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A REVIEW OF VENTILATION REQUIREMENTS FOR RESIDENTIAL BUILDINGS IN CANADA

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EXECUTIVE SUMMARY

This report has been prepared by T E S Limited for the Technical Research Division of Canada Mortgage and Housing Corporation (CMHC). The purpose of the report is to provide CMHC with an overview of ventilation conditions and requirements for low-rise residential buildings in Canada.

Ventilation is the process of supplying or removing air, to or from a space, by either natural or mechanical means in order to maintain an acceptable level of air quality. Ventilation is usually needed to maintain proper oxygen and carbon dioxide levels and to control the concentration of various contaminants such as odours, smoke, carbon monoxide, nitrogen dioxide, formaldehyde and radon which may produce objectionable odours or toxic effects and present potential health risks. Ventilation is also required to control humidity levels within a building in the winter and to reduce discomfort from over-heating in the summer. All of these needs for ventilation are reviewed in detail as are the ventilation rates necessary to satisfy these various ventilation requirements.

Codes and standards, both prescriptive or non-prescriptive, which specify ventilation regulations are discussed. The documents reviewed include the National Building Code of Canada; Residential Standards; the Canadian Heating, Ventilating and Air-Conditioning Code; Provincial building codes; standards of the Canadian Standards Association and the American Society of Heating, Refrigerating and Air-Conditioning Engineers; "Measures for Energy Conservation in New Buildings"; and the Swedish Building Code.

Ventilation of buildings can be accomplished by natural and mechanical means. Natural ventilation occurs by the random leakage of air through the building envelope as well as through deliberate openings in the house such as vents, doors and windows. Mechanical ventilation is usually achieved using fan, duct and intake systems of varying complexity. These methods of ventilation are reviewed along with related devices such as dehumidifiers, attic fans and air-to-air heat exchangers.

Ventilation is usually measured by the tracer gas technique or by fan tests. The tracer gas method is used to measure the natural ventilation rate of a building while fan pressurization tests provide a measure of the relative air tightness of buildings. These testing techniques are discussed and results of tests on buildings in North America and Europe are presented.

It appears that existing and new housing may benefit by incorporating mechanical ventilation systems in conjunction with tighter building envelopes. This would permit the amount of ventilation air to be reduced to the minimum necessary to satisfy both air quality and energy conservation requirements. However, several factors currently prevent the Canadian housing stock from utilizing these features. For example, there are currently no comprehensive Canadian guidelines, codes or standards concerning air tightness of buildings and ventilation air quality. As well, the shortcomings of present ventilation devices and controls combined with the lack of knowledge of both the general public and the building trades regarding ventilation problems and the operation of ventilation devices, has hindered the development of more efficient ventilation regulations and systems such as those now in use in the Scandanavian countries.

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INTRODUCTION

Ventilation is the process of supplying or removing air, to or from a space, by either natural or mechanical means in order to maintain an acceptable level of air quality. The air supplied for this purpose usually comes from the outside, either intentionally through an opening that is controlled manually or automatically, or unintentionally by air leakage through the building envelope.

In older housing and in some recent housing, ventilation has usually been uncontrolled, and, in most cases, may be regarded as accidental. Such informal control of building ventilation has been considered acceptable in the past. However, with the increased interest in energy conservation, measures are being taken to conserve the amount of energy used in the heating and cooling of buildings. Such measures as tightening the building envelope to reduce infiltration (the air flow into the building) and exfiltration (the air flow out of the building), improving insulation and reducing ventilation rates have lead to problems of poor air quality and high humidity levels which not only decrease the livability of a dwelling but can actually affect its structural integrity.

In order to alleviate such problems, a growing need exists for more exact and controlled methods of achieving proper residential ventilation. Such precise control of ventilation can be achieved mechanically and, in the future, may involve the recovery of heat from exhausted air by the wide scale use of such devices as air-to-air heat exchangers and heat pumps. As insulation levels increase, heat loss due to air change forms an increasingly larger portion of total building heat loss and thus, the use of recovery devices becomes significant.

OBJECTIVES AND SCOPE

The objectives of this program are:

A) To review the theoretical and real-life basis for the needs for ventilation air.

B) To review codes and standards, prescriptive and non-prescriptive, that legislate or otherwise specify the "parameters" necessary to ventilate an enclosure.

C) To investigate past, present and developing methods of ventilating houses to the levels codes have dictated.

D) To delineate the variance in specified conditions of ventilation and those actually measured in practice.

E) To determine the level of present-day methodology for providing ventilation, mechanical or otherwise.

F) To further decide on the applicability of existing methods for retrofit and new construction applications.

G) To recommend and pursue areas of Research and Development, as revealed in A) through D), to enhance and advance the environmental performance of existing and future housing.

H) To "illustrate" Policy and Standards directions for CMHC, based on the investigated and researched discoveries of the foregoing.

This report is limited in scope to a detailed review of the ventilation requirements for residential buildings (single-detached, semi-detached, duplexes and row housing) in Canada, as specified in Objectives A) through F), and presents a summary of these requirements which will assist CMHC in effectively addressing Objectives G) and H) of the program.

THE NEEDS FOR VENTILATION

A residential building must be adequately ventilated in order to maintain an acceptable level of air quality within the dwelling. The needs for such ventilation usually result from the necessity to:

- maintain proper oxygen (O_2) and carbon dioxide (CO_2) levels
- control the concentration of contaminants that may produce objectionable odours or toxic effects
- control the humidity levels within the building in winter and summer, and
- reduce discomfort from over-heating in summer.

These ventilation needs, and the amount of ventilation necessary to satisfy them and provide acceptable overall air quality, are discussed on the following pages.

Oxygen & carbon dioxide

Fresh outdoor air contains about 21 per cent O_2 and 0.03 per cent CO_2 on a volume basis (the remainder being mainly nitrogen). Significant variations in these proportions can render it unfit for human use. For prolonged exposure, a minimum concentration of 16 per cent O_2 and a maximum concentration of 0.5 per cent CO_2 are commonly accepted standards (1,2). * Oxygen deficiency in itself is not as serious a problem in poorly ventilated quarters, as high CO_2 concentration, which can cause unconsciousness or death before a corresponding oxygen deficiency would have serious physiological effects (3). In order to establish a satisfactory balance between the metabolic gases (oxygen and carbon dioxide) in an occupied environment, a ventilation rate of 0.09 m^3/min (3 cfm) per person is the minimum fresh air requirement for occupants of a confined space (1,2,3,4).

** References and information sources are noted by bracketed numbers at the end of the statement, e.g. (1) and can be found at the end of this report under the heading "REFERENCES".*

Indoor contaminants include a wide spectrum of gaseous, particulate and radioactive pollutants which may produce objectionable odours or toxic effects and present potential health risks. Examples of such contaminants include odours from smoking, cooking, garbage, occupants and pets; airborne particles such as dust, smoke, pollens and bacterial organisms; carbon monoxide (CO) and nitrogen dioxide (NO_2) from gas stoves; formaldehyde (HCHO) from gas stoves, particle-board, plywood and urea-formaldehyde foam insulation; radon (Rn) from soil and various building materials; and assorted chemicals from hygiene products, aerosol sprays, cleaning agents, air fresheners and solvents. This complex biological, chemical and physical mix of indoor air pollutants has been recognized only recently and, therefore, there is incomplete information available to determine the indoor air quality criteria required for establishing ventilation needs for such contaminants in buildings (5). The following discussions highlight several of these indoor contaminants which are of particular concern in residential buildings.

