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AIR QUALITY IN INTERIOR ENVIRONMENTS

Abstract

Excessive moisture is the major cause of poor air quality in buildings because it encourages the growth of mold. Awareness of mold contamination in homes has also focused the attention of building professionals on the legal consequences of interior air quality problems, especially with respect to liability insurance. Many North American and European studies indicate a link between dampness and respiratory health problems. This article describes the sources of air contamination and suggests ways to eliminate, reduce or separate these sources from indoor air. Preventive strategies in design and renovation are also suggested, as well as different aspects of architects' responsibilities related to air quality problems.

Objectives

After reading the article, an architect should understand the following:

1. Major air quality issues in residential buildings.
2. Sources and consequences of problems related to biological contaminants.
3. Design strategies to prevent air contamination.
4. Roles of architects with respect to indoor air quality.
5. Sources of information concerning indoor air quality.

Fig. 1. Investigating the Causes of an IAQ Problem

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1. Background

1.1 Introduction

Construction techniques do not always evolve at the same rhythm as the development of new materials. New synthetic materials, and industrialisation of the production of envelope materials have led to new construction techniques that produce better-insulated and more air-tight residential buildings. This has led to changes in the air quality of these interior environments. Although this new construction technology is more water-resistant, durable and energy efficient, the greater air-tightness of new construction lessens the opportunity for dilution of interior pollutants compared to older buildings with leaky walls and draughty windows. The 1995 National Building Code of Canada (NBCC) introduced new requirements for mechanical ventilation for houses that are intended to correct this gap (1). This regulation requires that houses be equipped with a method of ventilation to provide fresh outdoor air to all areas of the house. However, for larger multi-unit residential buildings, no such definitive requirements for ventilation exist. Ventilation systems have been left to the designer and have not changed significantly over the past 25 years. Most Canadian houses, especially those more than 25 years old, do not have adequate mechanical ventilation to maintain good air quality.

At the same time, the average time spent in conditioned environments has increased. A recent study shows that Toronto residents spend 12% of their time outdoors during a 5- day workweek in summer, and only 2% outdoors during a 7-day week in winter. Most of the time spent indoors is in houses, with the remainder spent in work and school, shopping and travelling. Almost one in five Canadians suffers from some form of respiratory ailment, such as asthma, bronchitis and allergic rhinitis. Young children and the elderly are most at risk because they are particularly sensitive to the effects of poor-quality indoor air.

Canada Health has set guidelines for short- and long-term exposure to certain air contaminants in dwellings, illustrated in Table 1. The full text of *Exposure Guidelines for Residential Air Quality* (1987), currently under revision, describes some of the health consequences of exposure to these chemicals (2).

Contaminant	Acceptable Short-term Exposure Range	Acceptable Long-term Exposure Range
Carbon Dioxide	-	[3500ppm
Carbon Monoxide	[11 ppm (8 hours) [25 ppm (1 hour)	-
Formaldehyde	Action level: 120 µg/m3 (0.10ppm) (Existing homes) Target level: 60 µg/m3 (0.05ppm) (New homes)	
Nitrogen Dioxide	[0.25 ppm (1 hour)	[0.05ppm
Ozone	[0.12 ppm (1hour)	-
Particulates	[100 µg/m3 (1hour)	[40µg/m3
Sulphur Dioxide	[0.38 ppm	[0.019 ppm
Water Vapour	30-80% RH summer* 30-55% RH winter**	
Radon	-	Action level is 800 Bq/m3 annual av. concentration in the living area

Table 1. A Sample of Canadian Residential Exposure Guidelines

Legend: µg/m3 microgram per cubic metre
Bq/m3 Becquerel per cubic metre
Ppm Parts per million

* CMHC recommends RH not to exceed 60% in basements in summer. During the coldest periods, the indoor RH should be close to 30% to avoid condensation.

Other contaminants may still be problematic but exist in concentrations too small to measure. Many volatile organic chemicals are emitted from building materials and furnishings. Acceptable levels for individual chemicals do not apply to mixtures of chemicals, when different chemicals react with one another with unknown consequences to health. It is best to limit their concentrations in the air by eliminating materials that are known sources of noxious gaseous emissions. Furthermore, individuals differ in their sensitivities, which influence each person's reaction to exposure to a certain chemical and its quantity. Problems of contaminated air have been increasing worldwide; the World Health Organization gathered world experts together in 1979 to propose guidelines for the protection of occupants of housing. Guidelines have been implemented for exposure to certain contaminants such as carbon monoxide, carbon dioxide and ozone, but safe levels have yet to be established for other pollutants.

1.2 Industrialisation

From its origins as a craft that used only natural materials, residential construction was transformed over the last century into an industry that uses many materials that contain a significant proportion of chemical products. The specialization and piece- work of the building trades further complicates the coordination necessary to ensure high-quality construction, especially at the level of air- and water-barrier materials. Quality construction is needed in order to achieve optimal building performance.

1.3 Air Impermeable Envelopes

New energy efficiency measures in the 1970s made buildings better insulated and more airtight, but houses still lacked controlled ventilation. More airtight buildings needed increased ventilation to maintain appropriate humidity levels, and to reduce condensation on poorly insulated building envelope elements such as windows and doors. Heat recovery ventilators were introduced in the 1980s to improve fresh air distribution, dilute airborne contaminants, exhaust air pollutants and reduce humidity in housing, while lowering the energy cost of ventilation.

2. Contamination of Air

2.1 Biological Contamination

Air contamination can be the result of gaseous biological and chemical pollutants or airborne particulates, from asbestos, dust, and lead-based paint products. Moisture in the air is a prime factor that contributes to mold growth. Mold, a microscopic fungus, is an important source of the various biological pollutants found in houses. However, we encounter molds every day and everywhere; in the exterior air, food, damp clothing, and in medicines such as penicillin. Not all molds are bad, but within our terms of reference in residential construction, they damage structural materials, furniture and finishes, and may cause health problems.

Several sources produce other types of biological contamination of indoor air. Domestic animals, such as cats and dogs, emit allergens into the air. Dust mites, cockroaches and other insects and vermin constitute other potential sources of allergens that may contaminate indoor air. Although mold proliferation inside buildings is the principal cause of biological contamination in air, the presence of insects is a warning to look for the water sources that sustain them.

Molds grow on organic materials when the conditions for their growth are favourable. These conditions are warmth, moisture, oxygen and nutrients. Unfortunately for us, conditions in our homes are ideal for mold growth. Most fungi thrive at temperatures between 25 and 32 deg. C. High moisture levels at the floor, ceiling and wall surfaces that often exceed the relative humidity at the centre of the room, support the growth of molds. A relative humidity level above 70% at the host surface, which equates with an RH level of about 60% at the centre of the room, is conducive to mold growth. The relative humidity at the surface, and not at the centre of the room, is the element that must be controlled in order to prevent mold growth. Methods for reducing condensation are discussed later in this article.

Wood decay fungus needs 25-40% wood moisture content in order to thrive. This fungus growth will be minimal in wood with moisture content that is below 20-25%. For more information on the characteristics and growth requirements of different fungi and molds, *Conserving Buildings* (3) by Martin Weaver is a useful reference for architects.

Water infiltration through the building envelope is the major moisture source for mold growth. Plumbing leaks and condensation on windows are other frequent sources. A CMHC study in 1991 showed that a significant number of multiple dwellings had problems related to water damage and to water infiltration (4).

Fig. 2. Mold Growth Near Water Entry at Sill Plate

Fig. 3. Wood Decay Fungus

Cleaning, cooking, showering and washing produce high levels of humidity that can condense on cold surfaces, producing the moisture needed to support fungal growth. Concentrations of moisture produced by these activities are often hidden from view within walls and under floors, and may go undetected for a long period of time.

Human activities create significant amounts of moisture, as shown by Table 2. Mold needs sufficient moisture and oxygen to grow. As it grows, it produces spores that can be inhaled by a building's occupants. The spores cause allergic reactions in some people. The effects of molds on human health range in nature and intensity. In general, the effects increase with the period of exposure. People with weak immune systems are most at risk, and the symptoms may not disappear even with the elimination of the exposure source. Symptoms may include irritability, sore joints, nausea, back and headache, stuffy nose, breathlessness and respiratory difficulty.

