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Ventilation Requirements and Natural Air Leakage in Residences

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In a modern residence, with reduced air infiltration, a problem may arise if the fresh air requirement is left to natural leakage. The article discusses this problem. Techniques for measuring air leakage are described and typical results presented. The contaminants which define the need for ventilation are described and the case for controlled ventilation systems (and possibly heat recovery devices) is made. Areas for further research are recommended.

With the recent increases in energy costs, emphasis is being put on energy conservation in residential space heating. The standard response is to upgrade the insulation levels in the house. Under these new conditions, the heat loss due to air leakage, ie, infiltration of cold outside air and exfiltration of warm inside air, begins to dominate all other sources of heat loss, as shown in Figure 1.

The fact that this component of heat loss can be significantly reduced with modest amounts of caulking and weather-stripping materials, and labour (or with a little redesign, extra material and care in installation in new construction) is only just beginning to be generally understood. Hence, the leak-tightness of Canadian homes may well increase dramatically in the near future.

In Canadian housing, required ventilation to replace stale or contaminated air with fresh air is at present provided by natural infiltration. The level of such infiltration is defined by the structure's leak-tightness, the wind velocity and direction and the temperature difference between inside and outside. Thus there are weather conditions under which such natural ventilation will not be adequate. This problem will become more general and more serious as houses are built or retrofitted for leak-tightness in an effort to save energy. The solution is to provide a means of forced ventilation, eg, an exhaust fan.

The seeming contradiction of tightening a house to lessen infiltration and then needing to provide extra forced ventilation is resolved by noting that infiltration is subject to the vagaries of the weather while forced ventilation can be controlled to the required level. The interests of energy conservation can be met by providing a heat recovery system on the forced ventilation exhaust. But even if this is not done, the required ventilation must be provided to ensure proper air quality. And if the ventilation is provided in a controlled manner, it will be adequate in all weather conditions and will also result in the least heat loss possible in providing fresh air.

Air Leakage

In cold weather, uncontrolled leakage of air into a house causes a steady loss of heat and the cold drafts of infiltrating air may lower the comfort level of a nominally well-heated room. Some indication of the sources of air leakage is shown in Figure 2.

An air-leakage measurement technique developed by one of the authors gives a quantitative measure of the aggregate leak-

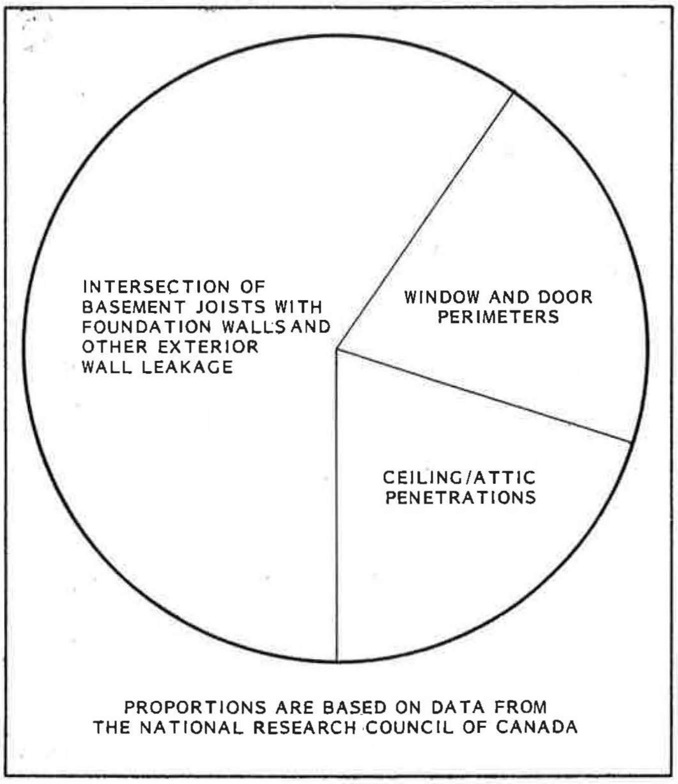

FIGURE 1 — Sources of heat loss in a well-insulated house.

