Indoor Air Quality

Indoor air quality is probably the most controversial aspect of residential building science. Since the Second World War, the product delivered by Canada's housing industry has evolved from a leaky, drafty structure which relied upon poorly understood and totally uncontrolled forces to provide ventilation, to today's house which often features draft-free construction and a sophisticated mechanical ventilation system. Countering this improvement has been the increased use of new materials which can threaten the air quality in the modern home.

The challenge for the housing industry is to identify affordable and practical measures to safeguard indoor air quality and to develop standards and systems to permit their effective implementation. We highlight several studies that have monitored aspects of indoor air quality in Canadian homes.

How good is the indoor air quality in R-2000 houses?

A three year monitoring program of 20 new houses in Winnipeg (16 R-2000 houses and 4 conventional houses) showed that the air quality in R-2000 houses is superior to that in the conventional structures. The "conventional" houses were somewhat better than the norm, as all had some type of mechanical ventilation system.

Formaldehyde, radon daughters, particulates, nitrogen dioxide, carbon dioxide and relative humidity levels were measured on a regular basis along with the total air change rates. While these contaminants represent only a small sample of the many pollutants found in residential environments, they are generally regarded as some of the more important ones.

Formaldehyde

Formaldehyde is a colourless gas with a pungent odour that is found in both the indoor and outdoor environments. It is an irritant that primarily affects the respiratory and nasal passages and the eyes. People demonstrate varying tolerances.

In new houses the major sources are particleboard, medium density fibreboard and hardwood plywood panelling. Consumer products including furniture, clothing and household chemicals also use it as a constituent of glues or coatings. Cigarette smoke is also a major source of formaldehyde.

The formaldehyde data was analyzed on the basis of the type of ventilation system. Houses with HRVs had lower levels than those with simple bathroom fans. The mean observed level in houses with central exhaust systems and make-up air ducts was slightly lower than that in houses with HRVs.

The Action Level for formaldehyde of 0.100 ppm, established by health authorities was readily achievable in the project houses. The mean concentration in the R-2000 houses was 0.060 ppm compared to 0.068 ppm in the conventional units. Significantly higher levels were noted in those R-2000 houses which were not operated according to R-2000 ventilation guidelines.

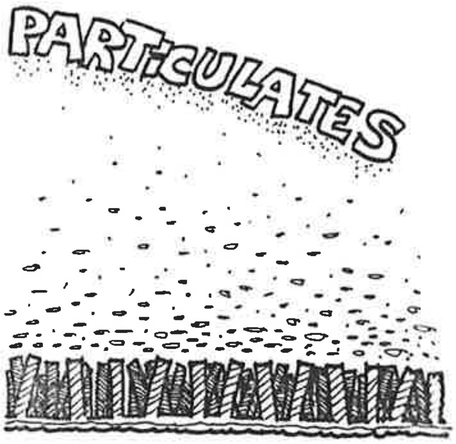
Radon

Radon is an inert, colourless gas which occurs naturally in the soil. Exposure to radon gas is acknowledged as a contributor to the development of lung cancer.

Common radon control methods include ventilation and source control to reduce entry of soil gases from the ground.

The gas enters buildings primarily by air infiltration through openings between the soil and the structure below grade level.

The Canadian guideline developed by health authorities is that action be taken when the average radon level exceeds 0.10 Working Levels (WL). The radon levels in the test houses were significantly lower compared to conventional houses in Winnipeg which had been tested in earlier studies (0.017 WL was the mean level). Radon levels in the R-2000 houses were 0.007 WL and the "conventional" houses 0.010 WL, well below the recommended action level.



Particulates

Particulates are materials suspended in the air. Household dust sources include tobacco smoke, construction materials, household products, humans, pets, plants, clothing, carpeting materials, mould, fungi, algae, wood smoke and outdoor sources such as automobile exhausts and wind borne dust. Health effects of particulates vary depending on the type, duration and intensity of exposure.

