Ventilation and Airtightness in New Detached Canadian Housing

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SOMMAIRE

Des enquêtes effectuées dernièrement visaient à obtenir des données distinctes sur la ventilation et l'étanchéité à l'air des habitations. La présente étude fait appel à des méthodes de probabilité pour combiner les données et évaluer les besoins ainsi que les répercussions possibles d'une norme de ventilation sur le débit d'air, la distribution d'air, la dépressurisation des maisons et la consommation d'énergie.

Le Canada suit la tendance vers un accroissement de l'étanchéité à l'air des habitations. En effet, les maisons neuves sont 30 p. 100 plus étanches à l'air qu'en 1982-1983. Comme on peut établir une corrélation entre le degré d'étanchéité et la rigueur du climat, le confort et le coût de l'énergie influent probablement sur cette tendance. Les exigences à l'égard de ces deux aspects, de même que pour la durabilité de l'enveloppe du bâtiment, devraient, selon toute attente, s'amplifier en raison de la population vieillissante et des préoccupations environnementales; il faut alors se préparer aux conséquences de cette tendance.

Les contrôles de la qualité de l'air indiquent que les logements neufs enregistrent, dans une proportion de 50 p. 100, des concentrations de formaldéhyde supérieures à la limite à long terme de 0,05 ppm fixée par Santé et Bien-Être social Canada et, dans 17 p. 100 des cas, supérieures à la limite à court terme de 0,1 ppm. Puisqu'on sait que les concentrations diminuent avec le temps, l'objectif à long terme devrait être atteint dans la majorité de cas, au cours de la durée utile des bâtiments. Un renouvellement d'air de 0,3 par heure élimine, semble-t-il, ce polluant dans les maisons individuelles. Les recherches de M. Haysom, tout comme la présente étude, établissent que le renouvellement d'air naturel dans les maisons neuves ne parvient pas à longue échéance à éliminer les polluants dégagés par les activités des occupants, notamment le gaz carbonique et les odeurs (ASHRAE et CSA F326).

L'enquête sur les conduits et les cheminées révèle que le rendement de nombreux appareils de ventilation est actuellement inférieur au niveau attendu. Dans le cas des appareils à fonctionnement intermittent, seulement 12 p. 100 des ventilateurs de salle de bain satisferaient à l'exigence de 25 l/s prévue par la norme CSA F326 et 50 p. 100 des ventilateurs de cuisine à celle de 50 l/s. La plupart des appareils existants ne se prêtent pas à un fonctionnement continuel à cause du bruit qu'ils produisent et de leur manque de durabilité. Cependant, 64 p. 100 des appareils de ventilation utilisés actuellement répondraient aux exigences de débit d'air de la norme CSA F326. On devra les améliorer en cherchant à réduire l'intensité sonore des ventilateurs et à améliorer leur débit d'air (conformément à la norme CSA C260, Residential Ventilation Equipment).

Malgré le rendement médiocre des appareils d'extraction, 18 p. 100 des maisons neuves équipées d'un ventilateur de salle de bain, d'un ventilateur de cuisine et d'une sécheuse fonctionnant simultanément, enregistreraient une dépressurisation supérieure à la limite de 5 Pa recommandée pour les appareils à combustion à évacuation par tirage naturel. De même, 20 p. 100 des maisons neuves subiraient une dépressurisation supérieure à 10 Pa en raison du fonctionnement simultané de la sécheuse, ainsi que des

ventilateurs de cuisine et/ou de salle de bain. Les exigences de ventilation touchant les maisons neuves ne doivent pas être mises en oeuvre avant d'avoir tenu compte des effets de la dépressurisation.