Source	**Moisture Produced litres/day**
Four occupants	5
Humidifier	2-20+
Whirlpool bath	2-20+
Firewood, by cord	1-3
Floor washing	2
Cooking	1.5
Gas cooking appliance	1
Plant, each	0.2
Seasonal release of moisture (ie:- autumn)	3-8+
Total /day	**30**

Adapted from G. Christian

Table 2. Daily Moisture Generated by the Activities of a Family of Four (5)

A number of studies have shown that *exposure to excessive humidity and mold has effects that are as serious for the respiratory health of young children as those from exposure to second hand smoke*. The CMHC *Wallaceburg Study* contains information about this subject (6). Exposure to a mold-contaminated environment means exposure to multiple contaminants, which may further increase the risk. Allergens of domestic animals, insects, rodents, bacteria and pollens are other biological sources that can complicate health problems.

2.2 Chemical Contamination

Chemical pollutants can cause either acute or chronic reactions in building occupants. Acute reactions are usually caused by accidents and brief exposure. However, chronic reactions are related to prolonged exposure to low concentrations of chemicals. Irritations, allergies and central nervous system effects are the common health risks. The long-term health effects from low concentrations and mixes of different chemicals are not well understood. In the absence of scientific proof, the principle of precaution suggests that it is best to avoid indoor exposure to them.

Chemicals are in many products and furnishings of buildings, including cleaning products, and they can be found in the air if they are volatile. Some contaminants can be odourless and not easily detected in the air. Outdoor air can also be a source of chemical pollutants when allowed to enter the building through leakage paths, openings or mechanical intakes. Unvented and unsealed combustion appliances such as fireplaces, stoves and heaters can also pollute the indoor air. Combustion appliances that are improperly vented, can sometimes cause fatalities, since carbon monoxide (CO) has no odour.

Building occupants also contribute some of the chemical pollutants found in buildings. Second-hand smoke has now been clearly implicated as a serious health hazard. Cleaning products and air purifiers can emit volatile chemicals, as well as the finishes we apply to walls, floors and ceilings or purchase in furnishings, cabinetry and decorations. Certain recreational pastimes such as painting, laminating and gluing can also generate a significant amount of indoor pollutants. Architects for the most part cannot influence lifestyle choices, except by choosing building materials that are less polluting. The CMHC publication *Building Materials for the Environmentally Hypersensitive* (7) provides more information about this issue.

Architects frequently select construction materials, finishes and cabinetry that may produce chemical pollutants known as volatile organic compounds. These chemicals are used in the fabrication of many construction products, from particleboard to adhesives. Volatile organic compounds (VOCs) are emitted and released into the air at ambient temperature over a long period of time, though emission rates tend to be strong at first and weaken with time. Some VOCs have strong odours but others, such as formaldehyde, are not necessarily detectable by smell (See Table 1). Perchlorethylene, commonly used in dry cleaning, is recognized as a toxic agent. Other chemicals may cause rashes and allergic reactions. Knowledge on the part of architects, of the potential for harmful emissions from the materials they specify can go a long way towards preventing problems before they start.

Some materials have the ability to act as chemical sinks for pollutants. They can absorb volatile chemicals that are later released to the air over a longer period of time. Porous materials such as gypsum board, acoustic tiles, carpeting, underpad and textiles are the most susceptible to act as this type of reservoir. We also know that some materials in older buildings can cause contamination of the air, such as the dust from asbestos products and lead paint. These materials should be removed by specialized professionals using approved abatement techniques.

3. Deterioration of Construction Materials

3.1 Wood Decay

High humidity and fungal growth progressively damage organically-based materials, such as wood and wood-based products. Water infiltration through the building envelope and plumbing leaks can cause extensive cosmetic and structural damage. Decay of wood is dependent on moisture and temperature. U.S. studies have shown that mold can become established on oriented strand board (OSB) in 30 days, and on plywood 45 days, at 95% relative humidity. When the materials are in contact with water, mold can become established on OSB in 3 days and on plywood in 6 days. (8). Furthermore, lumber and wood products are difficult to disinfect, and often need to be replaced when mold infestation has occurred.

3.2 Corrosion

Moisture also corrodes steel framing members and fasteners, creating new places for water entry and sometimes causing structural failure. Rusting can occur even without wetting, when the relative humidity is above 70% to 80%. A relative humidity of 70% at a surface such as a basement wall and floor, corresponds to about 60% RH at the centre of the room at normal indoor temperatures. Conditions of high humidity prolong the drying period necessary and permit molds and wood rot to become established. Therefore, it is important to keep room humidity levels within an acceptable range in order to prevent mold growth and to ensure the health of the occupants. There is some disagreement about what is an ideal relative humidity range for human comfort. Health Canada recommends between 30% and 55% RH, but relative humidity over 35% in the coldest days of winter may result in some condensation on cold surfaces. Generally, air between 25% and 35% RH at the centre of the room during the heating season is moist enough to prevent occupant discomfort and shrinkage of wood flooring, yet dry enough to avoid condensation on better-quality windows.

3.3 Mold Growth

Wetting of absorbent materials such as glass fibre insulation batts will reduce their inherent insulating properties and can accelerate mold growth and other damage to the envelope. Drywall in damp areas such as basements, laundry rooms, and bath tub and shower surrounds, is a likely place for mold growth. Blackening of the surface and on caulking joints is a sign that mold has become established.

4. Avoiding Indoor Air Quality Problems by Design

The design and construction of the building envelope has a significant effect on interior air quality. Several strategies can be used at the design stage to avoid problems of biological contamination and to ensure healthy indoor environments. They are:

- Avoid water penetration into and through the building envelope.
- Avoid condensation.
- Allow moisture in the building envelope to escape.
- Avoid damage from plumbing leaks.
- Provide balanced mechanical ventilation.
- Avoid contamination from attached garages.

The design of air- and weather-tight building envelopes where materials have been chosen and installed with care, coupled with effective mechanical ventilation, will help to avoid the problems of leakage and water vapour condensation inside the building that are the chief causes of mold growth.

4.1 Avoid Water Penetration into the Building Envelope

The initial strategy to ensure better indoor air quality is to keep water out of the building. Siting should respond to the physical characteristics of the property. A siting checklist should include the following:

- Build above the ground high water level, street level and flood plains.
- Use slopes that drain away from the building.
- Use the ability of the soil to absorb water.
- Orient for sunlight, ventilation and weather protection.

Proper choice of siting at this stage will limit the conditions that allow water to infiltrate below grade.

Basements

The basement is the most common location of dampness and mold growth because it is partly below ground level and cold air that accumulates in the lowest levels, often has a higher relative humidity. To add to the problem, basements can be difficult to waterproof and dampproof, and are often poorly ventilated. Water entry, via cracks, construction joints, windows and service penetrations, must be prevented. Due to the reduced amount of wall surface in contact with the soil, shallow basements are likely to have more ventilation and light, and to be less humid than deep basements. Condensation can be reduced in basements by placing rigid insulation beneath the slab and over the exterior surface of the wall and footing. A waterproof membrane should be placed between the wall and footing, so that the moisture barrier beneath the slab can connect to the one on the outer face of the wall. Houses without basements and built on well-drained foundations are less likely to have mold problems, and are less likely to be affected by storm run-off and flooding than those with basements.

Below grade foundations in flood plain areas with high water tables are problematic. Reliance on sump pumps to prevent basement flooding is not recommended because of the possibility of pump malfunction or power failure. The grade around the perimeter should slope away from the walls at least 5% and preferably more, to compensate for the soil settlement that will occur over time. As an added precaution, the backfill can be capped with a low-permeability (high clay-content) soil cap extending 1.5 to 2 metres from the foundation, to reduce water infiltration.