The type of heating system in the R-2000 houses had a major impact on particulate levels. Houses with forced air systems averaged 36 μg/m³ (micro-grams of particulates in every cubic meter) compared to 26 μg/m³ in baseboard heated houses. The lowest particulate concentrations were recorded in houses equipped with central exhaust systems and make-up air ducts (27 μg/m³) and the highest in houses with bathroom exhaust fans (50 μg/m³). Average values in houses containing HRVs were similar to those found in houses containing central exhaust systems with make-up air ducts (33 μg/m³).

Nitrogen Dioxide

Nitrogen dioxide is a colourless gas which is odourless in the concentrations normally encountered in residential environments. It is a combustion by-product and major indoor sources include unvented gas stoves and other combustion appliances (including wood stoves and fireplaces) as well as tobacco smoke.

Nitrogen dioxide readings were well below the recommended exposure guideline of 0.05 ppm but none of the houses had gas stoves, fireplaces, wood stoves or combustion appliances other than the furnaces and hot water tanks in the conventional houses.

Carbon Dioxide

Carbon dioxide (CO_2) is a colourless, odourless gas present in both indoor and outdoor air. It is a by-product of metabolic processes such as human respiration and by the combustion of fossil fuels. CO_2 can affect the rate and depth of respiration and produce feelings of fatigue, headaches and a general sense of discomfort.

The Canadian guideline for long term CO_2 exposure in residential environments is 3500 ppm. ASHRAE suggests a level of 1000 ppm not as a health risk indicator but as a measure for human comfort. Outdoor levels average around 320 ppm.

Over 1000 spot measurements of CO_2 concentrations were made. Only one reading exceeded 3500 ppm, and 94% of the readings were below 1000 ppm. None of the houses contained gas stoves, kerosene heaters or other major sources of carbon dioxide and average occupancy levels were two adults and one child per house.

The median CO_2 concentrations in houses with central HRV systems was 600 ppm, houses with make-up air ducts 725 ppm, and conventional houses with bathroom fans 800 ppm.

Relative Humidity

Moisture in indoor air is seldom viewed as a pollutant but if present in either small or large quantities, it can create adverse effects on the occupants and the structure.

Canadian guidelines for residential environments recommend that relative humidity levels be maintained between

30% and 80% in summer and 30% and 55% in winter (unless constrained by window condensation). 40% to 50% is suggested to minimize upper respiratory infections. Relative humidities in Canadian homes have been found to range from 21% to 68%.

Mean relative humidity levels were more commonly within the recommended winter range of 30% to 55% in the R-2000 houses than in the conventional houses.

Humidity levels were highest in the houses with bathroom exhaust fans (55% RH), followed by houses equipped with central exhaust systems and make-up air ducts (49% RH) and HRV (45% RH). The difference between houses with bathroom exhaust and houses with HRV was found to be statistically significant.

Mechanical Ventilation and Indoor Air Quality

The statistical relationship between the five measured pollutants and the corresponding air change rates were generally poor. With the exception of formaldehyde, air change rate was not observed to be a good predictor of pollutant concentration.

High air exchange rates don't guarantee low pollutant concentrations. However, it must be stressed that mechanical ventilation was necessary to achieve good indoor air quality in the study houses. Those operated at very low mechanical ventilation rates were more likely to suffer from higher indoor contaminant levels.

The findings highlight the limitations of using mechanical ventilation as the sole means of achieving acceptable air quality at the pollutant concentrations encountered. The study does not suggest that mechanical ventilation is not an important component of an effective indoor air quality control strategy, but rather that additional measures are needed. Greater emphasis must be placed on other control measures including source removal and isolation, pollutant entry control and improved ventilation system efficiency and effectiveness.

Source control should be seen as the first line of defence to protect indoor air quality.

Homeowner intervention with the mechanical ventilation systems was common and often resulted in lower than expected system utilization. Design rates used for ventilation systems, particularly those systems which do not have heat recovery capabilities, should be established both on the ability of the system to remove pollutants as well as the effect homeowner utilization will have on the net ventilation rate.

Ventilation systems with large installed capacities are likely to be used less frequently because of homeowner perceptions of increased energy costs, noise or discomfort.