En considérant le débit d'air, les besoins de distribution et les limites de dépressurisation, 40 p. 100 (± 10 p. 100) des maisons mises à l'essai répondent aux exigences de la norme CSA F326. On obtient ce pourcentage en tenant pour acquis que 63 p. 100 d'entre elles sont pourvues d'installations de chauffage à air pulsé au gaz, à évacuation par tirage naturel dans 90 p. 100 des cas. Là-dessus, on en soustrait 18 p. 100 puisque les installations à débit très élevé risquent davantage d'entraîner une dépressurisation excessive. Tout indique que le reste (10 p. 100) des maisons équipées d'une installation à gaz ne subiraient pas de dépressurisation. Sur les 63 p. 100 d'installations de chauffage à air pulsé au gaz, 35 p. 100 satisfont à la norme CSA F326. De même, en supposant que 50 p. 100 des maisons chauffées par des plinthes électriques sont pourvues d'appareils de chauffage à combustible solide, sensibles à une dépressurisation de plus de 5 Pa, seulement la moitié des maisons ainsi chauffées à l'électricité, également équipées d'une installation centrale de ventilation, satisfont à la norme CSA F326. Alors, 40 p. 100 des habitations satisfont aux exigences de la norme CSA F326. On recommande de vérifier ces hypothèses à l'aide de toutes autres données accessibles, mais les résultats ne devraient pas changer de façon appréciable (pas plus de 10 p. 100). Si, pour le chauffage au gaz, l'installation d'appareils d'efficacité moyenne et à tirage induit devenait une exigence minimale avant l'adoption de la norme CSA F326, environ 15 p. 100 plus d'habitations satisferaient à la norme. Pour que le reste des habitations soient conformes à la norme CSA F326, il serait nécessaire de munir les maisons chauffées au moyen d'appareils à convection (plinthes électriques ou à eau chaude) d'une installation centrale de ventilation (appareils de ventilation et d'extraction muraux), ainsi que d'appareils de chauffage au gaz peu sensibles à la dépressurisation (comme les appareils pour maisons mobiles conformes à la norme ULC S627).

Le coût en énergie lié à l'adoption de la ventilation contrôlée dans l'habitation se chiffre à 8 p. 100. On suppose pour cette étude un renouvellement minimal d'air commandé de 0,3 par heure, quoique le contrôle sur demande et à la source puisse le réduire considérablement. Ces moyennes ne tiennent pas compte du fait que chaque maison n'a pas nécessairement besoin de la capacité de ventilation calculée en fonction de l'occupation (calculs par pièce) ou des infiltrations et exfiltrations naturelles. La ventilation doit pouvoir se commander sur demande pour assurer autant la santé que le confort des occupants. L'installation de récupérateurs de chaleur mécaniques et l'amélioration de l'étanchéité à l'air peuvent entraîner une réduction de la consommation d'énergie excédant le coût accru de la ventilation. L'efficacité énergétique des récupérateurs de chaleur dépend considérablement de leur installation, mais le confort thermique n'est pas assujetti à la qualité de l'installation. L'installation d'un récupérateur de chaleur s'avère d'autant plus économiquement faisable si elle est accompagnée d'une étanchéité à l'air accrue et d'une mise en service satisfaisante.

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Ventilation and Airtightness in New, Detached Canadian Housing

SUMMARY

Recent field surveys have been performed which independently characterized ventilation or airtightness. This study uses probability methods to combine the data and assess the needs and potential impact of a ventilation standard (1) in terms of air flow, air distribution, house depressurization, and energy consumption.

Based on the samples available, about 2 in 5 new houses nominally meet this standard. One house in 5 could exceed depressurization limits for naturally aspirated combustion equipment. About two houses in 3 would meet the continuous ventilation capacity rate using bathroom and kitchen range hood fans but noise and durability may require upgrading of these. About 3 in 4 houses would meet air distribution requirements by forced warm air heating or ducted fresh air distribution.

1.0 INTRODUCTION

The constraints which must be satisfied when determining ventilation requirements are in general energy consumption, occupant health and thermal comfort. Any two of these can be satisfied disregarding for the other. For instance energy is well conserved in a house with no ventilation and good thermal conditions or infinite ventilation and thermal conditions similar to outdoors. A balance must be struck which respects all three constraints simultaneously for houses in general.

This study examines issues concerning ventilation in new houses in light of data relating to indoor air quality, airtightness, and ventilation equipment performance. Analysis has also been performed as to house depressurization due to existing ventilation and the energy consumption impact of providing mechanical ventilation.