Section 9.13 of the NBCC (1995) requires that basement walls not subject to hydrostatic pressure are to be dampproofed, while those subject to hydrostatic pressure must be waterproofed. Foundation dampproofing usually consists of a single bituminous layer that is spray-applied to the exterior face of the basement wall and footing. Several products, such as dimple membrane, are now available that provide improved dampproof protection. Section 9.13 of the Ontario Building Code requires that concrete or unit masonry walls to be waterproofed shall be covered with at least two layers of bitumen-saturated membrane, and coated with a heavy application of bitumen. Several proprietary waterproofing systems including modified bituminous membranes are accepted in some jurisdictions. When waterproofing is required, NBCC 9.13.6 prescribes a waterproof membrane applied to the basement floor between two layers of concrete, each layer at least 75 mm (3 in.) thick, and mopped to the wall membrane to form a complete seal.

Section 9.14 of the NBCC also requires that a perforated drainage tile or pipe surrounded by gravel or crushed rock, be placed around the exterior of the foundation and connected to either a sump pump or a storm drain. It is recommended that the drainage tile and the surrounding gravel be wrapped with a geotextile sock to prevent fines from blocking the drainage holes. The walls around habitable basements must also be protected by a drainage membrane or granular backfill, which allow water in the soil to reach the foundation drain. Native soils, such as clay, are unsatisfactory for backfill. Dry clay expands as it absorbs free water and contracts as it dries, causing soil to settle and possibly damaging the foundation. Moist clay is relatively impervious and prevents proper drainage of surface water. This type of soil should be removed from the area of the excavation. A geotechnical engineer can assess the suitability of native soil for backfill and recommend strategies to protect the foundation where high water tables are encountered.

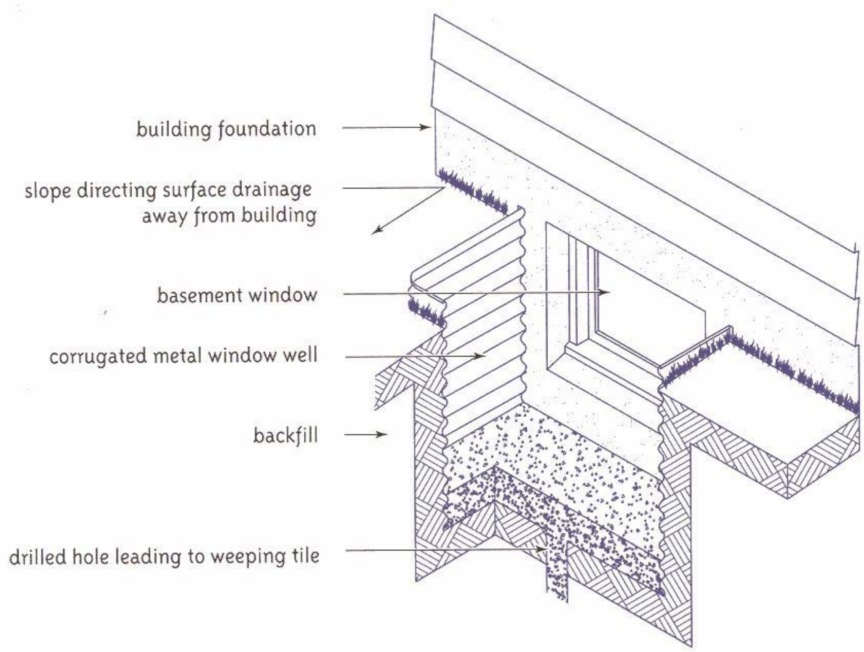

Fig. 4. Window Well at Basement Wall (9)

It should be emphasized that the primary defence against moisture problems in foundations is the provision of proper drainage away from the foundation. Directing roof, surface and ground water away from the foundation is essential to providing a dry basement. Window wells are common sources of insect, mold and water infiltration and should be avoided whenever possible. Where wells cannot be avoided, they should contain at least 200 mm. of gravel or crushed stone placed at least 150 mm. below the window sill, and be connected with a free draining material to the foundation drain.
Steel reinforcement can prevent cracks in foundations caused by shrinkage or soil pressure. Foundation cracks should be patched with non-shrinking grout or dampproof material prior to dampproofing or waterproofing and backfilling.

Above-Grade Walls
The rainscreen principle can be employed to significantly decrease water penetration into walls by providing two lines of defense against the elements. In a simple rainscreen wall, more precisely called a *'drainscreen'*, the cladding surface stops most of the wind, rain and snow to which it is exposed, but allows some moisture to pass through. This is stopped by an internal weather-tight barrier with flashings installed behind a drainage cavity, which together, convey the water to drainage openings at the bottom of the cavity and out to the wall face. It is anticipated that the next edition of the NBCC will require drainage cavities in all walls that aren't protected by a waterproof membrane. *The Rain Screen Wall System* in this series of technical articles describes the application of these principles in greater detail (10).
www.cmhcschl.gc.ca/en/imquaf/himu/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=48730

CMHC's *Wood Frame Envelopes* also contains information about the design of rainscreen walls (11).

Windows and Doors

The proper design and detailing of doors and windows will eliminate a common source of water entry and mold. Because door and window assemblies are seldom waterproof, flashings with end dams should be placed beneath the thresholds and sills, and should slope down and lap over the exterior face of the basement wall. The insulation plane of the glazing and door should also align with the wall insulation to avoid thermal bridging and condensation. Gaps between the door and window frames and the wall should be filled with moisture- and air-impervious insulation, such as low-expansion urethane foam (never chinked fiberglass or mineral wool), and the frame-to-wall junctions filled with a flexible and durable exterior-grade caulking. Window and door sills should be placed at least 150 mm. above grade.

Roofs

Recent studies in Canada and the U.S. have shown a correlation between rainwater damage to buildings and the size of roof overhangs (12). Predictably, those dwellings with overhangs of two feet (600 mm.) or less exhibited increasing amounts of moisture damage in walls and around openings, as the size of their roof overhangs decreased. Buildings with overhangs of three feet (900 mm.) or more exhibited significantly less water damage. Areas subject to prolonged or repeated water exposure are potential sites for mold infestation.

Ice damming is avoided primarily by ensuring the attic is separated from the house with a high level of insulation and proper air sealing. The attic space stays at or near exterior temperatures, and ice damming will not occur when house heat is prevented from migrating into the attic. The installation of a self-sealing protective layer under the roofing at eaves and valleys and at penetrations and projections is recommended to protect against water penetration caused by ice damming. The NBCC also requires adequate and well-distributed roof venting in conjunction with a sufficient amount of insulation where the roof meets the wall, to reduce the likelihood of ice damming.

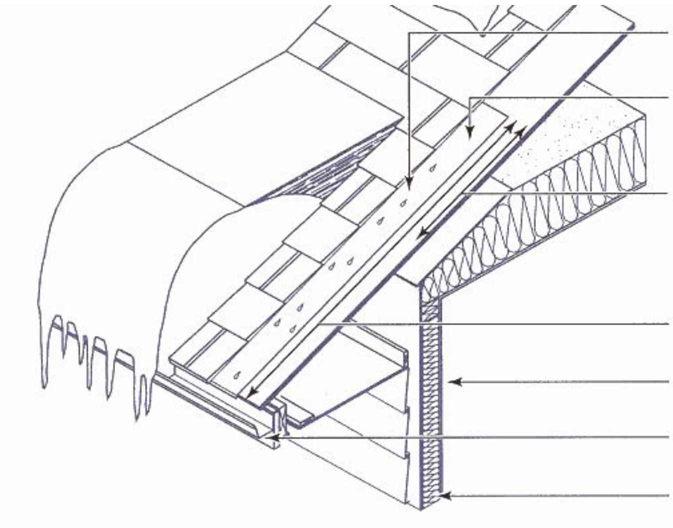

Fig. 6. Eave Protection at Roof Overhangs (13)

4.2 Avoid Condensation

Condensation can be avoided by increasing surface temperatures, decreasing the relative humidity (RH) of the inside air, and increasing warm air circulation across the cold surfaces.

Better-insulated windows with thermally broken frames have higher interior surface temperatures than poorly insulated windows. These colder poorly insulated windows are more prone to condensation and mold. Unbroken metal frames are colder than wood or vinyl frames, and are more likely to experience condensation, which contributes to rot on nearby organic surfaces. Insulation continuity can also reduce the occurrence of thermal bridging and condensation. Metal frame elements, should therefore be protected on their cold side with materials providing sufficient insulation. The use of continuous insulation covering the cold side of the building envelope will reduce the consequences of thermal bridging.