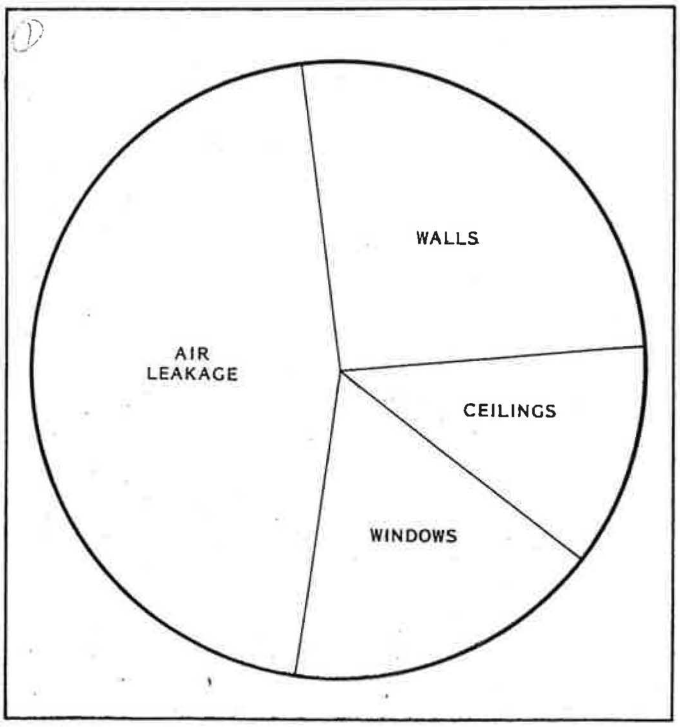

FIGURE 2 — Sources of air leakage into a typical house.

age area of a residence. Tests made on 24 electrically heated houses in the Toronto area a decade ago showed total infiltration leakage, equivalent to that which would occur through openings with areas ranging from 0.1m^2 to 0.4m^2 with a mean of 0.17m^2.

A figure of merit, called the leakage coefficient, was developed from this work by dividing the equivalent leakage area by the total house volume, and then multiplying by 10^4 to obtain a number close to 1. It was found that houses with leakage coefficients below 2.8 were prone to humidity problems, wall staining and other symptoms of too tight construction without provision for ventilation. Coefficients above 3.6 pointed to high heating costs and other indications of too loose a house. However, the use and applicability of this figure of merit have not been fully developed.

More recent measurements gave average leakage areas of 0.16m^2 for detached homes in Toronto and 0.13m^2 for residences, mostly townhouses, in Ottawa.[1] The Ottawa measurements also indicated that leak-tightness in highly insulated houses is not necessarily better than in houses that have normal insulation but are otherwise similar.

Leakage measurements on 63 recently constructed Ottawa houses[2] gave a range of equivalent leakage areas from 0.06m^2 to 0.23m^2 with a mean of 0.12m^2, somewhat tighter than the results on older buildings.

From comparable measurements in Swedish housing, the leakage there is around one-quarter of that found in North America, showing the potential for improvement in our present housing. The Swedish performance is due in part to the existence since 1977 of air leakage standards as a control on the quality of construction. (There is also a requirement for a minimum controlled ventilation rate to ensure air quality).

Factory pre-assembly of building components generally leads to higher levels of air tightness than is the case with site construction. The mobile home industry in the US and factory built house systems in Denmark are prime examples where excessive air-tightness and insufficient ventilation have led to problems with high humidity and high levels of air contaminants.

The technique used to obtain equivalent leakage areas of residences involves operation of a powerful exhaust fan, temporarily installed through a doorway or window, and measurement of both the pressure drop across the building envelope and the air in-flow induced through the leakage paths (Figure 3). Such observations describe the characteristic of the structure itself, independent of weather conditions.