Odours

As stated earlier, odours in buildings arise from a variety of sources such as food preparation, tobacco smoke, garbage and the occupants themselves. They can also originate from furnishing materials, cleaning agents and solvents, deterioration resulting from dampness of stored material and building materials, and from the wet coils of air conditioning units. However, many of these sources of household odour are intermittent and continuous removal is not required. Such odours are usually removed through the use of exhaust fans located at the source of the contaminant or by recirculating air through odour-absorption equipment containing activated charcoal or similar materials. It is felt that the continuous air requirement to control tobacco smoke and body odours may be adequate to control most of the other odours (2).

The ventilation rates required are dependent upon the types of activity and amount of smoking. These rates vary from 0.14 to 1.42 m^3/min (5 to 50 cfm) per person with a range of 0.28 to 0.85 m^3/min (10 to 30 cfm) per person covering the majority of situations (1,3).

Particulates A variety of airborne particles, such as dust, smoke, pollens and bacterilogical organisms are contained in the outdoor air brought inside for ventilation while higher concentrations of these contaminants may be brought indoors or generated by the activities of the occupants. Airborne particles are usually removed by circulation through an air-cleaning device such as an air filter for the removal of larger dust and fibre particles or an electrostatic air cleaner to remove finer particles such as pollen and tobacco smoke. As well, the normal ventilation process of bringing in fresh air helps to reduce the concentration of the particles to an acceptable or unnoticeable level.

Products of combustion Several recent field and laboratory studies have focused on combustion-generated indoor air pollution, namely air contaminants from gas stoves and heating systems in residential buildings (5). Field studies have shown that levels of CO and NO_2 approach or exceed U.S. ambient outside air quality standards in some residential buildings with gas appliances. In addition, laboratory studies have shown that gas stoves generate extremely high emissions of CO, nitric oxide (NO), NO_2 and formaldehyde (HCHO) and that the concentration of these gases becomes significant when the air exchange rate is controlled to less than 1 ach (air change per hour). For the 27 m^3 (800 ft^3) laboratory test room, a ventilation rate of at least 3.0 m^3/min (100 cfm) was required to keep NO_2 and HCHO concentrations to levels within the limits established by air quality health standards (5).

The work to date indicates that combustion-generated indoor air pollution may affect human health in buildings and, if borne out by further work, it may ultimately have a large impact on energy conservation strategies for buildings and on the need for more stringent control of air pollution from indoor combustion sources.

Formaldehyde Formaldehyde is an inexpensive, high volume chemical which is used in a wide variety of building materials such as insulation, particleboard, plywood, textiles and adhesives. Exposure to formaldehyde may cause burning of the eyes, weeping and irritation of the upper respiratory passages and may also have serious long-term health effects which are currently not well understood. European countries are moving rapidly to establish formaldehyde standards. In July, 1978, the Netherlands established a standard of 0.1 ppm as the maximum permissible concentration. Denmark, Sweden and West Germany are all considering establishing a standard at approximately the same value (6). Formaldehyde and other aldehyde levels were measured by the Lawrence Berkeley Laboratory at several energy efficient research houses at various geographic locations in the United States (5). It was found that, at low ventilation rates (< 0.3 ach), the indoor formaldehyde and aldehyde concentrations often exceeded the promulgated European indoor standard of 0.1 ppm while outdoor concentrations during these studies were typically 0.016 ppm or less. In general, it is evident that indoor air has higher formaldehyde levels than outdoor air and tests show that residential buildings have indoor formaldehyde concentrations that can exceed known health effect thresholds (5).

Radon Radon and its decay daughters are known to contribute a significant portion of natural background radiation exposure to the population. Scattered observations have shown that indoor concentrations of radon and radon daughters are typically higher than outdoor concentrations. This is presumably because the building structure serves to confine radon entering the indoor environment from various sources. Radon (Rn-222) is an inert, radioactive, naturally-occurring gas that forms from the radioactive decay of radium which in turn results from the radioactive decay of uranium (7). Since radium is a trace element in most rock and soil, sources of indoor radon include building materials, such as concrete or brick, and the soil under building foundations. Tap water may be an additional source if taken from wells or underground springs.

The knowledge of the effects of exposure to radon and its decay daughters comes from early experience in uranium and other mines where miners were exposed for several years to very high concentrations of radon and its daughters. Some of the miners contracted lung cancer and it was observed that the highest cancer incidences occurred amongst the groups of miners who had received the highest exposures to radon and radon daughters (8). The Lawrence Berkeley Laboratory has conducted measurements of radon levels in energy efficient buildings in the United States (5). Results indicated that houses with low air exchange rates (< 0.3 ach) seem to have higher radon concentrations than conventional houses (~ 0.75 ach). Results also indicated that an air exchange rate of approximately 0.5 ach is required in order to maintain radon concentrations below the maximum permissible concentration given by health guidelines. In addition, in the Nordic countries (Denmark, Finland, Norway and Sweden), concern about high radon levels has led to a recommended minimum ventilation rate standard of 0.5 ach in residential buildings (9).

The effectiveness and advisability of various measures to control radon depend on circumstances such as the type of building, the geographical location and the cost of the control strategy. The effects of elevated radon levels are highly uncertain and a long-term solution requires a comprehensive approach which balances factors such as the impact on human health of radon (and other contaminants) and the need for energy conservation through reduced infiltration and ventilation rates. At this time, there is insufficient information available to provide a basis for a considered regulatory decision (9).

Humidity and condensation

Although it is essential to maintain proper O_2 and CO_2 levels and control the concentration of contaminants in the indoor air, there is little question that the control of humidity levels within the building envelope during the winter is a source of increasing concern. In older houses, it is generally difficult to maintain sufficient moisture in the air, but in modern tighter homes, particularly those with electric heating where natural air exchange rates are very low due to the non-existence of chimneys, the situation is reversed and high humidity levels may be more prevalent. In the wintertime, high humidity levels can lead to excessive condensation of moisture on windows, walls and ceilings. This not only creates a nuisance by limiting visibility and by wetting wall, ceiling and floor surfaces, but in more severe cases can cause mould, rotting of wood and deterioration of paint and plaster (2,10).

Condensation within a building is generally not harmful if it is controlled within limits of 20 to 35 per cent. "Steamed" windows can be annoying and excessive air moisture can cause wetting of walls, mildew, growth of mould and water staining of fabrics and furnishings. However, more serious problems occur when water vapour is permitted to condense within the insulation inside walls and in crawl spaces and attics where it can cause deterioration of the insulation and of the building structure (11,12,13,14,15). This may seriously affect the structural integrity of the building.

Since high humidity levels and the resultant condensation problems are of such concern during the winter in Canada, it is worth reviewing, in detail, the condensation process, the parameters which affect moisture levels and the methods of controlling excessive moisture in houses.