Concrete surfaces below grade are usually cooler than the indoor temperature, which in the high relative humidity of summer, can lead to condensation on the inside of the basement wall or in the insulated wall assembly that may be placed against it. If the insulation is placed on the outside face of the foundation wall, the dew point is located towards the exterior where condensation can dissipate without affecting the more sensitive interior wall. This results in a warmer and dryer interior wall. The exposed interior surface of the foundation can shed its construction-related moisture more quickly than it otherwise could if an insulated wall assembly were placed against it.

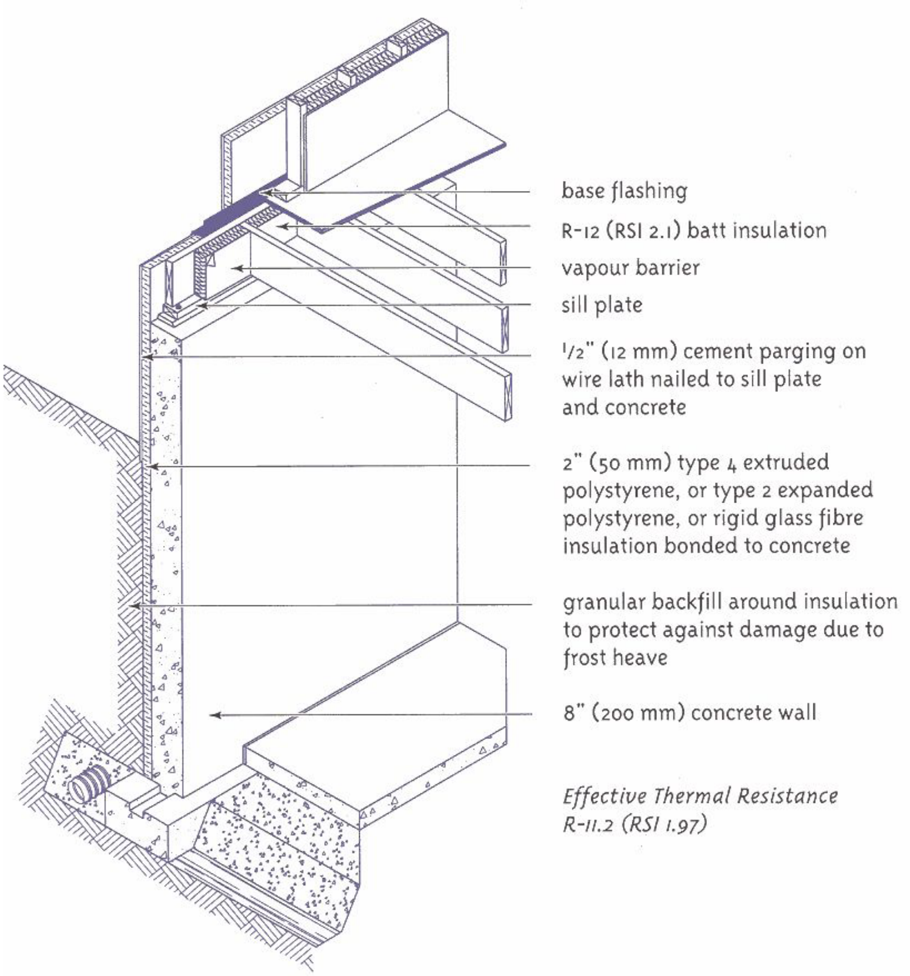

Fig. 5. Concrete Wall With Insulation on Outer Face (14)

Placing rigid insulation beneath the concrete slab and a thermal break between the slab and the foundation walls will have a similar effect on the basement floor. It will be warmer and drier. Polyethylene film should be installed over free-draining granular fill (or rigid insulation) directly beneath the floor slab. Basement walls should be left unfinished for one year following completion of the building, because fresh concrete has high moisture content and requires months before it has fully dried. The CMHC *Wood Frame Envelopes: Best Practice Guide* contains details for the insulation and water protection of foundations and basement floors (15).

The relative humidity of interior air can be lowered in winter by introducing outside air or in summer by keeping out humid outside air. Opening windows in the summer can increase the humidity in the dwelling by introducing hot humid exterior air. Moisture can be removed from the room air by mechanical ventilation, air conditioning and dehumidifying. Air conditioning can cause layering and cold air stratification in the lowest floor or basement, where humidity tends to be high during summer. An effective mechanical ventilation system should mix the air and even out surface temperatures by circulating air to all areas of the dwelling. Mechanical ventilation should also push inside air across cold surfaces to warm them and reduce condensation. This is discussed in more detail in the section on mechanical ventilation.

4.3 Allow Moisture in the Building Envelope to Escape

Once moisture enters walls and roofs, it must be given an escape route. Highly impervious materials, such as particleboard panels and polystyrene insulation, placed on the cold side of the envelope will create a barrier to the diffusion of water vapour and thus, a potential moisture trap within the wall assembly. For this reason, such materials should be loosely fit or perforated when used in locations in a wall where the temperature falls below the dew point temperature, to allow any trapped moisture to escape to the exterior. However, the installation of rigid insulation on the outside of wall assemblies, even if it has vapour retarder characteristics, may protect the walls from condensation. This is because the insulation keeps the walls relatively warm, thereby preventing condensation within the framed cavity. Nevertheless, the air barrier must be as continuous as possible in order to limit the movement of moisture-laden air through the envelope.

All new buildings in Canada are required to contain both vapour retarder and air barrier systems to inhibit the flow of moisture and air through the envelope. Two CMHC technical articles for architects in this series, *Guidelines for Delivering Effective Air Barrier Systems* (16) and *Design Considerations for an Air Barrier System* (17) contain details for the design and installation of appropriate air barrier systems. These publications may be found at: http://www.cmhc-schl.gc.ca/en/imquaf/himu/himu_002.cfm
The CMHC publication *Design of Durable Joints Between Windows and Walls* contains useful information about the design of window joints for durability http://www.cmhc-schl.gc.ca/publications/ en/rh-pr/tech/03-107-e.pdf (18).

Avoiding post-construction biological contamination requires diligence in ensuring that building details prevent moisture from unintentionally entering the building envelope. The sources of moisture include the construction materials themselves, such as wood, concrete or other products, that are not adequately dry at the time of installation, or that are wetted before the building is enclosed. Specifications should state that sensitive and absorbent materials are dry and protected before installation and during construction. Concrete structural elements naturally will introduce moisture into the building and require sufficient time for drying before being closed in by wall, ceiling or floor finishes.

4.4 Avoid Damage from Plumbing Leaks

Plumbing leaks are the second most common source of water problems in buildings. Mold is often found behind bathtubs and showers and near toilets, hot water tanks, sinks, dishwashers and laundry areas. Plumbing leaks can be anticipated in the design and construction of a dwelling:

- Avoid locating plumbing in exterior walls, where pipes are exposed to freezing temperatures and where breaks can have serious consequences.
- Design to facilitate access for servicing, so that leaks can be discovered more quickly and repaired more easily.
- Avoid porous or organic materials that can absorb moisture and support fungi in areas that are exposed to water. Cement board should be used in lieu of drywall at bath tub surrounds, showers, laundry areas, and behind sinks and dishwashers.
- Place hot water tanks and other equipment such as washing machines, in watertight pans when installed on wood frame floor assemblies, or on concrete slabs near floor drains in basements.
- Design showers with moulded acrylic or fibreglass floors with integral curbs, or install them over sealed waterproof membranes that extend at least 150 mm. up the walls. Provide floor drains in areas subject to large volumes of water, such as shower areas, laundry rooms and utility rooms.

4.5 Provide Mechanical Ventilation in Part IX Residential Buildings

Excessive humidity can be removed by mechanical and natural ventilation at certain times of the year. The 1995 National Building Code of Canada (NBCC) requires mechanical ventilation in all new Part IX residential dwellings supplied with electrical power, in order to ensure a continuous and adequate fresh air supply. NBCC 9.32.3 specifies the design and ventilation capacity of mechanical ventilation systems required for all new dwellings during the heating season. NBCC 9.32.2 requires that rooms or spaces in dwellings be ventilated by natural or mechanical means during the non-heating season. Provisions are also included in the building code for the exhaust appliances that must serve kitchen and bathroom areas. Because building occupants often neglect to open windows to ventilate unoccupied spaces, such as basements and store rooms, where conditions might be favourable to mold growth throughout the year, it would be prudent to provide mechanical ventilation year- round in all areas prone to dampness, and where natural ventilation is limited.