Indoor Air Quality Monitoring of the Flair Homes Energy DEMO/CHBA Flair Mark XIV Project. G. Proskiw, P. Eng., UNIES Ltd. for The Buildings Group, CANMET, Energy, Mines and Resources Canada

Volatile Organic Compounds Survey

Some volatile organic compounds (VOCs) are known to be human irritants or carcinogens. The list of compounds that are classed as VOCs can be very long, and analysis of the data can get very complex because there are so many variables. The range of sources is as diverse as the range of products encountered in construction materials, furnishings, clothing, occupants, food and pets in the home.

The major contributors to VOC levels in houses can include any of the following: carpets, carpet underlays, vinyl flooring, paints, household cleaning products and waxes, cooking odours, combustion gases, textiles, tobacco smoke, moulds and fungi, human bio-effluents, hair spray, disinfectant spray, glues and wood products.

What are the VOC levels in houses?

Forty-four houses in Saskatchewan and Ontario were surveyed. 20 were in Saskatchewan (Saskatoon and Regina) and 24 in Tillsonburg, Ontario. The Saskatchewan houses were standard new houses that had been used in a 1989 *Survey of Airtightness of New Merchant Builder Detached Homes*. The houses in Tillsonburg, Ontario dated as far back as the 1890's.

Air change rates, relative humidity and temperatures were noted. For this study a total of 26 volatile organic compounds commonly encountered were individually measured. Information on specific items present in the houses that might contribute to VOC levels were also noted.

The total volatile organic compound (TVOC) levels in 100 Canadian non-residential buildings have been found to vary form 100 to 100,000 $\mu g/m^3$ (micrograms per cubic meter; outdoor TVOC levels are about 100 $\mu g/m^3$), but measured values in the typical Canadian office environment have been reported in the 1000 to 3000 $\mu g/m^3$ range. A level of 200 $\mu g/m^3$ for TOVCs has been suggested as the limit before it starts to impact people.

Only 10 of the 44 houses had TVOC readings less than 200 $\mu g/m^3$, and the average TVOC reading was 555 $\mu g/m^3$.

As a result of the many different compounds and materials in each house it is difficult to make accurate generalizations. However, a number of interesting relationships were observed. Careful selection and use of products can contribute to a healthier home environment.

CONDITION	HIGH TVOC READINGS	LOW TVOC READINGS
Relative Humidity	Higher (34%)	Lower (32.7%)
Air Change	Lower (0.3 ACH)	Higher (0.36 ACH)
Temperature	Higher (21.4 C)	Lower (20.8)
Age of home	Newer (1975)	Older (1969)
Particle board underlay	Greater use (40%)	Lower use (20%)
Continuous ventilation	lower use (0%)	Higher use (20%)
Paint use previous 30 days	Higher (30%)	Lower (10%)
Number of smokers per house	Higher (0.6)	Lower (0.3)
House with much worse average air quality	Worse (10%)	Better (0%)
Use of perfume	Higher (5.5 times/week)	Lower (4.0 times/week)
Use of Pinesol	Higher use (30%)	Lower (0%)

The sample size was small, so that definitive conclusions can't be made from the findings. However, some relationships were noted that may be of interest. These are summarized in the accompanying table. Low TVOC readings were 10 houses with levels less than 200 µg/m³, while the high TVOC range were those with readings over 750 µg/m³.

It is also worth noting that only 4 out of the 44 houses had continuously running ventilation. Two of the ten houses in the low TVOC range had continuously running ventilation. None of the houses with VOC concentrations over 750 µg/m³ had continuous ventilation.

Volatile Organic Compound Survey and Summarization of Results by Dr. Rob Dumont and Lawrence Snodgrass, Building Science Division, Saskatchewan Research Council, for CMHC.

Illness and Indoor Air Quality

A Swedish study has confirmed that there is a direct relationship between the occurrence of colds and low indoor humidities. At lower humidities the viruses have better conditions for survival. In addition, changes in the resistance offered by mucous membranes means the body is less resistant to the viruses.

The study, done in ten day-care centres in the Stockholm area, found that 2-4 days after a period of very low humidities there was an increased frequency of illness. The same can be found with very high humidities. The lowest incidence of illness was found with indoor humidities in the 30-40% range during the coldest period.

