics; floor wax; moth balls; felt pens; permanent press fabrics; and polyesters.

ASHRAE = American Society of Heating Refrigeration and Air Conditioning Engineers, ASTER = Acceptable short-term exposure range,

CONTAMINANTS	SYMPTOMS AND HEALTH EFFECTS	STANDARDS
Sulphur Dioxide **SO_2**	Asthmatic attacks; eye, nose and throat irritation; acute chronic respiratory disease; impaired pulmonary function; intense irritation; decrease in nasal mucous flow and cilliary activity.	WHO 0.35 mg/m^3 (1 hr) WHO 0.5mg/m^3 (10 min) ASHRAE 0 (yr), 0.065 mg/m^3 (24h) NAAQS 0 (yr), 0.365 mg/m^3 (24 hr) ASTER <1 mg/m^3 (5 min) ALTER <0.05 mg/m^3
Hydrogen Sulphide **H_2S**	Unconsciousness and respiratory paralysis; Chronic exposure: seizure and death. Death within a few seconds.	WHO 0.15 mg/m^3 (24 hr) WHO 0.007 mg/m^3 (30 min) ASHRAE 0.04-0.05 mg/m^3 (24h) ASHRAE 0.042 mg/m^3 (1 hr)
Fibrous Materials	Skin and respiratory irritation; reduction in lung capacity, alveolar region; possible lung cancer.	
Particulate	Eye, nose and throat irritation; bronchitis; respiratory infection; allergic reaction; asthma; chronic respiratory disease; and possible lung cancer.	NAAQS 0.075 mg/m^3 (annual) NAAQS 0.26 mg/m^3 (24 hr) ASTER <0.1 mg/m^3 (1hr), RSP <2.5µm ALTER <0.04 mg/m^3 (1hr), RSP <2.5µm
Biological Contaminants	Infectious disease; allergic reactions; rhinitis; pharyngitis; dyspnea; conjunctival irritation; headaches; dizziness; nausea, rashes; fever; malaise; and possibly death.	
Environmental Tobacco Smoke **ETS**	Eye and throat irritation; headaches; rhinitis; coughing; wheezing; sneezing; nausea; blurred vision; dyspnea; sensory irritation; cancer; ischaemic heart disease; loss of appetite; sudden infant death syndrome; in some cases, retardation of children whose mothers where exposed to tobacco smoke during pregnancy.	
Volatile Organic Compounds **VOC**	Eye, nose and respiratory irritation; rhinitis; fatigue; headaches; impaired memory; decreased ability to concentrate; visual disorders; depression; heightened perception of odours; epistaxis; pharyngitis; worsening asthma; conjunctival irritation; nausea; myalgia. Chronic exposure: damage to the lungs, liver, heart, kidneys and nervous system.	

ALTER = Acceptable long-term exposure range, NAAQS = National Ambient Air Quality Standards, WHO = World Health Organization

TABLE A.1:
TABLE OF CONTAMINANTS CONT'D

CONTAMINANTS	CHARACTERISTICS	SOURCES
Aromatic Compounds	Distinctive odour.	Compounds derived from benzene.
Benzene **C_6H_6**	Known carcinogen.	Tobacco smoke; gasoline vapours; paints; building materials; varnishes; putty; auto exhaust; plastic and rubber solvents.
Xylene		Solvents; enamels; non-leaded fuels; paints; plastics; pesticides; dyes; and pharmaceuticals.
Styrene		Plastics; resins; adhesives; foams; lubricants; carpets; and insulation.
Toluene		
Halogenated Hydrocarbons The following are a few examples:	Compounds containing hydrogen.	Aquatic activities; swimming pools; wave pools; spas; whirlpools; waterslides.
Trichloroethylene $CClCHCl$		Adhesives; tape; cosmetics; insulation; photographic equipment; opaquing fluid; spot removers; lacquers; varnishes and cleaning fluids.
1Tetrachloroethylene CCl_2CCl_2		Dry cleaned clothes; degreasers; passive smoking; automobiles; pumping gas.
1,1,1-Trichlorethane CCl_3CH_3		Aerosol propellents; cleaning solvents; pesticides; household cleaners; fabric protectors; dry cleaned clothes.
Methylene Chloride CH_2Cl_2	Liquid/vapour evaporates quickly.	Paint strippers; spray paints; fabric care products; adhesives; adhesive removers; automobile products; and aerosols.