To avoid depressurization of the building that could cause the infiltration of exterior air, exhaust air must be replaced by an equal quantity of fresh air. Make-up air systems may be required to balance the air exhausted from the buildings by bathroom and kitchen exhaust appliances and clothes dryers. Not only does make-up air help to prevent infiltration, it can also prevent the back drafting of combustion appliances, such as fireplaces, and fuel-fired furnaces and hot water tanks. Heat recovery ventilators are often used as a way to simultaneously meet the supply and exhaust air ventilation requirements of Part IX of NBCC. A heat recovery ventilator (HRV) removes stale air and replaces it with fresh air, while transferring heat from the former to the latter to minimize heat loss. Mechanical ventilation equipment performance depends on its maintenance, which favours the use of rigid ductwork for ease of cleaning. The make-up air devices should provide as much air as is exhausted by the other appliances. These systems should be installed and balanced by ventilation experts to ensure their efficient operation.

Kitchen stove hoods and bathroom fans that exhaust directly to the exterior remove the excess humidity produced by the building occupants. NBCC 9.32.3.5. requires an exhaust fan with a rated capacity of 50 L/s in a kitchen and 25 L/s in a bathroom, where these rooms do not contain the principal exhaust fan for the dwelling. The noise level of the fans should not be greater than 1 sone as this could be an irritant to the occupants, who might choose not to use them. HRVs can be used instead of fans. They are relatively quiet and efficient when they exhaust several rooms at once. For example, a HRV containing one large fan could be located in an unoccupied space, such as a utility room. HRVs and ventilation fans should not be located in unheated attics, where they may contribute to air leakage and condensation, and may be difficult to maintain.

4.6 Avoid Contamination from Attached Garages

Recent studies show that houses are vulnerable to infiltration of air pollutants from attached garages. Auto emissions, such as carbon monoxide (CO) and benzene, emissions from stored chemicals and fossil fuel-powered equipment, and volatiles from garbage can enter houses from attached garages. Testing of 25 Canadian houses and their garages shows that ceilings, walls and weatherstripped doors that separate the garages from the houses are insufficient to keep contaminants out of the household air (19).

Modern cars with catalytic converters create relatively low levels of combustion pollutants, when compared with older vehicles. However, when the car and catalyst are still cold during winter start-up, the emission controls are not very effective and a significant quantity of pollutants can be produced. The Canadian study shows that garage pressures during winter are usually from 1 to 5 Pa higher than those inside the houses, causing garage air to migrate into the houses. Although CO levels were below 5 ppm in most cases, this was exceeded in three houses, with one peaking at 42 ppm.

The study found that garage air was the source of many undesirable compounds, including 1,3-butadiene and benzene. More than 75% of indoor exposure to benzene could be attributed to air entering from the attached garage. VOC concentrations were highest in tightly built garages. Computer modeling showed that in the tightest garage during a car cold-start test in winter, a 100 L/s (200 cfm) fan running for 30 minutes would reduce garage carbon monoxide concentrations to negligible levels. A leaky garage would require a much larger exhaust fan to develop the negative pressure needed to exhaust the air. Therefore, it is important to build attached garages tight so they can be exhausted, and to air-seal all surfaces and openings between garages and living quarters.

5. Avoiding Volatile Organic Compound Problems by Design

In order to avoid volatile compound (VOC) contamination, the priority should be to reduce the VOC emissions of materials that have large exposed surface areas or that have high initial, or long-term emission rates. The most common sources of VOCs in construction materials are floor coverings, such as carpet, and the adhesives used to attach them. Paints are also a common source, but low emission alternatives are commonly available. Particleboards and other manufactured wood products may also produce VOCs. In the case of cabinetry, architects can specify that all unfinished edges and surfaces of the particleboard be sealed before delivery to prevent emissions. Materials that have a high level of VOC emissions, particularly those in bedrooms where people spend long periods of time, should be scrutinized. Select less risky alternatives, whenever possible. Information about materials that contain VOCs can be found by consulting the 'GreenSpec' database at *www.BuildingGreen.com*

Material	**Notes**
Paint & Finishes	
Oil-based Paint, Stain, Varnish, Sealers	
Vinyl Wall Cover, Wallpaper	
Flooring & Adhesives	
Rubber Flooring, Vinyl Cushion Flooring, Linoleum, Vinyl Composite Tiles	
Flooring Adhesives	
Carpet	
Rubber and Foam Underpad	
Framing, Shelving & Cabinetry	
Oriented Strand Board, (Wafer Board), Construction-grade Plywood	Manufactured with phenol formaldehyde resins
Particleboard, MDF, Hardwood Plywood	Manufactured with urea-formaldehyde resins
Cellulose Insulation	Contains chemical additives for fire retardancy
Exterior Finishes & Sealants	
Vinyl Siding, Wood Composite Siding	Located near windows and air intakes
Asphalt Shingles	"
Bituminous Roofing, Modified Bituminous Roofing, Asphaltic Adhesives	"
EPDM Roofing	"
Asbestos Siding and Shingles	"
Caulking, Sealants	"

Windows	
Vinyl Windows	

Adapted from Mendler and Odell. (20)

Table 3: Potential Sources of Chemical Emissions

The factors that influence the chemical emission levels of materials are:

- *Composition* of the material and its constituents, especially volatile organic compounds
- Physical characteristics such as *surface area, porosity,* and *texture*
- *Rate of emission*
- *Temperature:* Higher temperature increases the rate of emissions
- *Humidity:* Higher humidity increases the rate of emissions
- *Age of the material:* Emissions generally decrease over time
- *Reactivity* with other materials that are present

Some furniture and carpets can emit heavy concentrations of contaminants immediately after their manufacture, followed by gradually lessening emissions, to finally stabilize at acceptable levels. Requiring suppliers to specify a period of quarantine during which these products are left in a well-ventilated place before installation, may help to reduce the quantity of emissions to which the occupants will be exposed.

Architects should require that Material Safety Data Sheets (MSDS) be supplied by the manufacturer before selection of potential VOC-emitting materials. The Workplace Hazardous Materials Identification System (WHMIS) offers information about dangerous materials used in a working environment (21). This reference data can help architects to evaluate the potential effects of a large number of products used in construction. To obtain information on WHMIS, one may visit the Canada Health website: http://www.hc-sc.gc.ca/hecs-sesc/whmis/

Manufacturers are obliged to provide MSDSs. Sometimes, the MSDS will provide sufficient information to evaluate the product. Most often, however, one would need to look up the MSDS of individual components of the products that are listed as hazardous ingredients as well as other ingredients. Refer to CMHC's *How to Read a Material Safety Data Sheet* (22). The best among alternative materials can then be chosen, considering at the same time the other performance qualities required. Architects must realize, for example, that for melamine/particleboard products, the levels of emissions may vary by a factor of 3.

The MSDS were developed to protect workers who use these products. They mention the dangerous ingredients and provide information on the danger of fire, explosion or other physical and toxicological hazards. They do not provide information on the properties of materials that compose less than 1% of the product, nor do they provide information on the long-term health effects of prolonged exposure. However, they are the only source of information available which evaluates the noxious effects of products on air quality. The following web site is useful if one is interested in finding information about individual chemicals: http://physchem.ox.ac.uk/MSDS/

The CMHC guide *Building Materials for the Environmentally Hypersensitive* is another resource for finding and evaluating alternative construction and finishing materials (23).

Once the potential sources of indoor air pollution have been identified, there are six recommended strategies for reducing the level of noxious chemical or biological emissions:

- Control at source: Eliminate the products that emit them.
- Reduce the quantities of emission sources.
- Seal or otherwise encapsulate materials that have high emissions.
- Exhaust the emissions at source.
- Dilute by ventilation.
- Provide the occupants with a dedicated clean space.