Condensation problems arise because air can hold only a limited amount of water vapour, an amount that varies with temperature. When air at a certain temperature contains all the water vapour it can hold, it is said to have a relative humidity of 100 per cent. If, at the same temperature, it contains only one-half the water vapour it is capable of holding, then the relative humidity is 50 per cent. If the temperature changes but no water vapour is added or taken away, then the relative humidity will also change and will increase as the temperature falls. The relative humidity will continue to rise with falling temperature until the dew-point is reached - the temperature at which the relative humidity becomes 100 per cent. Any further decrease in temperature will force some of the vapour to condense as water (when the temperature is above freezing) or as frost (when the temperature is below freezing). Condensation usually occurs first on windows since they have the lowest temperature of any of the interior surfaces in a house. Air, cooled by contact with the cold interior surface of a window, will deposit some of its water vapour on the window glass, frame or sash whenever it has more water vapour than it can hold at this new temperature. As soon as visible condensation occurs on the inside surface of a window, it is an indicator that the relative humidity is too high and that steps should be taken to control the humidity level. It is a common belief by the general population that, for health reasons, there should be "a lot of moisture" in the air during the winter months. However, there is no conclusive evidence that either the health or the comfort of most people will be adversely affected if humidity is kept at a level that will prevent excessive condensation on the interior surfaces of double windows (10).

Several parameters make important contributions to the moisture level inside a building. These include the various sources of moisture within the dwelling, the tightness of the building envelope and the type of heating system. Geographic location may have considerable influence on moisture problems, for instance, in housing in Northern Canada (12,15) or coastal regions. However, all areas of the country appear to suffer from such problems (13) and geographic considerations will not be discussed further.

Sources of moisture

The principal sources of moisture in a typical house are household activities, which vary with the living habits of the family. Moisture can be produced by such activities as cooking, dishwashing, personal bathing and showering, washing and drying clothes, as well as human contributions through respiration and perspiration. Other sources of moisture include plants, use of humidifiers, evaporation from exposed soil in crawl spaces, release of moisture from various materials used in construction and leakage of outside water through the building envelope. In general, increases in moisture from these sources will lead to increased humidity levels inside the building and/or increased moisture problems within the building fabric in the winter months.

Recent causes of high humidity

If a house were completely air tight, such that no outside air could enter, the continued addition of moisture to the house air would raise the humidity to the point where condensation would occur. In practice, no house is completely air tight and some air will always infiltrate and tend to lower the humidity within the house in winter. It is the reduction in such infiltration that has been largely responsible for the prevalence of condensation problems in modern housing (10). Older houses were generally more loosely constructed and the resulting high air leakage rate was sufficient to prevent excessive humidities. In many cases, the use of a humidifier was required to prevent excessive dryness. Modern houses, with much tighter building envelopes (due in a large part to more effective air/vapour barriers), have lower natural air leakage rates with the result that there is a greater tendency toward excessive humidities due to internally generated moisture sources.

Electrically heated housing

In dwellings that are electrically heated (or that have heating systems that require no chimneys), the rate of natural ventilation will tend to be lower than in dwellings with fuel-fired heating systems (4). Electrically heated houses do not experience the same air infiltration losses as do fuel-fired houses since they do not exhaust air through chimneys or flues. As well, electrically heated houses have been built tighter, by use of better vapour barriers and higher levels of insulation, to ensure that electric heating bills remain competitive with other forms of residential heating. As a result, electrically heated houses are more susceptible to high humidity levels and moisture-related problems (12,13,15).

In early electrically heated homes there was a tendency for more light fixtures to be used than in a house heated with conventional fuels (15). The use of these extra fixtures resulted in many more holes through the air/vapour barrier. These holes acted as replacements for chimneys but permitted the leakage of moist air into walls and the attic rather than leakage to the outside air directly. Elimination of the chimney also results in higher air pressure in the house at the ceiling level and thus an increased potential for leakage of air from the house into the attic (15).

Elimination of high humidity

Excess condensation and high humidity levels within a house can be controlled by eliminating or reducing the sources of moisture, isolating areas which are suspectible to moisture (walls, attics, etc.) and by ventilation. In fact, in modern houses all of these methods of humidity control are typically employed. Since the main thrust of this report deals with ventilation, the control of moisture by elimination/reduction and isolation will only be discussed briefly.

Elimination at source

High levels of moisture should be reduced or eliminated at the source by avoiding hanging wet clothes inside, by venting automatic clothes dryers outside, by reducing the use of humidifiers and by limiting moisture producing activities. In addition, dehumidifiers may be an effective device for condensation control in winter, although they may not be capable of lowering the relative humidity enough to prevent condensation on double-glazed windows (4).

Air leakage and vapour barriers

Air leakage is now considered to be the prime cause of most condensation problems in walls and roof spaces (16). Excessive condensation is caused primarily by the flow of warm (moisture-laden) indoor air into these insulated enclosures. Such insulated areas can be protected by isolating them from the moist air inside the building by means of continuous air/vapour barriers. The details of such installations are beyond the scope of this report but the methods developed for the construction of the Saskatchewan Conservation House are recommended (17).

If a tight air/vapour barrier has been installed which blocks the entrance of moisture into the walls and ceiling, then the water vapour inside the house must be removed by other means. The most effective means available for removing this excess moisture is by ventilation. Such ventilation can be accomplished naturally, by the intentional displacement of humid inside air through specified openings such as windows, doors and ventilators or mechanically, by exhausting moist air by fans and providing fresh air through vents and intakes.

Ventilation required for humidity control

The amount of ventilation required in winter to control the build-up of humidity inside the house depends on several factors such as the number of occupants and the amount of moisture produced. However, it is generally accepted that a rate of ventilation below about 0.25 ach will result in the formation of condensation (4). In the design of the Saskatchewan Conservation House (17A), it was determined that a ventilation rate of 0.125 ach is adequate during periods of occupant inactivity and a rate of 0.25 ach is adequate during periods of activity. Others indicate that, for average-sized houses*, a continuous ventilation rate of 1.68 - 2.24 m^3/min (60 to 80 cfm) should be adequate to control excess humidity in a well-sealed house (17). This is similar to the derived ventilation rate of 3.06 m^3/min (108 cfm) required to control the moisture build-up in a home with four people (2).

Summer ventilation

Often, so much emphasis is placed on providing adequate ventilation in winter to control odours and humidity that little thought is given to summertime ventilation. Odours and moisture levels are generally not as severe a problem during the summer. However, ventilation does play an important role in providing comfort from overheating in the summer.

In dwellings without summer air conditioning systems, ventilation with outdoor air can be used to dissipate internal heat gains and heat gained from solar radiation. At this time of year, indoor conditions will be tolerable only if indoor temperatures are not allowed to exceed those outdoors by more than a few degrees (1). Buildings without air conditioning should, therefore, be designed to minimize heat gains and to provide high rates of ventilation. Heat gains can be minimized in summer by various means. These include the use of higher levels of insulation, the shading of southward-facing windows and the use of light-coloured roofing and exterior cladding.

* The relationship between house size, ventilation rate and the ach is discussed in Table 1 at the end of this section.

In general, people will accept higher than normal air temperatures in summer, so long as these temperatures are not accompanied by relative humidity levels that cause perspiration. Even under such conditions, the degree of discomfort can be reduced by increasing the rate of air movement past the body. In this way, the cooling effect is augmented by evaporation from the skin. The air velocities required for this purpose are much greater than those afforded by the air recirculation fans of normal heating systems or exhaust fans.