1.1 Background

As understanding of the health and productivity effects of indoor air quality increases, concern about the quality of the air in houses is growing. Researchers have discovered that there is a wide variety of possibly harmful chemicals and substances in the air found in houses. Some of these substances, such as formaldehyde, are released from construction materials and furnishings used in the house. Others, such as carbon dioxide, are released by the occupants of the house. Still others, carbon monoxide and oxides of nitrogen, for example, are products of combustion released into the house by improperly vented, fuel-fired heating appliances. Radon, a naturally occurring radioactive gas, enters the house air from the soil surrounding the basement or in the water supply. Particulates, small enough to be inhaled, are also common in indoor air in varying concentrations. High concentrations of water vapor can promote the growth of moulds, some of which are harmful to human health. Water vapour condensation in the walls and roof spaces of houses can lead to premature deterioration of finishes and structural members, in extreme cases.

The concentration of these substances in the air inside houses is directly related to the source strengths of the various pollutants, and the rate at which they are exhausted from the space. Localized concentrations within the living space are also dependent upon the ventilation distribution within the house.

For many years, energy prices in Canada were so low that it made little economic sense to insulate houses and reduce uncontrolled air leakage. However, during the last decade the costs of heating fuels has risen considerably. The demand for good thermal comfort conditions has also risen. In recent years, Canadians have also become more concerned about the detrimental environmental impact of energy production and use.

For these reasons steps have been taken to improve the energy efficiency of new houses and reduce the potential for moisture damage to the building. Since space conditioning accounts for the bulk of the energy load in a typical house, the insulation levels and airtightness of the building envelope have received the most attention.

Building codes and material and equipment standards have been modified to reflect the need for improved energy efficiency. The National Building Code of Canada (2) includes specific provisions for airtightness and vapour barrier details and mechanical ventilation.

It is generally accepted that improved airtightness provides for better levels of comfort and reduces: energy consumption; the potential for moisture damage to the building envelope; soil gas entry; and noise transmission through the building shell.

Most older buildings rely on wind and temperature driven air leakage to provide ventilation. As well, combustion appliances which operated most of the year in poorly insulated houses provided ventilation air in older buildings.

Many building codes now include specific requirements for mechanical ventilation capacity, but provide little guidance on the design, capacities, installation and operation of systems. The Canadian Standards Association (CSA) is developing a consensus standard, CSA F326-M1989 "Residential Mechanical Ventilation Capacity Requirements" (1) which will provide builders and installers with guidance concerning the design and installation of ventilation systems for houses. The CSA committee includes representatives from the building industry, ventilation equipment manufacturers, building regulatory officials, consumer groups, the research community and government.

The ventilation rates specified in the standard are based upon the rate of air change required to maintain acceptable levels o carbon dioxide and other occupant generated pollutants in the living space. This is a similar approach to that used by the American Society of Heating, Refrigerating and Airconditioning Engineers (ASHRAE) in developing ASHRAE 62, "Ventilation for Acceptable Indoor Air Quality"(3). Rates of carbon dioxide generation as a function of occupancy and activity are well known. Carbon dioxide is used as an indicator of occupant generated pollution which also includes moisture and odors.

The requirements of CSA F326.1M-1989 provide that a typical minimum three bedroom house should have a continuous ventilatio rate of 55 liters per second (L/s). (See Table 1.)

It is difficult to conduct a thorough cost/benefit analysis of the need for mechanical ventilation in houses because it is not easy to assign dollar values to the benefits associated with improved health, increased attendance and productivity in the workplace, decreased use of government medical insurance programs, and other "social" aspects of the equation. This stud examines the need for ventilation based on improving conditions relative to indoor air quality guidelines (Interprovincial Committee on Indoor Air Quality (4)and ASHRAE).