ASHRAE = American Society of Heating Refrigeration and Air Conditioning Engineers, ASTER = Acceptable short-term exposure range,

CONTAMINANTS	SYMPTOMS AND HEALTH EFFECTS	STANDARDS
Aromatic Compounds	Skin irritation and dermitis; organ damage.	
Benzene C_6H_6	Headaches; dizziness; fatigue; loss of appetite; irritability and nervousness; repiratory irritation; drowsiness; loss of conciousness; anemia; possibly leukemia; blood and liver disease.	
Xylene	Skin irritation; decrease in the number of white and red blood cells; damage to heart, liver, kidney and nervous system; and menstral problems.	
Styrene	Headaches; fatigue; stupor; depression; lack of co-ordination; and possible eye injury.	WHO 0.8 mg/m^3 (24 hr) WHO 0.5 mg/m^3 (10 min)
Toluene	Symptoms similar to drunkenness; impairment of judgement and reflexes; irritant to the skin, eyes and upper respiratory tract.	WHO 0.8 mg/m^3 (24 hr) WHO 1 mg/m^3 (30 min)
Halogenated Hydrocarbons The following are a few examples:	Respiratory distress through: wheezing, coughing, bronchospasms, difficulty in breathing; extreme exhaustion; lacrimation; eye irritation; potential of liver and kidney damage and possible death; narcotic effects ranging from mild drunkenness to deep anesthesia.	
Trichloroethylene CClCHCl	Eye and respiratory irritation; dizziness; fatigue; headaches; nausea and loss of co-ordination; liver and kidney damage; heartbeat irregularity; lung damage and death.	WHO 1 mg.m^3 (24 hr) ASHRAE 2 mg.m^3 (annual), 5 (24h) ASHRAE 16 mg.m^3 (30 min)
1 Tetrachloroethylene CCl_2CCl_2	Hepatitis; loss of appetite; weakness; headaches; liver damage; burning irritation of eyes; excessive tearing; nose and throat irritation.	
1,1,1-Trichlorethane CCl_3CH_3	Eye irritation.	
Methylene Chloride CH_2Cl_2	Eye irritation; urinary tract irritation; skin dryness; dermatitis; loss of co-ordination and alertness; lung damage; pulmonary edema; bronchitis; asphyxiation; carcinogenic.	WHO 3 mg.m^3 (24 hr) ASHRAE 20 mg.m^3 (annual) ASHRAE 50mg.m^3 (24h)

ALTER = Acceptable long-term exposure range, NAAQS = National Ambient Air Quality Standards, WHO = World Health Organization

The following is an example of a consent form used by students at The University of Calgary. As such, it will require revision for use at other schools.

Research Project : Investigation of a building with potential air contaminants.

Investigator(s): ______________________________

This consent form, a copy which has bee given to you, is only part of the process of informed consent. It should give you the basic idea of what the research project is about and what your participation will involve. If you would like more detail about anything mentioned here, or information not included here, feel free to ask. Please take the time to read this form carefully and to understand any accompanying information.

The purpose of this study is to use your premise (by invitation) as a case study for conducting an indoor air quality investigation. The person(s) conducting the study is enrolled in the Faculty of Environmental Design at The University of Calgary. The following note will be added to the final report:

> *This report is submitted in accordance with formal requirements for the course, EVDS 621: Health and the Built Environment, in the Faculty of Environmental Design at The University of Calgary. The purpose of this report is strictly an academic exercise and not intended to offer professional judgement. As such, neither the authors, the instructor nor The University assumes responsibility if the content of this report is used for any other purpose.*

In conducting this investigation, the student(s) will be asking you a series of questions to determine if your symptoms can be co-related with a type of air contaminant. Please note that you have the option to:

- refuse to answer any or all of the questions,
- terminate the interview and investigation at any time,
- restrict the student(s) from any or all parts of the building, and
- ask the student(s) to leave the premise at any time.