Portable propeller fans or breezes through open windows can be effective (4). Large openable windows, arranged to provide cross-ventilation through the house, can take advantage of natural air currents and create the kind of circulation required. In addition to portable fans, whole-house ventilation may be achieved by the use of large diameter propeller fans mounted in a window or in the ceiling at a central location of the living space. These fans are used with the windows open and exhaust air from inside the house at rates of up to one air change per minute. Such whole-house fans consume approximately 1/10 the energy of an operating central air conditioner.

Summary

A summary of the various ventilation requirements, discussed in this section of the report, is shown in Table 1.

Purpose for Ventilation	Ventilation Rate Required			Comments
	m^3/min	cfm	ach	
Metabolic Process	0.09	3		Per person
Odour/Smoke Control	0.28-0.85	10-30		Per person
Control of Combustion Products	3.0	100		Rates are for a laboratory test room to stay within air quality health standards
Formaldehyde Control			>0.3	Or promulgated European indoor standard is exceeded
Radon Control			0.5	Or maximum permissible concentration given by health guidelines is exceeded
Humidity Control	1.68-2.24$^{\Delta}$	60-80$^{\Delta}$	0.25*	* 0.125 during periods of inactivity
	3.06$^{\Delta}$	108$^{\Delta}$		

Sample House: - Assume a 100 m^2 (1076 ft^2) bungalow with full basement and 2.44m (8 ft) high ceilings

- Volume is 488 m^3 (17216 ft^3)
- 1 ach = 8.13 m^3/min (287 cfm)

Δ 1.68-2.24 m^3/min (60-80 cfm) = 0.21-0.28 ach

3.06 m^3/min (108 cfm) = 0.38 ach

TABLE 1

SUMMARY OF VENTILATION REQUIREMENTS

CODES AND STANDARDS

Due to the complex nature of the various contaminants that contribute to indoor air pollution, there is currently incomplete information for determining the indoor air quality criteria required to establish ventilation requirements in buildings. However, a comprehensive effort is now underway, at several institutions in the United States and Europe, to establish a scientific basis for existing standards, to measure the actual levels of indoor air contaminants in several categories of buildings, and to provide a consistent set of recommendations for the establishment of energy-efficient ventilation standards in residential, institutional and commercial buildings (5). The following is a summary of existing standards.

National Building Code

In Canada, the two primary codes or standards which prescribe ventilation requirements for residential buildings are the National Building Code of Canada (NBC) and the Residential Standards. The NBC (18) is essentially a set of minimum regulations respecting the safety of buildings with reference to public health, fire protection and structural sufficiency (19). It is an advisory code only, until legally adopted by a jurisdictional authority. In the past, the NBC has received extensive use through voluntary adoption by municipal governments (20). More recently, most provincial governments and the two northern territories have adopted or are using the National Building Code as the basis for their own building codes, having withdrawn from their municipalities previously delegated rights to establish local codes (19).

Residential Standards

The residential provisions of Part 9 of the NBC (Housing and Small Buildings), combined with additional requirements concerned with both quality and amenity, make up the Residential Standards (21). This document, Residential Standards, is not part of the NBC, but its requirements are applied by CMHC to all residential construction under the National Housing Act (NHA) and are used as a guide in much other residential construction not under the NHA. It, therefore, greatly influences residential building in Canada (22).

Since the National Building Code and Residential Standards are essentially identical with respect to their requirements for ventilation of buildings for residential occupancy, only the one document - Residential Standards 1977 - will be reviewed. It contains requirements for the ventilation of crawl spaces and roof spaces as well as requirements for ventilation by natural or mechanical means. It should be noted that the requirements for mechanical ventilation apply only to buildings that are not more than 3 storeys in building height, with a building area of not more than 600 m^2 (6,000 ft^2) and where the rated fan capacity does not exceed 115 m^3/min (4,000 cfm). In general, the types of residential buildings which are under consideration in this report will not exceed these limits. However, if the limits are exceeded, then the requirements of the Canadian Heating, Ventilating and Air-Conditioning Code 1977 (23) shall apply. This code contains the requirements for the design and installation of heating, ventilating and air-conditioning systems. It also includes an appendix which contains the corresponding requirements for heating, ventilating and air-conditioning from Part 9 (Housing and Small Buildings) of the NBC. The Canadian Heating, Ventilating and Air-Conditioning Code is published separately from, but referenced in, the NBC. It can, thus, be adopted for legal use by a municipality or provincial body jointly with or separately from the NBC. However, it is contemplated that separate publication of this code will be discontinued in 1980 and its requirements included directly in the NBC (19).

Canadian HVAC Code

Residential Standards requires that rooms or spaces in buildings be ventilated by natural or by mechanical means. However, if a dwelling is heated with other than fuel-fired equipment within the dwelling (electric heating, for example), a mechanical exhaust system of one or more fans or blowers having a total capacity of at least 3 m^3/min (100 cfm) must be provided. In addition, a space that does contain a fuel-fired heating appliance must have a natural or mechanical means of supplying the required combustion air. Air contaminants released within the building must be removed, insofar as possible, at their points of origin and cannot be permitted to accumulate in unsafe concentrations. Thus, the requirements recognize the needs to control contaminant levels and supply adequate air for combustion. Houses without chimneys (houses which are inherently susceptible to air quality and moisture problems) must have mechanical ventilation of at least 3m^3/min (100 cfm).

Statutory air change requirements

In rooms or spaces in buildings ventilated by natural means, adequate ventilation is achieved by specifying a minimum unobstructed area to the outdoors for various types of rooms (bathrooms, dining rooms, bedrooms, etc.). These minimum unobstructed areas are usually provided by openable windows. Where rooms or spaces are mechanically ventilated, the system must be capable of providing at least 1 air change per hour. The remainder of the requirements for mechanical ventilation deal mainly with design and installation of ducts, air intakes and exhaust outlets.

Crawl and roof spaces

The requirements for the ventilation of crawl and roof spaces are quite straightforward and recognize the need to provide ventilation of these areas to prevent the build-up of odours, contaminants and moisture. In general, natural ventilation is accomplished by providing a certain amount of unobstructed vent area to the outdoors based on the floor area in crawl spaces and the insulated ceiling area in roof spaces.

As mentioned previously, most provincial governments have adopted or are using the National Building Code as the basis for their own building codes, having withdrawn from their municipalities previously delegated rights to establish local codes. As an example, in Ontario, the Ontario Building Code (24), which is a regulation under the authority of the Building Code Act, is based on the NBC and applied throughout the province to all new construction and to all substantial alterations or repairs to existing buildings. Its requirements for ventilation of residential buildings are almost identical to the NBC with the following exception:

Provincial building codes

- when washrooms are ventilated mechanically, it is required that the exhaust air flow rate be at least 1.5 m^3/min (50 cfm) per sanitary fixture in the washroom.

There are other codes, standards and publications which are non-prescriptive in nature but may have considerable influence on ventilation of residential buildings. For instance, the Canadian Standards Association has two standards applicable to residential ventilation (25). One deals with the installation of mechanical exhaust systems - CSA Standard C260.1 - 1975 - while another deals with the equipment itself - CSA Standard C260.2 - 1976. However, at the present time, these are not prescribed in codes and standards such as the NBC or Residential Standards (12).