1.2 Objectives

The objectives of this study can be summarized as follows:

- to examine whether current practice with respect to the design and installation of residential ventilation syste in new houses results in systems which provide for acceptable indoor air quality;

- to investigate whether air leakage provides sufficient air to ensure acceptable air quality in new houses and;

- to determine whether air leakage provides sufficient ma up air to avoid excessive depressurization and potential combustion product spillage in new houses;

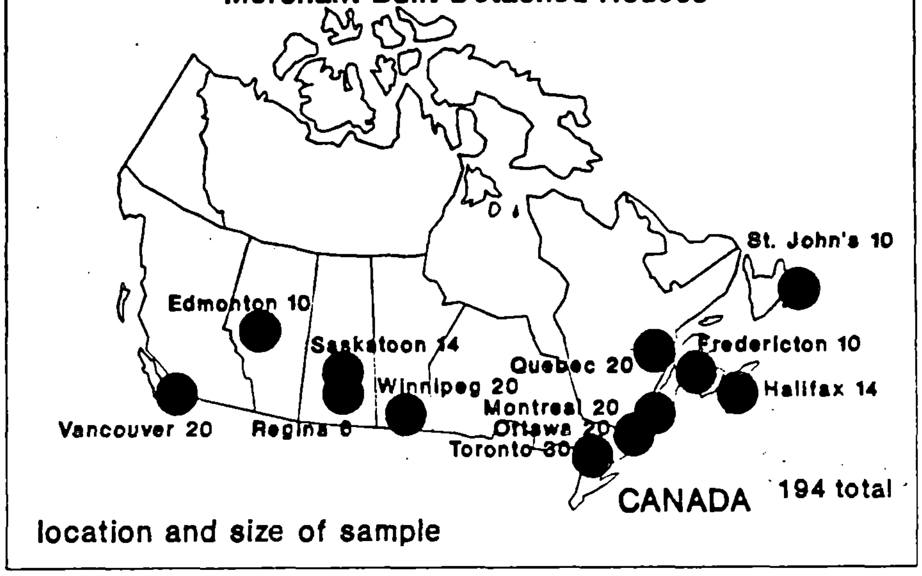
- to determine the energy impact of various levels of mechanical ventilation in conjunction with air leakage reduction and ventilation equipment options.

2.0 METHOD and OBSERVATIONS

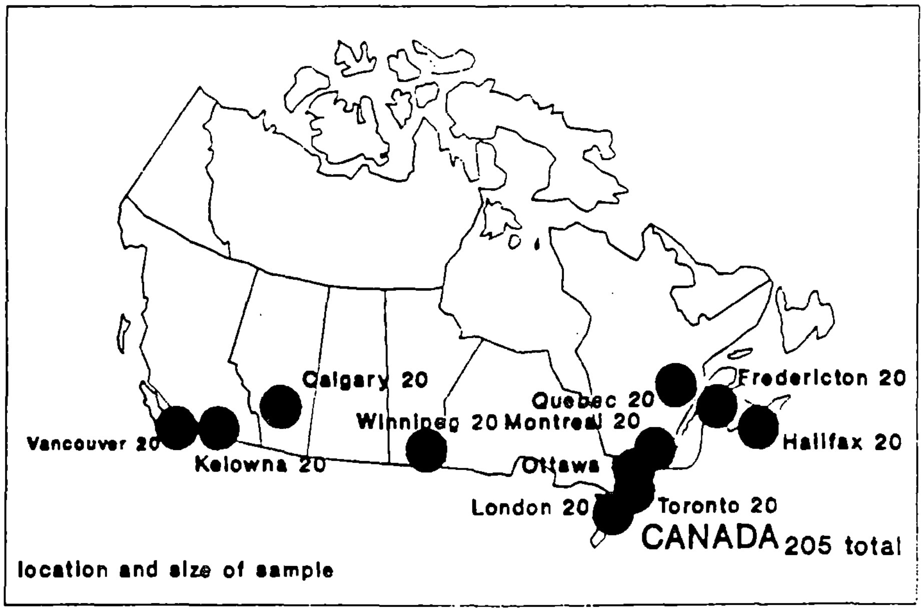
This paper is the result of a combined analysis of existing research data. It makes use of several sets of data which had been collected during other projects. Specifically, the author examined data collected during the following projects:

The Canadian Residential Duct and Chimney Survey, Canada Mortgage and Housing Corporation, 1989 (5);

Fig.1 1989 Survey of the Airtightness of New Merchant Built Detached Houses



The Canadian Residential Duct and Chimney Survey



1989 Survey of The Airtightness of New, Detached, Merchant Builder Houses, Canada Mortgage and Housing Corporation, Institute for Research in Construction, Energy Mines Resources Canada, Canadian Home Builder's Association (6); and

Airtightness Tests on 200 New Houses Across Canada, Energy, Mines and Resources Canada, 1982/83 (7).