Control at the source is the solution that often has the best cost / benefit ratio, since elimination of the source is usually easy to do. An example would be to reduce the humidity sources within homes, such as firewood or the line-drying of wet garments inside or correcting wet basement problems. Eliminating potential locations for water ingress to prevent mold growth can be achieved by thorough and careful detailing of unusual envelope joints and penetrations. The use of low emission paint, solid wood cabinetry and trim, ceramic or wood flooring, as well as the reduction of carpeted areas, vinyl and engineered wood products, are examples of source control. Materials on which molds are established should be removed since they can release contaminants into the air. Because some molds are toxic, protective measures for workers and occupants should be taken during renovation cleanups.

When it is not possible to totally eliminate contaminant sources, architects can take measures to reduce their quantities in the air. This can be achieved by sealing or encapsulating unfinished surfaces of particleboard, such as those used in kitchen cabinets.

A further, but relatively extreme technique to reduce the exposure of occupants to air pollutants, would be to create an oasis within the home where the emission of noxious substances in the air is greatly reduced or eliminated. The oasis may be the bedroom, which can be more easily, and more affordably, separated and cleared of emissions than the complete home. Such spaces must be provided with separate space conditioning and ventilation systems to be truly effective. This is not usually necessary for the majority of the population, but is an option for hypersensitive persons.

Mechanical ventilation should be installed to reduce the emissions that are not removed by the other techniques. Continuous outdoor air ventilation of all habitable rooms can dilute pollutant concentrations to some extent, but cannot be relied upon to achieve good indoor air quality.

Complementarity of Strategies

None of the strategies proposed will, on its own, guarantee adequate air quality. It is important to consider the building as a system of interrelated parts. For example, the avoidance of indoor air pollutants is desirable, but it must be supplemented by
ventilation to ensure the maintenance of appropriate relative humidity and the control of building air leakage. Used in a comprehensive manner, these measures will improve air quality more significantly, practically and affordably than any of these strategies employed separately. Designers must therefore use a multi-pronged approach to new design or remedial action in an existing building.

6. Multi-Unit Residential Buildings with Common Corridors

The indoor air quality within multi-unit residential buildings (MURBs) with common corridors is a function of the same variables that exist in other buildings but with certain differences. To better understand the primary influencing factors that govern indoor air quality in MURBs, it is worthwhile examining how this class of building tends to perform. Multi-unit residential buildings tend to operate not unlike large chimneys: during the winter months, air enters at the bottom, rises through the middle and exits the top. This is known the “stack” effect. The immediate consequence of winter stack effect is that heated, buoyant and humid indoor air is driven outside and is replaced with drier, colder outdoor air. This results in drafts, uncontrollable indoor air temperatures, poor humidity control and high heating costs. Occupants on the lower floors tend to be colder due to the infiltration of outdoor air at these levels. Occupants on the upper floors tend to overheat because of the continuous delivery of warm air from the lower floors. During summer, spring and fall, there is often not much of an indoor-outdoor temperature difference so air movement is more limited. This can be problematic, since such conditions provide little opportunity for natural ventilation. Stale, overheated indoor air can result.

Wind induced pressures force air from the windward side to the leeward side of some high MURBs. This means that people in windward apartments tend to receive a great deal of fresh air that must be heated in winter, while people in the leeward apartments tend to receive used, transferred air of questionable quality. Corridor air systems can pressurize the building, while mechanical exhaust serving bathroom and kitchen areas tends to depressurize it.

The immediate consequence of air movement in MURBs is the uncontrolled, and unwanted, transfer of air throughout the building that can carry with it cooking odours, second hand tobacco smoke, vehicle exhaust from underground parking garages, and moisture from basement areas. Such interzonal air movement easily carries smoke throughout the building during fire emergencies. In fact, most fire fatalities are due to smoke encountered in stairwells and corridors during building evacuation.

It is important to note that the primary reason stack effect, wind pressures and mechanical systems can move air throughout MURBs is the availability of leakage pathways through the internal floor and wall partitions. Even though many MURBs have concrete floor slabs and mechanical and electrical services are firestopped, research has shown that the partitions between apartments and common areas are surprisingly porous, especially where they are penetrated by mechanical services and other openings.

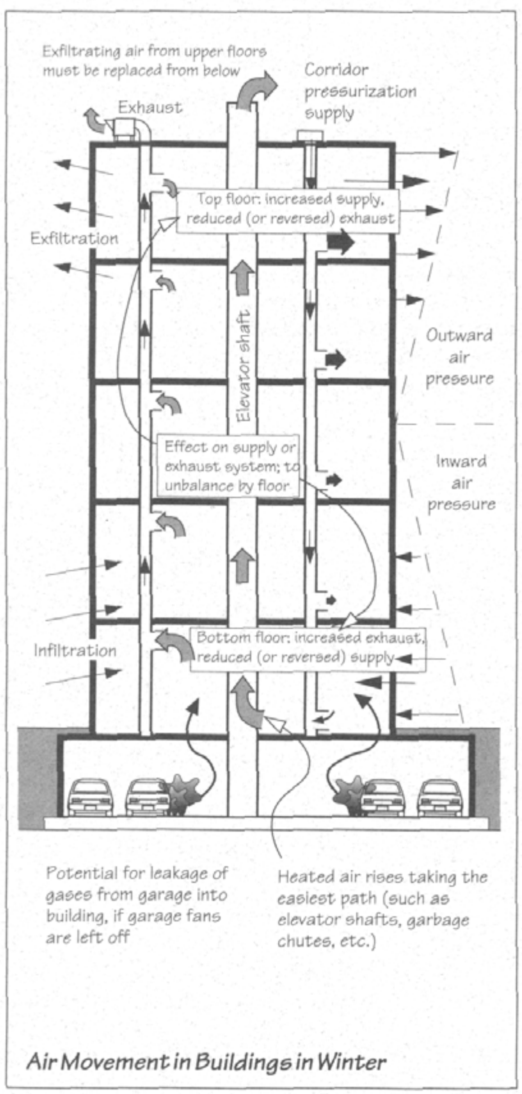

Fig. 7. Winter Air Movement (24)

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Fig. 8. Exhaust from Garage Infiltrates Apartments

Contrary to most opinions, MURBs are not provided with ventilation systems to the same extent as low-rise residential buildings. MURBs are most often supplied with corridor air systems and some form of central, or in-suite, kitchen and exhaust fans. While corridor air systems can ventilate corridors, their impact on the indoor air quality of adjacent apartments is limited and unpredictable as they do not distribute outdoor air directly to the apartments on each floor. Consequently, *fresh outdoor air supply to apartments happens more by accident than design*, and the amount of air that is actually delivered tends to be of questionable quality because it has travelled through occupied spaces. Bathroom and kitchen exhaust within the apartments can ventilate the rooms they serve but since the quality of the air that replaces the air exhausted is unknown, such systems cannot be considered apartment ventilation systems per se.

The consequences of uncontrolled air movement and the absence of effective and efficient mechanical ventilation are relatively predictable and common in all MURBs regardless of age, size, occupancy, location and construction. Occupant complaints are consistent and include the presence of cooking and smoking odours from other apartments, indoor air temperatures that are difficult to control, indoor humidity levels that can be too high or too low, drafts and stale air. The concerns of property owners and managers focus on subsequent high space heating costs, occupant complaints and the lack of appropriate mechanical systems.

MURBs also tend to have lower insulation levels than single-family houses. Less energy efficient windows, thermal bridging of steel stud assemblies and concrete floor slab edges, balconies and shear walls contribute to low effective insulation values. Low insulation levels, combined with thermal bridging and inadequate ventilation, can result in condensation forming on the interior surfaces of exterior wall and adjacent floor areas as well as on windows. This provides the conditions necessary for the growth of mold on, and around, the affected areas.

Building designers should be concerned that MURBs continue to be constructed that do not offer their occupants *integrity of space.* This is true in both rental units and condominiums. The concept of integrity of space evokes the idea that the occupants are separated from one another by internal partitions that prevent the transfer of air, light, noise, fire, smoke, pests and heat. This would provide the occupants of MURBs with conditions similar to those in single-family houses. As it stands now, the occupants of MURBs essentially share their indoor air and this has many consequences. Apart from eliminating the annoyance of migrating cooking odours or tobacco smoke, and uncontrolled temperature and humidity , greater integrity of space would also improve the safety of occupants in fire emergencies and conserve energy.