CSA

"Measures for Energy Conservation"

Similarly, the ACNBC (Associate Committee on the National Building Code) has issued a document entitled "Measures for Energy Conservation in New Buildings" (26), which is aimed at providing a basis for controlling energy consumption in new buildings. This document has been prepared using the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90-75 (27) as a guide, but contains modifications to adapt the requirements to Canadian conditions. These measures are intended to provide a basis for improving the energy use characteristics of new buildings and are intended for use either as a guide or as the basis for regulatory requirements for the design of new buildings (26). The portion of the measures dealing with ventilation states that non-mechanical or natural ventilation of buildings shall conform to the requirements of the NBC 1977. However, where mechanical ventilation is provided, the design air quantities used for such ventilation shall be the minimum values permitted in ASHRAE Standard 62-73, "Natural and Mechanical Ventilation", except when otherwise required by the NBC 1977. Thus, the measures indicate that the current Building Code residential building ventilation requirement (e.g. rooms or spaces shall be mechanically ventilated at a rate of 1 ach) is higher than the ASHRAE ventilation rates suggested to conserve energy. Since the measures are addressed to energy conservation, it is possible that ventilation requirements have not been studied in detail and higher rates may be required to control contaminants. ASHRAE Standards are used in these new measures and information from ASHRAE is used extensively in Canada in the design of ventilation systems. The Canadian Heating Ventilation and Air-Conditioning Code states that ventilation of rooms and spaces, in other than residential occupancies, shall be in accordance with good engineering practice and that the procedures described in the ASHRAE Guide and Data Books and the ASHRAE Handbook shall be considered good engineering practice.

ASHRAE

Ventilation requirements for residential buildings are contained in ASHRAE Standard 62-73 and are summarized in Chapter 21, "Infiltration and Ventilation" of the 1977 ASHRAE Fundamentals (28). The ventilation requirements for residential single unit dwellings are based on a minimum and on a recommended amount of ventilation air, per human occupant, and are also dependent upon the area of the dwelling. For example, in general living areas, bedrooms and utility rooms, the minimum air change requirement is 0.14 m^3/min (5 cfm) per occupant and the recommended change rate is 0.20 - 0.28 m^3/min (7-10 cfm) per occupant. These low ventilation rates recognize that such rooms will likely be used for purposes which only require air to be supplied for the metabolic process. However, rooms such as kitchens, baths and toilets are required to have a minimum ventilation rate of 0.56 m^3/min (20 cfm) per occupant and a recommended rate of 0.84 - 1.42 m^3/min (30-50 cfm) per occupant, since odours, contaminants and high levels of moisture are likely to be produced in these spaces.

The review of prescriptive and non-prescriptive codes and standards, which are applicable to residential buildings in Canada, reveal that there are no standards of minimum air-tightness for houses. Air tightness specifications would require houses to be tight to reduce energy consumption, but ensure a minimum level of ventilation which would provide adequate air quality. Sweden has had such codes in force since 1977 (29) and the ventilation requirements, for residential buildings in Sweden, are discussed below.

Swedish building code

In the Swedish Building Code, the air tightness of various components of the building envelope, such as the outer walls, windows, doors, roof and floors in contact with open air, is specified. This air tightness is specified in terms of a maximum air leakage allowable based on the surface area of the component in contact with the outside air (in $m^3/m^2.h$). These tests are conducted at a specified pressure difference across the component. The maximum air leakage permitted varies with the building height, for high-rise structures, but is a fixed value for all one and two-storey residential buildings. Although the tightness of these individual building components is prescribed by law, the air tightness of the building as a whole is not. The air tightness of the building is stated as a code recommendation (34) and for detached and row houses, the maximum air leakage recommended corresponds to approximately 0.1 - 0.2 ach (34).

The ventilation requirements for buildings are extensively covered in the Swedish Code. Ventilation of dwellings may be accomplished by fan ventilation or by non-forced ventilation in single-dwelling houses and multi-dwelling houses with not more than two storeys. There is a general aim to have an air change rate in homes of 0.5 ach (34). The general philosophy is that maximum air tightness should be obtained and that ventilation should be accomplished through a controlled ventilation system to achieve a hygienic air quality in the dwelling.

For fan ventilation, the Code specifically states the air exchange rate required for each activity area or room such as kitchens, living rooms, washrooms, etc., as well as specifying the ratio of new air to alternate room air that may be used to ventilate certain areas. For example, low contaminant level air from an area such as a bedroom or living room can be used to ventilate kitchens or hygiene rooms, at the specified room ventilation rate. For non-forced ventilation systems, each room has a specified minimum open duct area for exit air into the general exhaust air system. This system works using a ventilation chimney which extends above the roofline of the house to provide a natural draw.

Instructions for owners

As well as air ventilation specifications, the Swedish Building Code states that, for each system in the dwelling (ventilation, heating, cooling, etc.), the owner be supplied with a comprehensive list of operating instructions, set point values, equipment models, names of manufacturers and a description of the overall operating principle of each system.

Heat recovery

In addition, the Swedish Code specifies that there must be heat recovery from exit air, in air treatment installations in large dwelling homes, when the heat content of the exit air exceeds that of the make-up air by more than 50 MWh/year (180 x 10^3 MJ/year) during the heating season.

VENTILATION METHODS

The ventilation of enclosed spaces within houses can be accomplished by natural and/or mechanical techniques. Natural ventilation occurs by the random leakage of air through the building envelope as well as through deliberate openings in the house (such as vents, doors, and windows). Mechanical ventilation is usually achieved using fan and duct systems of varying complexity.

Two approaches to ventilation are direct exchange of air and dilution of stale air:

1) If a source of contamination (such as excessive heat, moisture, odours, etc.) can be readily isolated, air can be exhausted from that immediate vicinity. The contaminants are captured and discharged with the air to the outside before they can diffuse into the occupied space. An exhaust hood over a kitchen range and an exhaust fan in a bathroom are common examples of this ventilation process. In removing contaminants in this manner, provision must be made for an equivalent supply of replacement air. This may constitute a heating load in winter and a cooling load in summer.

2) In most cases, the sources of contamination within a dwelling cannot be readily isolated and the ventilation process then employed is that of dilution. The fresh air supplied mixes with the air in the occupied space, displacing an equivalent amount of room air and lowering the concentration of the contaminant in the room. The basic assumption in removing contaminants by the process of dilution is that complete elimination is not necessary. A person can assimilate small quantities of contaminants without any objectionable effects or permanent injury. This concept is applied broadly in the field of industrial hygiene and is the basis of maximum allowable concentration

values for short and long-term exposures that have been developed for a wide range of contaminants (1).

Present building technology

To date, houses have had no designed ventilation systems and relied on natural ventilation. It has been assumed that sufficient fresh air will leak through the building envelope to provide for both ventilation and combustion air in fuel-fired furnaces. Natural infiltration and exfiltration has become accepted as an intrinsic feature in buildings to the extent that it has been regarded by some as a necessary characteristic (30). In some currently constructed houses, with much tighter building envelopes and with energy conservation in mind, it is considered desirable to make unintentional air leakages as small as possible and to use mechanical means to obtain the desired ventilation. Natural ventilation still plays an important role in ventilating the modern house. The various methods of providing for natural and mechanical ventilation in residential buildings are reviewed below.