The authors also reviewed related publications and documents for information concerning residential ventilation equipment, its field performance, and the impact that it has on the operation of houses. The distribution of air tightness and ventilation performance were assumed not to be correlated. This permits analysis by permutation and combination of the distributions.

2.1 Airtightness

In 1989, Canada Mortgage and Housing Corporation, Energy, Mines and Resources Canada, Canadian Home Builder's Association, and Institute for Research in Construction performed a study of the airtightness of new, merchant builder houses in Canada. Local contractors collected data related to the airtightness of 194 new houses across the country (Fig.1) using blower doors and three separate sealing schedules. The sealing schedules can be described briefly as follows:

A -intentional openings sealed as per the Canadian General Standards Board Standard CAN/CGSB 149.10M87 (8),
B -as per CGSB, but with additional combustion system openings sealed to assess the availability of makeup air; and
C -with most openings left unsealed as per normal operating conditions.

Details concerning the three sealing schedules can be found in Appendix A. The B schedule was prepared to simulate the airtightness of the house under a condition where only a makeup air inlet was open. Flues and combustion air inlets of fuel fired appliances were sealed since their primary function is not to provide ventilation makeup air to living spaces. The C schedule represents the "as is" operation of the house in that the test is conducted without sealing some openings that normally allow air into the house under typical operating conditions.

Analysis of air tightness trends is based upon the measurements collected using the A sealing schedule. Field contractors measured flow coefficients (C), flow exponents (n), building volumes, and building envelope areas for each of the houses tested using each air sealing schedule. This information was used to compute airtightness in air change per hour (ac/h) @ 50 Pa and normalized leakage areas (NLA) for each house under each test scenario. The normalized leakage area is an equivalent leakage area divided by the total envelope area. The equivalent leakage area is the size of a sharp edged orifice (exponent of

0.5) which will provide equivalent air flow to the actual leakage at 10 Pa pressure difference. There is a wide variation in air leakage rates for new houses. Table 2 shows that the average ac/h at a 50 Pa indoor/outdoor pressure difference for the entire sample is 3.44. Fig.2 shows a relatively smooth distribution except for loose houses. Airtightness varies from a low of 0.98 to a high of 11.13. Vancouver exhibited the highest variability in air change rates, the highest being 11.13 and the lowest 2.86, a ratio of almost 4:1. Saskatoon and Quebec City showed the least variation, the highest air change rate being only 2.1 times the lowest.

The survey also found that there is a wide variation in NLAs of new houses Fig.3 Winnipeg houses tend to have the lowest NLAs and Vancouver the highest. The lowest variation in NLA was found in the Quebec sample, where the highest NLA was 2.5 times the lowest. Edmonton displayed the highest variation, the highest NLA being 5 times the lowest.