Direct measurement of the natural air infiltration in a dwelling is done by releasing a small quantity of tracer gas, mixing the air thoroughly, and observing the decay of the concentration of the tracer gas with time. The usefulness of this quantity in characterizing a house is limited by its great variability during the year, depending as it does on the weather factors mentioned earlier. In houses where fuel-fired heating systems use indoor air for combustion, additional air infiltration takes place due to chimney output. Although gases such as sulfur hexafluoride which do not occur naturally are normally used as tracers, an indication of leak-tightness can be obtained using water vapour: tight houses maintain higher relative humidity levels than do leaky houses. In fact, a characteristic of new tight housing is that a humidifier is not required to maintain a minimum humidity level through the winter (humidity from natural sources is adequate or may need to be dissipated by ventilation).


FIGURE 3 — Fan equipment for air-leakage tests.

Work is continuing to characterize the correlation between the two types of measurements, thus allowing use of the simple fan test to obtain an indication of the infiltration rate for a structure.

The general direction of work in this field is towards determining whether improved restriction of leakage can provide natural infiltration at rates ranging between desirable upper and lower limits. Natural infiltration has been observed to vary by a factor of five with changing weather conditions. It may be sometimes well in excess of residential requirements, resulting in discomfort of occupants and expensive energy loss, and sometimes quite inadequate, permitting possibly hazardous accumulations of undesirable gases and particulates. There is some doubt, therefore, that natural infiltration will continue to provide an acceptable means of residential ventilation as energy costs rise.

Table 1 - MAXIMUM PERMISSIBLE LEVELS REPORTED IN THE LITERATURE FOR COMMON CONTAMINANTS IN HOUSEHOLD AIR

Contaminant	Concentration Permissable for 24-Hour Residential Occupancy mg/m^3
Water Vapour	10 000 *
Carbon dioxide	9 000 **
Carbon monoxide	25
Nitrogen dioxide	0.4†
Formaldehyde	0.15
Ozone	0.1
Odorous Gases:	
Carbon disulphide	70
Ammonia	40
Hydrogen sulphide	30
Aniline	20
Methyl mercaptan	20
Pyridine	15
Sulphur dioxide	15
Nitrobenzene	5
Total suspended particulates	0.1
Radon and daughter products	1×10^{-11} (75 Bq/m^3)

* 50% relative humidity at 21°C

** The normal concentration of carbon dioxide in outside air is about 600 mg/m^3

† Permissible for one hour exposure only

Note: The concentrations quoted in the table may be put into perspective by comparing them with the normal density of indoor air, which is about 1 200 000 mg/m^3

By providing a sufficiently airtight structure and controllable ventilation, it should be possible to optimize both the amount of energy needed for space heating, and the level of air quality. Where high ventilation rates are required over long periods, heat recovery devices may be justified.

Ventilation and Contamination Levels

Residential ventilation should provide the following:

- —adequate oxygen and low enough levels of carbon dioxide to support life;
- —humidity levels adequate for comfort and minimization of respiratory disease, yet low enough to prevent moisture damage to the building;
- —acceptably low odour levels;
- —sufficiently low levels of particulates (smoke, dust, trace metals and organics);
- —safe levels of gaseous contaminants;
- —a minimum of energy loss during the heating season (and gain during the cooling season) while still providing adequate "fresh" air.

The required ventilation rate can be expressed as an air flow rate (L/s) per person, but it is more often related to the size of the building by use of the unit, air changes per hour (ach). With one ach of ventilation, the volume of conditioned air in the building is replaced once every hour.

Table 1 lists the maximum levels of household contaminants for 24-hour exposure, as suggested by various authors[3,4,5,6] on the basis of the best available information. No proposals or tentative recommendations for residential air quality standards yet exist in Canada, although a federal-provincial task force of health experts has just been constituted to develop this information.

The difficulty in maintaining acceptably low levels of contaminants is that not only are most contaminants odourless and colourless, but the ventilation rate which dilutes their concentration is usually variable and uncontrolled.

Ventilation requirements for human occupancy depend on the rate of generation of contaminants, on the maximum allowable level of contamination, on the ambient level in outdoor air, and on the rate of removal of contaminants by methods other than dilution. Descriptions follow of those contaminants which define the required rate of ventilation.