Natural ventilation

Natural ventilation is commonly used to ventilate crawl spaces and attics. Appropriately-sized vents are usually placed on opposite sides of a crawl space, as high as possible, and ventilation is accomplished by natural wind action. Provided the floor over the crawl space is insulated, natural ventilation of crawl spaces can be used year round to prevent build-up of odours and moisture. Natural ventilation can also be used to ventilate attic spaces throughout the year. In winter, ventilation keeps insulation dry and effective by removing moisture, while in summer, ventilation dispenses warm air and reduces heat gain through the ceiling. For adequate attic ventilation, appropriately-sized vents are usually located as high and as low as possible on the roof in order to provide good cross-ventilation from end to end and from top to bottom of the attic space. Various types of soffit, gable, ridge and roof vents are usually used in combination to provide the required natural ventilation.

Rooms and spaces within a building may be ventilated naturally by opening doors and windows to the outside. Natural air flow, from openable windows in the summer,provides cross-ventilation. Similarly, windows may be relied upon in winter to provide general ventilation even though uncomfortable drafts may be created and such ventilation is quite inefficient from an energy point of view.

Mechanical ventilation

In most new houses, it is desirable to make unintentional air leakage as small as possible. Some form of mechanical ventilation is provided by utilizing exhaust fans and fresh air inlets in the most advantageous locations. Forced warm air heating systems also offer a simple means for positive mechanical ventilation. Outside air can be drawn into the system and treated (heated, filtered, humidified, etc.) before being distributed throughout the house. If the system is equipped with cooling coils, this air may also be cooled and dehumidified in summer. Forced air systems offer an alternative to complete reliance on natural air leakage. As well, the advantages of control and conditioning of the ventilating air and avoidance of drafts are provided. If the furnace fan in a force warm-air system is operated continuously, the process of dilution will reduce the concentrations of contaminants (such as odours) to a level that may not require additional outside ventilation.

Exhaust fans

Exhaust fans are commonly used in kitchens, bathrooms, basements and attics. These fans are usually vented to the exterior and are used to remove odours, moisture, heat, smoke and grease at the source. Propeller fans and centrifugal blowers are the two air moving devices commonly used. The propeller fan is usually used in through-the-wall applications because it can exhaust large volumes of air where there is little or no resistance to air flow. It becomes considerably less effective, due to air flow resistance, when any duct work is attached. When there is duct work attached to the fan, the centrifugal blower provides quieter, more powerful and effective exhausting (11). These units can be located in the range hood, in the ceiling or outside the roof or wall. The latter location results in much quieter operation as most of the fan noise is then outside. Exhaust fans are usually equipped with a manual switch but they may also be controlled by a dehumidstat, in addition to the manual switch. This then, provides for automatic humidity control.

Fresh air make-up

Air that is exhausted must be replaced with outside air. This can be done in a haphazard way by natural infiltration or by controlled methods such as fresh air intakes. These intakes are suitable for any house and usually consist of a simple outside air vent. When an exhaust fan is in operation, the vent provides an inlet for dry outside air to enter the home due to the slight negative pressure created inside the structure. In houses with a forced warm-air furnace, the fresh air intake can consist of a duct, with an adjustable damper, running from the outdoors to the cold air plenum of the furnace (31). These dampered ducts are a common feature of warm-air heated dwellings in the Prairies and in other areas where low winter temperatures prevail (4). The damper may be manually controlled or automatically controlled by a dehumidistat which positions the damper. A system such as this ensures a controlled and continuous ventilation supply and prevents the direct entry or leakage of cold air into the living space.

Heat recovery

Mechanical ventilation using fan, duct and intake systems of varying complexity can provide controlled ventilation of a house and ensure a minimum continuous flow of fresh air to maintain adequate air quality.

A considerable amount of energy is required to warm the intake air and this energy is lost in the exhausted air. Recent emphasis on energy conservation has lead to increased interest in heat recovery from such mechanical ventilation. One method of achieving this heat recovery is through the use of an air-to-air heat exchanger in which heat from the warm exhaust air is transferred to the cold intake air. Such air-to-air heat exchangers are now in limited use in residential buildings across Canada and such devices will be reviewed in more detail later in this report.

Dehumidification

The use of dehumidifiers presents an attractive alternative to mechanical ventilation as a means of humidity control inside dwellings. The use of an electric dehumidifier is attractive since it helps to reduce the need for excessive ventilation. The energy used to run the dehumidifier is given up to the house as a form of electrical heat, except for that portion which is in the condensate discharged to the sewer. Dehumidifiers are limited to drawing moisture levels down to only 50 per cent relative humidity (12) which is too high for the colder parts of Canadian winters (10,32). Even though dehumidifiers may not be capable of lowering the relative humidity enough to prevent condensation on double-glazed windows, they may still be an effective device for condensation control in winter at the higher humidities permitted by triple glazing (4). In summer, dehumidifiers tend to prevent the formation of condensation on cool basement walls.

Attic fans

One specific method of mechanical ventilation which requires further discussion is the use of exhaust fans to cool attic spaces in the summer. Such fans can be manually operated or be governed by a thermostat to turn them on when the attic temperature reaches a predetermined level. In homes which have central air conditioners, these power attic fans and ventilators are commonly used in an attempt to decrease the electrical consumption of air conditioning equipment through a reduction in the ceiling heat gain. However, it is controversial whether the use of these ventilators is an effective energy conservation procedure. Such ventilators received considerable attention at a recent Summer Attic and Whole-House Ventilation Workshop held in the United States (33). Several papers were presented on the subject and would indicate that no savings in the net energy used for summer cooling can be realized from the use of attic fans. In general, the reason that attic fans do not save energy is that heat gain through the ceiling insulation is small (even though the attic can be quite hot) and the fan requires as much or more energy to operate than the cooling energy savings from reduced ceiling heat gain. In houses with normal levels of ceiling insulation and adequate natural attic ventilation, the use of attic exhaust fans appears to be of questionable value.

MEASUREMENT OF VENTILATION

The determination of the air tightness of houses and their natural ventilation or air infiltration rates is of increasing importance. Since a great energy saving potential exists in reducing the air leakage of buildings, the testing of relative air-tightness can be a most useful tool in assessing the effectiveness of different air-tightening measures. When used in conjunction with thermography (infra-red photography) to discover the location of air leakage paths in the building envelope, it is an especially useful tool.

Tracer gas test method

- Infiltration

The natural ventilation rate of a building is usually determined by the tracer gas technique which is by far the most accurate method of predicting the air infiltration rate in a house (2). The normal tracer gas technique for measuring air infiltration is to inject a quantity of a non-toxic tracer gas, such as helium (He), carbon dioxide (CO_2) or sulfur hexafluoride (SF_6), into a building space and measure the rate of decay of the gas. After ensuring that the initial quantity of tracer gas is well mixed in the dwelling, concentration measurements are made at 5 to 15 minute intervals. The air exchange rate is then determined by fitting the best exponential curve to the concentration decay data to obtain a detailed record of air exchange rates during the period of the test. Although the tracer gas technique is the most accurate method, it has several disadvantages in that it is both complicated and expensive (34,35). The concentration monitoring equipment is costly, its use requires highly trained technicians, the duration of the test is usually 2-4 hours, and every measurement with this method is unique to the weather conditions at that time.