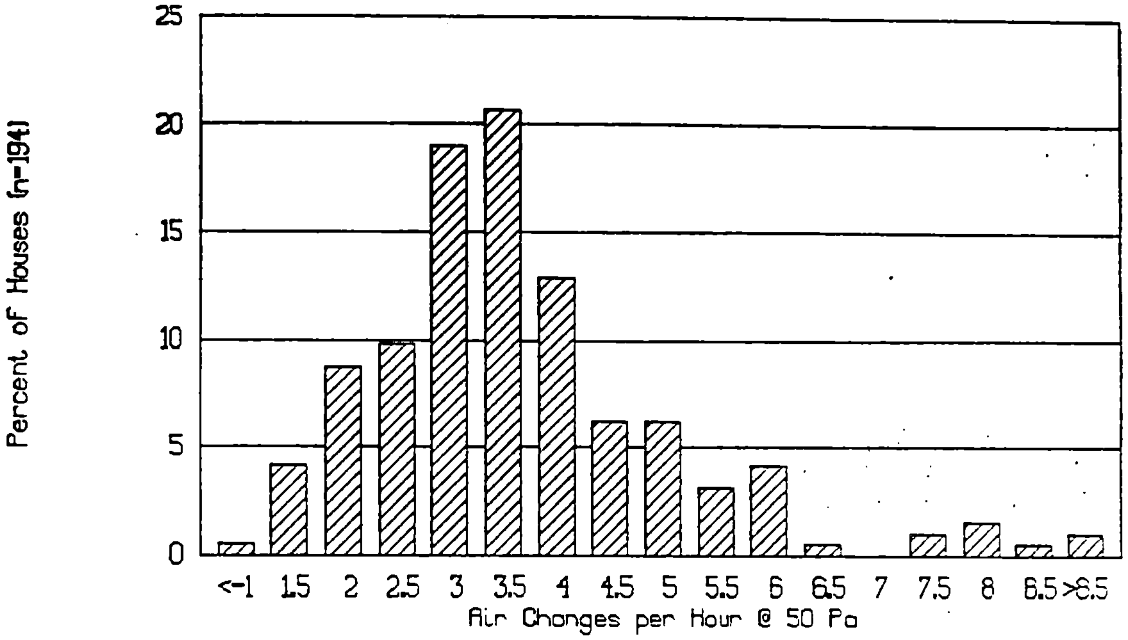
The data collected during the 1989 study was compared to data gathered during a similar study undertaken for Energy, Mines and Resources Canada in 1982/83. Evidence indicates that new homes are being built with less potential for air leakage through the building envelope. (Fig.4) A study conducted for Energy, Mines and Resources Canada in 1982/83 found that the air change rate @ 50 Pa for a Canada wide sample of 200 houses was 4.89. The average ac/h @ 50 Pa for a 1989 sample of 192 houses from coast to coast was 3.44. This suggests that houses built today are approximately 30 percent "tighter" than homes built less than a decade ago. The protocol used in 1982/83 is thought to be closest to the A sealing schedule. Comparison to the B schedule is not dramatically different.

The most significant improvement has occurred in British Columbia, where the average ac/h @ 50 Pa has decreased by almost 40 percent (from 9.33 to 5.95). Part of this change may be due to the increased size of homes being built in Vancouver. New houses built in British Columbia still tend to have the highest rates of air leakage. In areas where houses were already built with low levels of air leakage, the change has not been nearly as dramatic.

The "1989 Survey of The Airtightness of New, Detached, Merchant Builder Houses" also shows that the degree of airtightness was related to severity of climate, as indicated by the number of heating degree days. (Fig.5) Houses in the colder regions of the country tend to be more airtight than those located in more temperate areas. If the cost of energy is a factor influencing airtightness, increasing consumer cost of energy due to peak electrical generation cost and environmental impact of fuel combustion will reinforce the trend toward tighter housing.