Your signature on this form indicates that you have read and understood to your satisfaction the information regarding your participation in this research project and agree to participate as a subject. In no way does this waive your legal rights nor release the student(s), or institution from their legal and professional responsibilities. If you have any further questions, please call Professors Tang Lee or Dixon Thompson at (403) 220-6601.

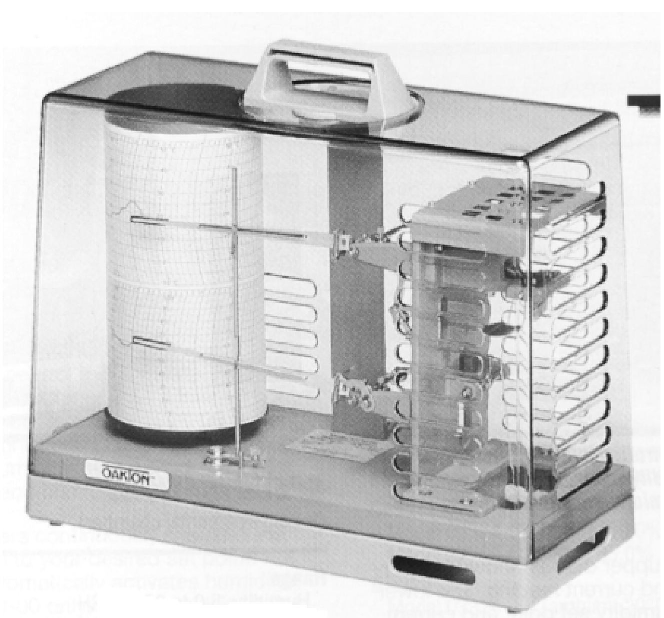
Name: ____________________ Signature: ____________________ Date: __________
A copy of this consent form is provided for your records.

EQUIPMENT DESCRIPTIONS

ABSORPTION TUBES

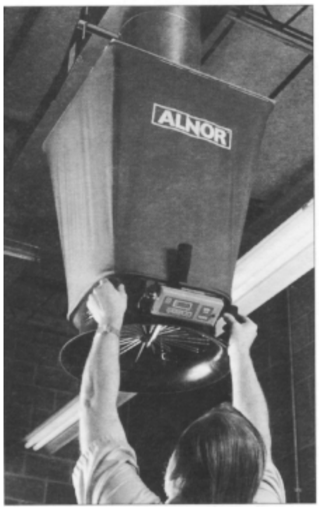
The detector tubes provide an on-the-spot observation of a given contaminant. The three steps to operate the detector tubes are as follows:

1) break off the tip of a fresh detector tube;
2) insert the tube with the arrow pointing toward the pump, into the pump's inlet; and
3) pull the pump handle until it has automatically locked, drawing a 100 cc sample.



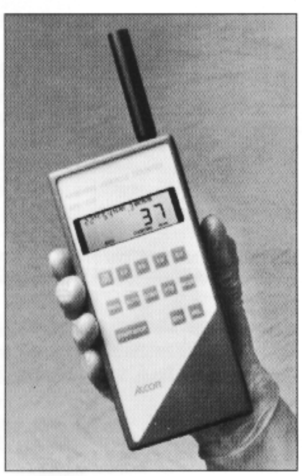
HYGROTHERMOGRAPH

Quartz controlled drive mechanism rotates a drum at a constant speed. The hygrothermograph can operate for six months on a single AA battery. The hygrothermograph records temperature and humidity on a seven day rotation. The humidity sensor is two human hair bundles providing increased accuracy. Sensors are coupled to pens through a mechanical lever.



BALOMETER

The balometer contains a multipurpose reader which save time and effort while providing direct, accurate measurements and commonly performed calculations, such as sum/ averages. A selection of probes are also available to measure volumetric flow rates.



AIRBORNE PARTICLE COUNTER

The APC-1000 sizes particles in the ranges of 0.3, 0.5, 1.0 and 5.0 µm while simultaneously monitoring relative humidity and temperature. It continuously stores up to 200 data sets automatically or as the user chooses, the data can later be reviewed on display or printed.

The following is a selective list of companies within North America which supply indoor air quality equipment.