Microbiological Pollutants in Older Houses

Older houses are often considered superior to new energy efficient houses, as the houses supposedly "breathe" and "flush out" contaminants.

Is there any truth to these ideas? Are older houses really healthier?

An in-depth study of 28 homes in Tillsonburg, Ontario was done in early 1991. The study concentrated on indoor air quality, in particular airborne moulds and bacterium. Homes were selected randomly, on the basis of the willingness of the occupants to allow researchers into the home. The age of the houses varied between 1 and 100 years, with the average age being 30 years.

Measurements of temperature and humidity, airborne fungal spores and bacteria were taken in the living areas of the houses when they were under natural conditions. An effort was made to carry out the visits during colder weather between January 15th and March 15th.

A depressurization test was done to evaluate the relative air tightness of the house. The normalized leakage area (i.e. the total leakage area per unit area of exterior building area at 10 Pascals pres-

sure difference) ranged from 1.03 to 7.91 cm^2/m^2 (the R-2000 limit is 0.7 cm^2/m^2). This is equivalent to an air change rate of 0.101 to 0.728 air changes per hour (ACH) (15 to 161 l/s). Ten of the houses averaged less than 0.3 ACH.

It is important to note that these air change rates are the real effective air changes. R-2000 builders will be familiar with the limit of 1.5 ACH which is a calculation and test done at a condition where the house is under a uniform negative pressure of 50 Pascals which in reality the house never sees.

From the human health point of view, the presence of large numbers of fungal spores in the air would more likely be associated with hypersensitivity problems, especially in patients with illnesses involving the immune system. However, none of the fungi isolated are species that are regularly associated with clinical syndromes in people. Analysis of 56 samples produced 29 different species which were considered as being prominent. 10 have been identified as "Toxigenic" or "Mycotoxin-producing".

The mechanisms which were most often found to lead to high levels of mould and bacterium were low air-change rates and exposed soil, although the existence of these did not automatically mean there were high mould and bacterium levels.

Analysis of construction features, equipment and appliances found that houses with central air conditioning and gas fuelled heating and hot water systems tended to have lower airborne microbial levels. Houses with crawlspaces, electric or sealed combustion water heating, mouldy walls and mouldy smelling basements had higher levels of mould and bacterium. The number of plants in the house had little impact on the level of mould and bacterium.

Occupants who frequently operate humidifiers and who set back the space temperature often and for longer periods of time tended to have homes with higher levels of microbial activity. Those who kept their furnace filter in good condition had more mould and bacterium than those who had filters in poor condition. (Typical furnace filters are ineffective at removing fine particles until heavily loaded with dust, when it starts to filter out smaller particles.)

Refrigerators where the defrost drain tray was not heated by the condenser or compressor were found to be sources of pollutants. Windows in general were found to be the most common source of moulds, especially bedroom windows. Basement surfaces, cold-rooms and exposed soil were also productive sites for mould and bacterium, as were bath/shower enclosures.

While there is a strong relationship between the air-change rate and the interior humidity level, no relationship between airborne mould and bacterium concentrations and the air-change rate or humidity level could be derived in a statistically satisfactory analysis.

It is normally considered a given fact that low levels of air-change contribute to higher levels of microbiological activity. This was not supported statistically by the group of houses in this study.

The premise that houses with moisture-related faults such as water leakage, damp basements or previous flooding are more microbiologically active was also not supported statistically by the group of homes in this study. Another, more extensive survey is needed to determine if this group of houses was just a fluke, or whether the basic assumptions are faulty.

The interaction of higher humidity levels, condensation and mould growth is poorly understood, ignored, or considered less important than other issues in our daily lives. In most instances where condensation and mould growth was linked to how the house was operated, such as the use of a humidifier or temperature set-back, the occupant had little awareness of the mechanism which led to the condensation and fungal growth.

In most instances the fungal growth was considered to be a cosmetic annoyance only. Where lack of ventilation was an issue, the main concern was to minimize heating costs, and to accompanying fungal growth was considered an annoyance.

"Testing of Older Houses For Microbiological Pollutants" prepared for: Canada Mortgage and Housing Corporation by: Bowser Technical Inc., with Chiron Consultants, Dr James L Whitby