Carbon Dioxide

The main sources of carbon dioxide are biological metabolism and combustion. The high maximum allowable concentration given in Table 1 means that this gas is seldom a controlling factor in determining ventilation rates. However, a complaint of headaches in an Ontario house was traced to high carbon dioxide levels in the bedroom.

Water Vapour

The rate of generation of water vapour in normal household activities — breathing, cooking, washing, drying, bathing, etc — is large enough to require dilution by ventilation in many instances. The situation is aggravated in cold weather by condensation on cold interior surfaces (windows, corners of exterior walls, etc), forcing a decrease in allowable relative humidity, and thus an increase in the required ventilation rate. More insidious is the exfiltration of warm, moist air into the building shell during the winter, where the moisture can condense and freeze. Water damage during spring thaw, or structural damage to wooden members in severe cases, can result. Sealing such exfiltration leaks (normally into the house attic or upper walls because the warm air escapes from the upper areas while the cold replacement air leaks in below) is one solution; lowering the indoor relative humidity is the most effective long-term answer. However, when relative humidity is low (especially below 20%), respiratory problems intensify.

Odours

Odours are generated biologically and in cooking, as well as by other particular activities (smoking, hobbies, etc). Control at the source (for example, by the use of an exhaust fan above the range during cooking) is most efficient. Body odours are normally controlled by ventilation rates of the same order as those required to control humidity (often suggested as 8 L/s per person). Much larger rates are needed to control the products of smoking, which include particulate matter.

Carbon Monoxide

Carbon Monoxide is produced as a result of incomplete combustion, in gas cooking and smoking, for instance. The best defence against this gas, which interferes with the blood's ability to carry oxygen, is to ensure that all sources of combustion have a supply of excess oxygen so that the combustion is complete. Recently, a banked wood stove in a tight house nearly caused a fatal accident.

Formaldehyde

Formaldehyde is an important, low-cost, high-volume chemical used mainly in phenolic, urea, melamine and acetal resins. These resins are used in quantity for the production of chipboard, plywood, insulation materials, adhesives, textiles, etc. When the latter materials are used in enclosed spaces such as mobile homes and other almost air-tight structures, formaldehyde slowly diffuses out for extended periods and may rise to objectionable levels, causing eye and nose irritation, or hyper-allergic reactions such as rashes or asthma. The amount of ventilation required in a new house will depend on the age of its building materials, the surface finish of the materials containing formaldehyde, and the temperature of the materials. Large variations in ventilation requirements are expected for this contaminant due to the large variability in the rate of release of formaldehyde from the contributing structural materials.

Ozone

Ozone is a colourless gas which occurs in nature as a result of ionization of oxygen gas during electrical storms, or from the reaction between ultraviolet radiation and air in the upper atmosphere. In cities ozone is produced by photo-chemical reactions of hydrocarbon pollutants from automobile and industrial emissions. In concentrations typical of outdoor urban environments, the odour is barely detectable. At concentrations well above the recommended level or the level in polluted city environments, ozone may cause headaches and irritation in the upper respiratory tract.

Electronic air cleaners generate small amounts of ozone while ionizing air. Simultaneously, ozone is consumed by materials in the house, and a balance is quickly reached. Ozone infiltrating from outdoors will also be consumed by the materials in the house, especially by wool and nylon carpeting. Occasionally, ionization devices and ozonating purifiers appear in the market place for residential and commercial use for which the amount of ozone generated is not always specified. There should be cause for concern in the misuse or misapplication of these devices, particularly since the chronic local and systemic effects are not known.

Nitrogen Dioxide

Nitrogen dioxide is produced outdoors by a photochemical reaction of hydrocarbon pollution in sunshine, and indoors by gas appliances such as stoves and unvented gas heaters. It has a red-brown colour, is highly toxic and irritating, and may cause death or permanent injury after very short exposure to small quantities. The maximum recommended allowable level for one hour exposure is 0.4 to 0.8 mg/m^3. In houses with gas cooking, levels of nitrogen dioxide as high as 1.6 mg/m^3 have been observed.[7] Even with a normal recommended kitchen ventilation rate of 25 L/s, this concentration did not decrease below the recommended level. Ventilation requirements for houses where products of gas combustion are vented indoors may be higher than for other houses.