Modified tracer gas test methods

- Infiltration

A low-cost method for measuring air infiltration rates using a modified tracer gas technique has also been tested (35). This method replaces the tracer gas decay rate determination technique with a concentration monitoring technique using equipment deployed throughout the building to fill sample air bags at time intervals of one to two hours. These sample bags are then analysed later in a laboratory. This test method can be applied to a large number of dwellings at one time by relatively inexperienced persons. The method will provide actual air exchange rates under test weather conditions. This data can be used to assess the typical air leakage performance of a building. Preliminary testing of this method has indicated that it is a feasible method for obtaining air infiltration data at a low cost and using inexperienced personnel (35).

Fan pressurization

- Air tightness

Testing of the air tightness of buildings is usually conducted using a fan pressurization (or depressurization) method. These tests are performed by installing a powerful fan in an opening in the envelope of the house. The ventilation openings in the house (chimney, fireplace, windows, exhaust fans, etc.) are closed and the house is pressurized by operating the fan. Since the ventilation openings of the house are closed during the test, the air-flow through the fan is equivalent to the leakage through the building envelope. Thus, the measured pressure level and the resulting air leakage give an air leakage characteristic for the house. The main advantages of a fan pressurization method compared to the tracer gas technique are that the test equipment is relatively inexpensive, easy to operate and thus, well adapted for routine testing. The test method also produces results that are reasonably reproducable (34). When combined with thermography, these tests provide a means of detecting air leakage paths in the building. The main drawback of the fan pressurization method is that, although it provides data on the leakage characteristics of a house and on the relative tightness of houses, it does not provide a measure of the natural ventilation rate of the house. Air tightness testing using fans has been conducted in Canada by both Ontario Hydro and the National Research Council of Canada (NRC).

Ontario Hydro fan test

Ontario Hydro use a powerful fan temporarily installed through an open window and measure the resulting pressure drop in the house. This measurement, combined with the fan pressure-flow characteristics, can be used to obtain the area of an opening that permits a similar air flow at the same pressure difference as that measured. The area of this opening is defined at the Equivalent Leakage Area of the house, or ELA (36). Ontario Hydro has used this technique to measure the air-tightness of a number of houses both with and without problems and have developed a scale of ELA versus susceptability to problems (12,36).

NRC fan test

In the NRC tests, a fan is installed in an opening in the building envelope and air is blown out of the house to create a negative pressure. This pressure difference causes air to infiltrate through the building envelope at the same rate it is extracted by the fan. This method has been used to measure the air leakage characteristics of the various components of a house enclosure (37) and to measure the relative tightness of new houses (38). To obtain the relative tightness of these houses, the volume rate of infiltration air flow at a fixed pressure difference is divided by the area of the air barrier which is defined as the area of the building envelope that separates the heated volume from the outside conditions. This value of the relative tightness is, at present, the most meaningful parameter for comparing the air tightness of different houses (38).

Swedish infiltration tests

Fan pressurization tests have been conducted in Sweden on a number of houses which were also tested using the tracer gas technique. An attempt was made to find a correlation between the results of a pressure test and the natural ventilation rate of the building (34). The results of the pressure test were expressed in terms of the air leakage rate divided by the area of the air barrier (similar to the procedure used by NRC). The resultant value can be related to the natural ventilation rate determined with a tracer gas technique under some specific weather conditions.

Infiltration/ air tightness research findings

Typical results from various tests on buildings conducted in North America and Europe clearly show the difference in the tightness of older housing, recent housing and modern energy conserving houses. Twenty houses of wood-frame construction, in the Saskatoon area, which were built between the early 1940's and 1975, were tested using a fan test for air tightness and a tracer gas technique for air change rate during the heart of the heating season. These houses had air change rates between 0.62 and 1.71 ach with the average being about 1.0 ach (12). Newer houses in Canada (with fuel-burning furnaces and chimneys) appear to have average winter infiltration rates of about 0.5 ach (2,4,17,39,40). Lower infiltration rates are found in dwellings that have electrical heating or no chimneys (2,4,12,39) and are in the order of 0.2 to 0.33 ach (2,12). Houses which are built to high standards of insulation and tightness can have quite low natural ventilation rates. For instance, tracer gas experiments conducted on the Saskatchewan Conservation House reveal that it has an air leakage rate of about 0.05 ach (12). It is interesting to note the natural ventilation rates of ordinary houses measured during a study in Sweden (34). The average natural ventilation rate of the houses in this study was about 0.20 ach with rates similar to the Saskatchewan Conservation House not being uncommon.

APPLICABILITY OF PRESENT VENTILATION METHODS TO NEW AND RETROFIT CONSTRUCTION

At the CMHC industry/science seminar on "Controlled Ventilation with Exhaust Air Heat Recovery for Canadian Housing" held in 1978 (12), the need for Canadian Housing to evolve from its present state of accidental ventilation to mechanical ventilation used in conjunction with a much tighter building fabric was discussed and agreed upon. This would permit the amount of ventilation air to be reduced to the minimum amount necessary to control air quality and humidity, thus eliminating energy waste problems due to excessive ventilation and eliminating air quality/ condensation problems due to too little ventilation.

Heat recovery

Methods are presently available to construct very tight, highly insulated building envelopes (17). As previously discussed, methods are now in use which can provide for adequate ventilation of these buildings by natural means for attics, crawl spaces and summer cooling, and by mechanical means using exhaust fans and fresh air intakes. However, increased shell tightness and controlled ventilation systems may also permit the use of heat recovery equipment to reduce ventilation heat losses even further. Heat recovery devices, currently available, are being used on a very limited scale in Canada. However, increased concerns over energy conservation, air quality and humidity related problems may lead to more wide-spread use of such devices in future residential buildings in Canada.

Air-to-air heat exchangers

The most common means of recovering heat from ventilation air is through the use of an air-to-air heat exchanger. Such devices transfer the heat from warm, stale air that is being exhausted from the house to the cool, fresh air that is being brought indoors. The two most common types of air-to-air heat exchanger for residential building applications are the rotary type and the parallel plate type (12). Each type of heat exchanger has its own particular advantages and disadvantages. Static heat exchangers such as the parallel plate type are typically larger in size than rotary heat exchangers and generally are less efficient. Static heat exchangers usually have no leakage problems between the exhaust and intake air passages and isolate the exhaust air from the incoming air. Static heat exchangers are passive. Air leakage is a problem with rotary heat exchangers and seals in these systems tend to wear. Since the rotary body passes through both air streams, it is possible for biological contamination to re-enter the house via the fresh-air stream. The rotary device requires a drive motor to turn the disc.