Air Quality Research
P.O. Box 14063
Research Triangle Park, NC
27709 USA

Airflow Developments Ltd.
150 Armstrong Ave, Unit 8
Georgetown, ONT
Canada L7G 5G8

Alnor Instrument Company
7555 N. Linder Ave.
Skokie, IL 60077 USA
In Canada:
40 North Rivermede Rd., Unit 5
Concord, ONT L4K 2H3

BGI Incorporated
58 Guinan Street
Waltham, MA 02154 USA

Cole-Parmer Instrument Company
7425 North Oak Park Avenue
Niles, Illinois 60714 USA
In Canada: Labcor Technical Sale
7565, Ave. M.B. Jodoin
Anjou, QC H1J 2H9

Gasonic Instruments Inc.
#16,4220-23rd Street N.E.
Calgary, AB
Canada T2E 6X7

GENEQ inc.
8047 Jarry East
Montreal, QC
Canada H1J 1H6

Industrial Scientific Corporation
1001 Oakdale Road
Oakdale, PA 15071 USA

Integra Environmental Inc.
11871 Horseshoe Way, Unit 1159
Richmond, BC
Canada V7A 5H5

ITM Instruments Inc.
5715 Kennedy Road
Mississauga, ON
Canada L4Z 2G4

Matheson Gases and Equipment
Worldwide Headquarters:
30 Seaview Dr.
Secaucus, NJ 07096 USA
Canada: 1-800-263-2620

Neotronics of North America, Inc.
P.O. Box 370
2144 Hilton Drive
Gainesville, GA 30501-6153 USA

Response Rentals
1057 East Henrietta Rd.
Rochester, NY 14623 USA

SKC Inc.
863 Valley View Road
Eighty Four, PA 15330 USA

Solomat, A Neotronics Company
The Waterside Building
26 Pearl Street
Norwalk, CT 06850 USA

Transcat
10 Vantage Point Drive
Rochester, NY 14624 USA
In Canada:
5700 Timberlea Blvd.
Mississauga, ON   L4W 5B9

TSI Incorporated
500 Cardigan Road
P.O. Box 64394
St. Paul, MN 55164 USA

Table A-2: Specific Equipment List including the most common indoor air quality equipment with manufacturer names, address and approximate cost.

EQUIPMENT LIST	AVAILABLE FROM	APPROXIMATE PRICE
SKC DC 1100 Formaldehyde	SKC In USA: 863 Valley View Road Eighty Four, PA 15330 Tel: (412) 941-9701 Fax: (412) 941-1369 In Canada: 6031-103A Street Edmonton, Alberta T6H 2J7 Tel: (403) 438-3028 Fax: (403) 436-0063	$ 1,500.00
Haz-Dust Mass Particle Counter Data Logger	SKC, as above	$ 3,500.00 $ 1,000.00
Aircheck Sampler	SKC, as above	$ 1,000.00 per pump
Balometer	Alnor Instrument Company In USA: 7555 N. Linder Ave. Skokie, Illinois 60077 Tel: (708) 677-3500 Fax: (708) 677-3539 In Canada: Baker Instruments 40 N. Rivermede Road, Unit 5 Concord, Ontario L4K 2H3 Tel: 1-800-561-8187	$ 3,000.00
Atcor Airborne Patricle Counter APC-1000	Geneq Inc. 2628 Granville St. Victoria, BC V6H 3H8 Tel : (604) 739-0889 Fax: (604) 731-9445	$ 4,000.00
Ecosensor Ozone Gas Sensor Model A-20	Geneq Inc.	$ 600.00
Radiation Alert by Monitor 4	Geneq Inc.	$ 400.00
Gasman CO Monitor	Geneq Inc.	$ 700.00
Telaire Systems CO_2 Monitor	Geneq Inc.	$ 700.00
F.W. Bell ELF Meter	Geneq Inc.	$ 350.00
Digital Temperature and RH Meter	Geneq Inc.	$ 500.00
Hygrothermograph	In USA: Cole Parmer 7425 N. Oak Park Ave. Niles, Illinois 60714 Tel: (708) 647-7600 In Canada: Labcor Technical Sales 7565 Ave. M.B. Jodoin Anjou, Quebec H1J 2H9 Tel: 1-800-363- 5100	$ 2,000.00
Anemometer	Cole Parmer, as above	$ 1,500.00