Radon

Radon gas occurs naturally in soils as a result of the radioactive decay of radium which occurs in trace amounts in most materials. In a few special locations (close to uranium mining areas or refining operations) radon concentrations are abnormally high. The gas is radioactive and occurs in such minute amounts that it is imperceptible to humans. It decays through several stages to solid materials which are also radioactive. The danger to health is the likelihood that these radioactive materials, when inhaled, will lodge in the respiratory tract, where subsequent radioactive decay can destroy tissue and initiate latent cancer of the lungs (sometimes not seen until 20 or 40 years later). The normal method of controlling the level of radon gas in occupied spaces is by ventilation with uncontaminated air. Some control of the daughter products may be possible by filtration. Houses built of or on top of materials enriched in radium can reach levels of radioactivity higher than the recommended maximum safe levels.

When the source of radon is ordinary concrete (as in a basement wall), a ventilation rate of one air change per hour will reduce the radiation level to 0.8% of the original level.[4] Under special circumstances, the level of radon may determine the minimum ventilation rate required for the building. The rate may be high enough to control all contaminants of concern, but may create other problems, such as dryness during the heating season, and high energy usage.

Required Ventilation Rate

In the past, the required ventilation rate for residential buildings was unspecified. Natural infiltration and the ability to open windows were assumed to give adequate provision for fresh air. When exhaust fans were installed in kitchens and bathrooms, they were over-sized to allow control of infrequent, localized sources of contamination through intermittent operation. The present trend to tighter houses for energy conservation has begun to make such provisions of ventilation inadequate. We may have to follow the Swedish lead in specifying that a suitable exhaust system for the whole house be installed and an adequate method or device to control its operation be used. A specific ventilation rate cannot be recommended in any given situation without knowing the nature and levels of contaminants to be controlled. However, assuming normal contaminants, rough recommendations have been made, ranging between 0.25 and 0.7 air changes per hour. Caution must be exercised in applying any such recommendation to a particular case.

Heat Recovery Devices

When controlled ventilation systems are installed, it becomes possible to save part of the energy exhausted by using a heat recovery device. Whether the potential energy savings justify the capital cost of such devices is not clear.

Areas Requiring Further Work

Consideration of the state-of-the-art of control of infiltration, air leakage and contaminants, of problems with humidity control and of the high cost of energy, indicates that further development is needed in the five areas outlined below:

Control of house tightness — Site-built houses in Canada are assembled by half a dozen or so trades working in concert to build a structure which may or may not be particularly air-tight. Even when special measures are taken to make conventionally built buildings air-tight, only marginal improvements are observed. In Sweden, a variety of techniques have been successfully developed for tightening new buildings and similar methods may be applicable to Canadian buildings. Ultimately, a minimum tightness level for new construction may need to be specified in building codes.

Allowable levels of contaminants — Because no single authority proposed the maximum residential contamination levels cited in Table1, there is the possibility that the values quoted are not all based on the same criteria of healthfulness nor on criteria appropriate to residential occupancy in Canada. The recently constituted task force of Canadian health experts should answer the above concerns in due course.

Ventilation control by air-contaminant level — The critical contaminant which should determine the ventilation requirements of the house may differ from house to house depending on the local sources of contaminants. The requirements may differ from one site to another, and with families, time, and season. Suitable controls are not available.

Economic means for ventilation and waste-heat recovery — Tightly built houses which have no central air handling system may need a means of mixing, diluting and exhausting indoor air, and a heat recovery device where economically justifiable. A balance between efficiency and cost needs to be established for heat recovery devices for residential use.

Removal of contaminants by treating rather than exhausting air — Particular cases of contaminants should be investigated to find alternatives to exhausting large quantities of air, such alternatives being the electrostatic filtration of the radioactive daughter products of radon, or chemical reactions to remove such contaminants as nitrogen oxides and formaldehyde by recirculation of house air over a "regenerator"

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