While the building industry has failed to provide for the integrity of space in most MURBs constructed to date, there is a growing awareness on the part of both occupants and owners of the need to improve buildings in this regard. It is encouraging to note that most of the technologies, materials, construction techniques and skills necessary to build apartments that achieve integrity of space conditions, presently exist. A few of the requirements are listed below:

- Air-tighten floor, ceiling and wall assemblies.
- Air-tighten electrical outlet and switch boxes in partition walls.
- Seal electrical and mechanical services with fire-rated caulking and foam.
- Provide airtight seals around apartment-corridor door.
- Downsize central corridor air systems.
- Provide in-suite mechanical ventilation that can exchange, condition, distribute and circulate ventilation air throughout the apartment.
- Eliminate or minimize indoor air pollutant sources.
- Consider make-up air sources for in-suite exhaust appliances, such as range hoods and clothes dryers.
- Meter space heating, space cooling, domestic hot water and water use.

By incorporating such measures in the design, construction and operation of MURBs, the persistent complaints regarding indoor air quality conditions that have characterized the performance of these buildings to date will be greatly reduced and many of the other benefits mentioned above will accrue.

7. Retrofit Strategies

In many architectural practices, retrofit projects are an important source of work. Architects need to understand how to identify and deal with the mold or other noxious agents, such as asbestos and lead, which may be present. Unless they are treated correctly, noxious dust can be spread into the air during demolition or renovation work. It is also important to remember that the serious effects on the health of workers exposed to asbestos, and that special precautions are required in dealing with this material.

Many species of mold inhabit our buildings. They are found in multiple hues including black, white, red, orange yellow blue and violet. They are often first detected by their characteristic earthy or musty odour. As mentioned previously, they grow in locations of humidity on organic materials, but may be found in areas that appear to be dry. Once they begin to develop, some molds can produce their own moisture and sustain the humidity they need. *Any mold found in significant numbers to be seen or smelled requires removal.* Often, the mold is not discovered until an inaccessible space is opened. Mold must be removed, not killed with chemicals. If cleaning the affected area with detergent and water does not succeed in removing the mold, the material should be removed and replaced. Tri Sodium Phosphate (TSP) may be used to clean concrete surfaces.

Due to the inherent difficulty in formally detecting the presence of biological contaminants in the air, problems are most easily identified by the risk factors. Different situations can cause mold to grow:

- Plumbing leaks and breaks follow leaks through the building envelope as the most common source of moisture problems. Finished laundry rooms are often subjected to water spills, which then pool in hidden locations, such as under finish flooring.
- Sustained high humidity levels of more than 60% RH in basements, and over 35% in upper floors during the winter, are conducive to mold growth. Finished basements are problematic. For example, carpeting laid on cold floors in rooms with high relative humidity is frequently infected with mold.
- Defects in the building insulation and thermal bridging encourage condensation on cold surfaces. Window sills and baseboards along exterior walls frequently harbour mold.
- Absence of effective ventilation, especially in basements, bathrooms and kitchens, contributes to mold growth.

8. Roles of Architects in Improving Indoor Air Quality

Correction of air quality problems requires good cooperation between the professionals involved. The architect plays a significant role in ensuring that air quality questions are treated in a comprehensive and systematic way. Working with the mechanical engineer in developing a strategy that considers the building as a system will make the solutions more effective. Architects must allow for the space requirements by designating space for air handling equipment, if the occupants or building managers are to ensure proper maintenance. Too many buildings have this equipment stuffed into closets with insufficient space for repairs or maintenance. In renovations of small buildings that do not require the expertise of engineers, architects must consider the potential of IAQ problems to be one of their preoccupations. The design professional must be able to understand IAQ issues from a technical point of view, and also be aware of the consequences on the occupants' health.

Architects can also play an important role in making the public aware of the importance of good air quality and explain to their clients how to avoid potential problems. The architect should ensure acceptable IAQ through careful detailing, material selection and specifications, as well as through construction review. Clients should be made aware of the importance of appropriate on-site review of work progress in ensuring the economic value and the quality of the building. Left to his own economic concerns, and lacking the research background on air quality that influenced the product selection, the owner may accept substitutions that do not integrate into the whole building system.

At present, there are no minimal standards concerning the quality of interior air. However, air quality is important to healthful housing conditions. Municipalities have the jurisdictional authority and responsibility to apply measures to ensure healthy housing. In large urban centres, regulations apply specifically to the maintenance and cleanliness of housing. For example, in Montreal, fines of between $500 and $20,000 are imposed when owners fail to clean up visible mold in apartments.

When mold is caused by error or negligence in envelope design or field supervision, and compromises the integrity of the building, the professionals involved can face legal action. According to the Canadian Insurance bureau, health problems that are caused by prolonged exposure to bad air quality are not covered by most house insurance policies from the point of view of civil responsibility. Only the material damages related to water are insurable. The occupants affected by chronic problems with air quality are, therefore, not able to be compensated if their health is affected by those conditions.

9. IAQ Case Study

In a multi-family building in Montreal, a large majority of the tenants had to leave their apartments because of health problems. These problems seemed to be caused by the proliferation of mold observed in several areas of the building, but most significantly on the 3rd floor and the basement. The 1970 building, with 21 apartment units, was part of a group of several identical buildings that allowed interesting comparisons of the level and consequences of degradation on the appearance of air quality problems.

The expert analysis of the property showed that different deficiencies and lack of maintenance had given rise to the complaints. The building was sited on land with a high water table, with inadequate drainage slope away from it. As a consequence, water was constantly close to the foundation walls. The earth had insufficient load bearing capacity that caused the foundation to crack and sink in several locations.

The exterior walls were also of inadequate design for water and air tightness. The windows were at the end of their life and not salvageable. Deficient caulking had allowed water to enter the wall. Furthermore, as the walls did not even have an air barrier membrane, it is not surprising that moisture entered and condensed inside the wall. The wet insulation lost its effectiveness and continued the cycle of degradation. This situation, combined with the foundation movement made the building ripe for severe mold proliferation.

A retrofit in the 1980s added a new roof over the existing one. Construction defects during this retrofit resulted in the condemnation of the top floor of the building: The roof space had been completely filled with insulation without provision for ventilation. Without an air barrier in the original design to prevent it, warm humid air from below had wet the insulation, providing a perfect home for mold growth.

The design of the mechanical system was also deficient and encouraged fungal spread.
The bathroom and kitchen exhausts were incorrectly connected to the exhaust duct which leaked infected air throughout the building. Their exit points were located within the roof space instead of outside, adding more warm moist air to the roof condensation problem. Moreover, washers and dryers were not originally planned for the apartments and the occupants had added them over the years, with no attention paid to regulations.
Maintenance was neglected. Water leaks from pipes and spills from washers were only dealt with cosmetically, leaving in place wet and mold contaminated materials.
The building value plummeted because of the problems, aggravated by the exodus of the tenants. As a result, the cost of the decontamination and repair work required was greater than the economic value of the building, and it was demolished.

In contrast, an identical building at the same location showed that when maintenance and the necessary repairs are carried out, biological contamination is much less severe. In the second building, the tenants were able to remain in their apartments while deficiencies that included similar envelope and mechanical faults were repaired, and decontamination performed.

10. Conclusion

Although interior air pollution can affect individuals differently, there is consensus among medical specialists that prolonged exposure has serious negative health effects. With their construction expertise, architects are called upon to play a major role in the resolution of this type of problem. Unfortunately, many practising architects today are not familiar with the different questions that surround this subject.

Retrofit and renovation work, which is an important source of work for architects, often requires the correction of current IAQ problems. To do this, architects must be able to identify the causes of IAQ problems and to elaborate long-term solutions for them. They must know how to detail buildings to avoid water and air infiltration problems, and have knowledge of ventilation and pollutant reduction strategies that may be required. When their expertise is not sufficient, they must be aware of the testing resources and expertise that may exist to help them carry out their tasks.