Considerable work on rotary type air-to-air heat exchangers for residential building applications has been undertaken by Ontario Hydro (2,12). A simple parallel plate air-to-air heat exchanger for residential use has been developed at the University of Saskatchewan (40). It is suitable for do-it-yourself or on-site fabrication and is the type currently in use in the Saskatchewan Conservation House as well as in a number of houses in Saskatchewan. A Canadian-made air-to-air heat exchanger is currently available from Enercon (41). Heat recovery devices are readily available in the Scandanavian countries and Japan (12). It is possible to obtain these heat exchangers from Canadian representatives of these manufacturers. Although air-to-air heat exchangers are available in Canada, their use is not wide-spread, and it is evident that North American manufacturers are reluctant to embark on programs to develop, manufacture and market such products without a sizeable guaranteed market.

In assessing the viability of air-to-air heat exchangers for application to new and retrofit construction, it must be remembered that such devices will be of little use in a poorly sealed house (40). Thus, a key requirement for the wide-spread use of an air-to-air heat exchanger will likely be a very tight house in order to realize the full potential benefit of heat recovery. Most new houses are not being built to sufficiently high standards of tightness to warrant the use of such devices.

In new houses which are constructed to suitably air-tight standards, i.e. with natural ventilation rates in the order of 0.1 ach (2,12,42), heat recovery utilizing an air-to-air heat exchanger may be economically feasible but is by no means clear cut. The most expensive part of any air-to-air heat exchanger installation is not the exchanger itself but the duct work and structural design changes which are required to allow installation of the unit and to increase the building air tightness to make the heat exchanger unit effective (12). Limited cost/benefit figures are available regarding the use of air-to-air heat exchangers. As of 1979, builders in Saskatchewan were producing energy conserving houses incorporating a full range of conserving features (highly insulated, air tight, shutters on windows, air-to-air heat exchangers, etc.) for $3,000 to $4,000 of additional cost on a new house of average size, although additional costs of $7,000 to $10,000 have been quoted by other builders (17).

Air-to-air heat exchanger units, like those developed at the University of Saskatchewan (40), were being installed in 1979 for approximately $400 a house and yielding savings of approximately $50 per year (17). The price of the basic Enercon heat exchanger (41), excluding ducting and installation fees, is $699 per unit and it is estimated that approximately $60 per year can be saved on heating bills. Scanada estimated in 1978 that approximately $45 could be saved yearly through the use of an air-to-air heat exchanger (12) while Ontario Hydro (2) estimates that a tightly constructed house incorporating a mechanical ventilation system and rotary air-to-air heat exchanger (of their design) could anticipate approximate yearly energy savings of $150, $180, and $80 for gas, oil and electrically-heated houses respectively, compared to a current conventionally-constructed house without such features. Thus, in houses which are built with sufficiently high standards of tightness to incorporate an air-to-air heat exchanger, such devices appear to be economically viable.

DISCUSSION

In summary, it appears that both existing housing and new housing can benefit by incorporating improved ventilation systems in conjunction with much tighter building envelopes. Methods are available to build houses to such standards and to provide for controlled mechanical ventilation.

As a result of the work carried out during this review, it has become evident that a number of factors in several areas relating to the ventilation of residential buildings in Canada have prevented the Canadian building stock from attaining these desirable goals.

Ventilation rates

Currently, there are no comprehensive Canadian guidelines or ventilation standards for residential housing which will ensure adequate air quality and at the same time be energy efficient. In order to establish air quality criteria and ventilation standards necessary to control the effects of such contaminants, further study of the complex nature of various indoor contaminants such as formaldehyde, nitrogen dioxide and radon may be necessary.

In general, the Swedish Building Code appears to be quite comprehensive with regard to ventilation requirements for residential buildings. In fact, this Code and other European Codes may prove to be adaptable in whole, or at least point the way, for the development of a similar Canadian Code. The general philosophy in Sweden is that the house should be very airtight and that the ventilation rate should then be controlled through the house ventilation system in order to achieve proper air quality.

Air tightness

There is a trend towards the concept of an airtight shell structure for new housing which is supported by researchers in the building sciences. If this concept is to be adapted universally in Canada by the building industry, it will be necessary to establish air tightness standards for new houses and to develop and test techniques for monitoring the tightness of houses which can be practically applied by Canadian house builders.

It would be of interest to establish a correlation between the natural infiltration rate of a house and its tightness when measured by a simple fan pressurization test and to develop such a test to the point where it may be used to establish the compliance of new houses with any future air tightness standards which may be established. If building codes and standards were to adopt air tightness criteria for new residential buildings, a relatively cheap and accurate air tightness test will likely be required as a matter of routine. It appears that, in the future, it will be possible to estimate the natural ventilation rate of a house using the results of a fan pressure test (34).

Requirements for codes and standards

A lack of manditory codes and standards concerning air tightness and ventilation requirements hampers the development of a market for ventilation devices and controls. Without these manditory standards, there is little incentive, in the Canadian market, for manufacturers to pursue the development of ventilation devices as the present market is limited to quantities below those which are viable in production. Due to the marginal cost-effectiveness of these devices, the general public is not likely to install these devices voluntarily. The present building methodology and quality control on building sites is such that the air tightness of new houses is not likely to improve below 1/3 ach without active involvement by governments.

Without regulatory codes and standards, the building industry is unwilling to improve the quality of homes or add the necessary systems because the consumer will not readily accept the added cost of these improvements. These opinions have been put forward by local builders, HUDAC, and attendees at the CMHC conference on ventilation. The difficulty and expense in increasing the air tightness on retrofit of an older house, makes the addition of controlled ventilation systems to such houses marginal or sub-marginal (in most instances).

Control systems

With the development of ventilation devices for industrial applications, there has been a wide range of advanced control systems developed to compliment them. For the control of mechanical ventilation of residential buildings, the control systems that have been developed for general use are simplistic. Although the mechanical equipment is available, control systems which are capable of optimizing ventilation rates to satisfy both air quality and energy conservation requirements are non-existent or in the preliminary development stages.

Energy saving devices

The current generation of air-to-air heat exchangers is costly and marginally effective in existing housing due to the lack of air tightness and thus, the inability of ventilation systems to control infiltration air.

The development of air-to-air heat exchangers for use in the future, when the new housing stock reaches higher levels of air tightness and controlled mechanical ventilation becomes more feasible, may prove to be a desirable research aim. High infiltration rates effectively eliminate air-to-air heat exchangers from the existing house market (12). Most new houses are currently not being built to sufficiently high standards of tightness to warrant the use of such devices.

It seems that other methods of heat recovery, such as heat pumps and "grey water" heat exchangers for hot water heating, which are not subject to the constraint of requiring a very tight building envelope, are perhaps more suitable for both new and existing housing. However, an indepth study of these devices was not within the mandate of this report.

Public education

The general lack of education of both the general public and the building trade, in the operation and function of the various mechanical ventilation devices and systems which are currently in the house or could be added to the house, may render these devices ineffective and in many cases introduce a negative benefit through improper adjustment of many devices. These improper adjustments can be due to many factors such as improper installation, improper initial adjustment, misunderstanding of the operation (either incorrect information or no information) and misunderstanding of the function of the device.

Education of a wide spectrum of people, from builders to residents, on the subject of residential ventilation, the problems that exist and the solutions to these problems would perhaps be more beneficial than most other programs and improved hardware. The Swedish Building Code requires that the owner/purchaser of the residence be supplied with all operational and service information on each hardware device in the house. This would appear to be a worthwhile approach to institute in Canada.

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