Remember these strategies to ensure good indoor air quality:

- Provide equipment that will help to limit indoor relative humidity levels during both summer and winter.
- Design building envelopes that stop leaks of humid air and water.
- Use the approach of elimination, reduction, containment and dilution of noxious emissions.
- Use the MSDS information sheets to guide product selection.
- Specify the most benign materials that suit the building's performance requirements and employ compatible methods of attachment.
- Encourage building owners to require architectural review of construction progress.

11. Questions

1. What are the two types of pollutants most likely to damage indoor air quality? What are the sources of these pollutants?

2. What levels of relative humidity at a surface will support mold growth?

3. What are 6 sources of moisture problems in building envelopes? Suggest a strategy to resolve each problem.

4. How can an architect determine the potential effects on air quality of different building finish products?

5. What materials and products used inside a dwelling are most likely to emit chemical contaminants into the air?

6. What 6 strategies can be adopted when an air quality problem is discovered?

7. Name 5 strategies that can improve the integrity of multi-unit residential buildings.

8. What are the signs that internal partitions in multiple unit residential buildings are relatively permeable to air movement?

9. Identify 3 indoor air quality problems associated with conventional ventilation systems in multiple unit residential buildings.

10. What are the architect's roles concerning indoor air quality issues?

12. References

1. National Commission on Building and Fire Codes, *National Building Code of Canada 1995,* National Research Council Canada, Ottawa, ON, 1997.

2. Health Canada, *Exposure Guidelines for Residential Air Quality,* Ottawa, ON, 1987.

3. Weaver, M., *Conserving Buildings– A Guide to Techniques and Materials,* Ottawa, ON, 1992.

4. Drysdale, R., *Construction Problems in Multi-Family Residential Buildings,* for Ontario New Home Warranty Program and Canada Mortgage and Housing Corporation, Ottawa, ON, 1991.

5. Christian, G., *Bugs, Mold and Rot*, a paper presented to the BETEC Conference, Alexandria, VA, 1993.

6. Canada Mortgage and Housing Corporation, *Moldy Houses: Why They Are & Why we Care,* Ottawa, ON, 1995. (a)

7. Canada Mortgage and Housing Corporation, *Building Materials for the Environmentally Hypersensitive,* Ottawa, ON, 1995. (b)

8. Wilson, A., Moisture Control in Buildings: Putting Building Science in Green Building, for *Environmental Building News, Vol. 12, Number 7,* Brattleboro, Vt., July, 2003.

9. Canada Mortgage and Housing Corporation, *Wood Frame House Construction,* Ottawa, ON, 2003. (a)

10. Ontario Association of Architects and Canada Mortgage and Housing Corporation, *The Rain Screen Wall System,* Ottawa, ON, 2001.

11. Canada Mortgage and Housing Corporation, *Wood Frame Envelopes: Best Practice Guide – Building Technology,* Ottawa, ON, 1999.

12. Canada Mortgage and Housing Corporation, *Wood-Frame Envelopes in the Coastal Climate of British Columbia: Best Practice Guide – Building Technology,* Ottawa, ON, 2003. (b)

13. Canada Mortgage and Housing Corporation, 2003. (a)

14. Ibid

15. Canada Mortgage and Housing Corporation, 1999.

16. Ontario Association of Architects and Canada Mortgage and Housing Corporation, *Guidelines for Delivering Effective Air Barrier Systems,* Ottawa, ON, 2001.

17. Ontario Association of Architects and Canada Mortgage and Housing Corporation, *Design Considerations for an Air Barrier System,* Ottawa, ON, 2001.

18. Ontario Association of Architects and Canada Mortgage and Housing Corporation, *Design of Durable Joints Between Windows and Walls,* Ottawa, ON, 2003.

19. Fugler, D., C. Grande and L. Graham, Attached Garages are Likely Path for Pollutants, for *ASHRAE IAQ Applications, Vol. 3, No. 3*, Atlanta, GA., 2002.

20. Mendler, S. and W. Odell. *The HOK Guidebook to Sustainable Design,* John Wiley & Sons, New York, NY, 2000.

21. The Workplace Hazardous Materials Identification System (WHMIS) is regulated by the Federal and Provincial governments. Contact the Canada Health website: http://www.hc-sc.gc.ca/hecs-sesc/whmis/

22. Canada Mortgage and Housing Corporation, *How to Read a Material Safety Data Sheet (MSDS),* in *About Your House CE 18*, Ottawa, ON, 1999.

23. Canada Mortgage and Housing Corporation, 1995 (b).

24. Canada Mortgage and Housing Corporation, *Healthy High Rise: A Guide to Innovation in the Design and Construction of High-Rise Residential Buildings,* Ottawa, ON, 2002.

Canada Mortgage and Housing Corporation (documents / expertise)

CMHC has carried out research on this subject for over ten years, and offers technical support, courses for professionals and consumer bulletins entitled *About Your House*, as well as technical references entitled *Research Reports.*

Selected titles from the *About Your House* Series on the CMHC website at:
http://www.cmhc-schl.gc.ca/en/burema/gesein/abhose/

Attic Venting, Attic Moisture, and Ice Dams
Before you Start Renovating your Basement - Moisture Problems
Before you Start Renovating your Bathroom
Before you Start Window and Door Renovations
Choosing a Dehumidifier
Carpet Streaking
Fighting Mold: The Homeowners' Guide
Maintaining Your HRV
Measuring Humidity in Your Home
After the Flood
How to Read a Material Safety Data Sheet (MSDS)
The Condominium Owner's Guide to Mold

Selected titles from the *Research Report* Series on the CMHC website at:
http://www.cmhc-schl.gc.ca/publications/en/rh-pr/index.html

Canada Mortgage and Housing Corporation, *The Clean Air Guide: How to Identify and Correct Indoor Air Problems in Your Home,* Ottawa, ON, 2002.

Canada Mortgage and Housing Corporation, *Building Materials for the Environmentally Hypersensitive,* LNH 6743F, Ottawa, ON, 2000.

Canada Mortgage and Housing Corporation, *Let's Clear the Air: An Indoor Air Quality Seminar,* (Participants' Work Book), Ottawa, ON.

Canada Mortgage and Housing Corporation, *Mold in Housing: Information Kit for First Nations Communities,* Ottawa, ON, 2000.

Canada Mortgage and Housing Corporation, *Healthy High Rise: A Guide to Innovation in the Design and Construction of High-Rise Residential Buildings,* Ottawa, ON, 2002.

Canada Mortgage and Housing Corporation, *Moisture and Air: Problems and Remedies,* Ottawa, ON, 2002.

Canada Mortgage and Housing Corporation, *Design of Durable Joints Between Windows and Walls,* Ottawa, ON, 2003.

Canada Mortgage and Housing Corporation, *Guide to Mechanical Equipment For Healthy Indoor Environments,* Ottawa, ON, 2000.

Canada Mortgage and Housing Corporation, *Moisture and Air – Problems and Remedies,*
Ottawa, ON, 2003. http://www.cmhc.ca/en/burema/gesein/Momo/moaipr/index.cfm

CMHC Website: www.cmhc-schl.gc.ca

Specialized Documentation

Association provinciale des constructeurs d'habitations du Québec, *Tournée qualité 2000: L'enveloppe des bâtiments résidentiels,* Association provinciale des constructeurs d'habitations du Québec, Anjou, QC, 2000.

American Society for Heating, Refrigerating and Air-Conditioning Engineers, *Standard 62.2: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings,* Atlanta, GA, 2003.

D'Halewyn, M.-A. et *al*. *Moissisure en milieu intérieur et risques pour la santé,* Bulletin d'information en santé environnementale, Québec, Institut national de santé publique, Vol. 14, no 1, p.1-7, Québec, 2003.

Weaver, M., *Conserving Buildings – A Guide to Techniques and Materials,* Ottawa, ON, 1992

Institut National de santé publique du Québec, *Les risques à la santé associés à la présence de moisissures en milieu intérieur,* Québec, QC, 2002.

Hansen, A. T. *Humidity Problems in Houses,* for IRC, Canadian Building Digest, CBD-231-E, Ottawa, ON, 1984.

Mendler S. et W. Odell. *The HOK Guidebook to Sustainable Design,* Ed. John Wiley & Sons, New York, NY, 2000.