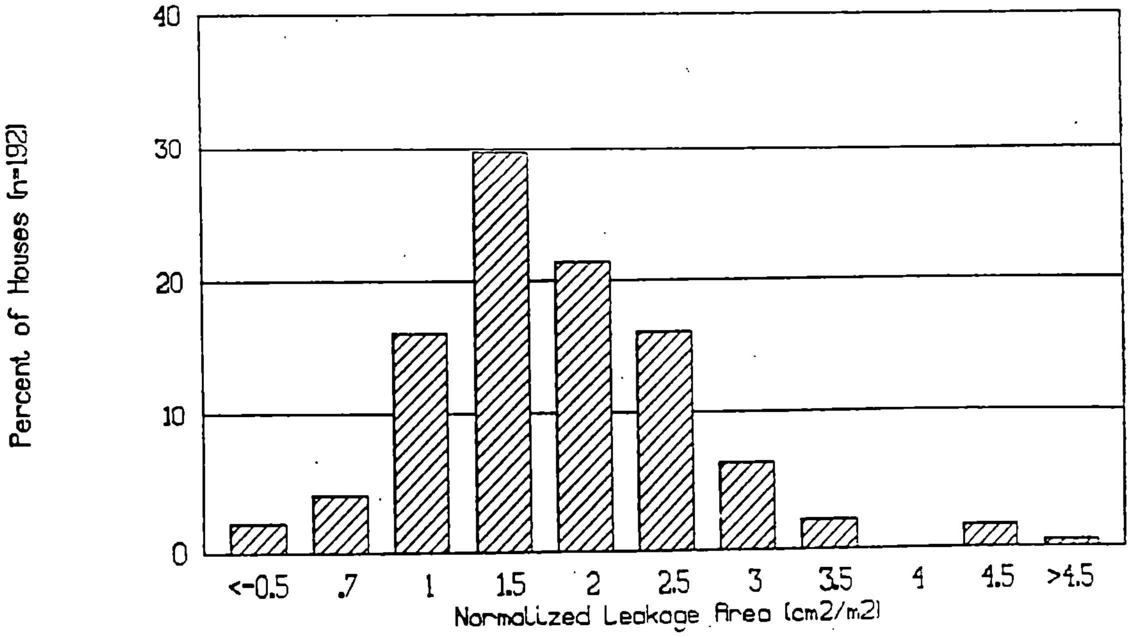
2.2 Indoor Air Quality

Fig.2 1989 Survey of Airtightness in New, Detached Merchant Builder Houses



X-axis scale: <= 1.0, 1.0 to 1.5, etc.

Fig.3 1989 Survey of Airtightness in New, Detached Merchant Builder Houses



X-axis scale: <=0.5, 0.5 to 0.7, etc.

Fig.4 Comparison of Air Change Rates @ 50 Pa - 1982/83 Data versus 1989 Data

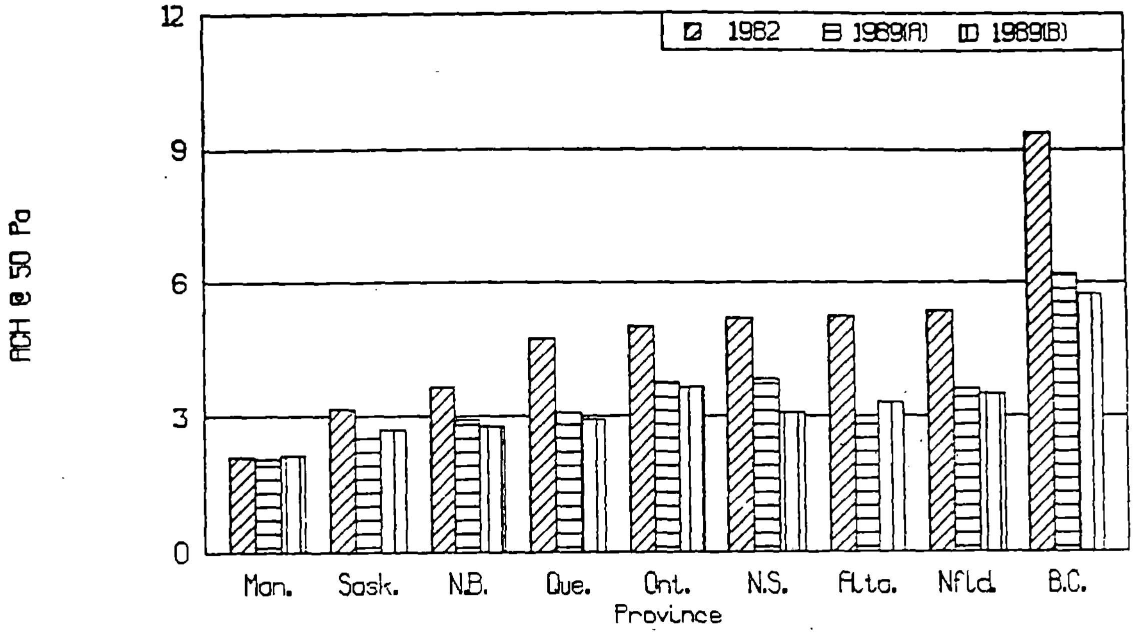


Fig.5 Average ACH @ 50 Pa versus Degree Days (Below 18C)

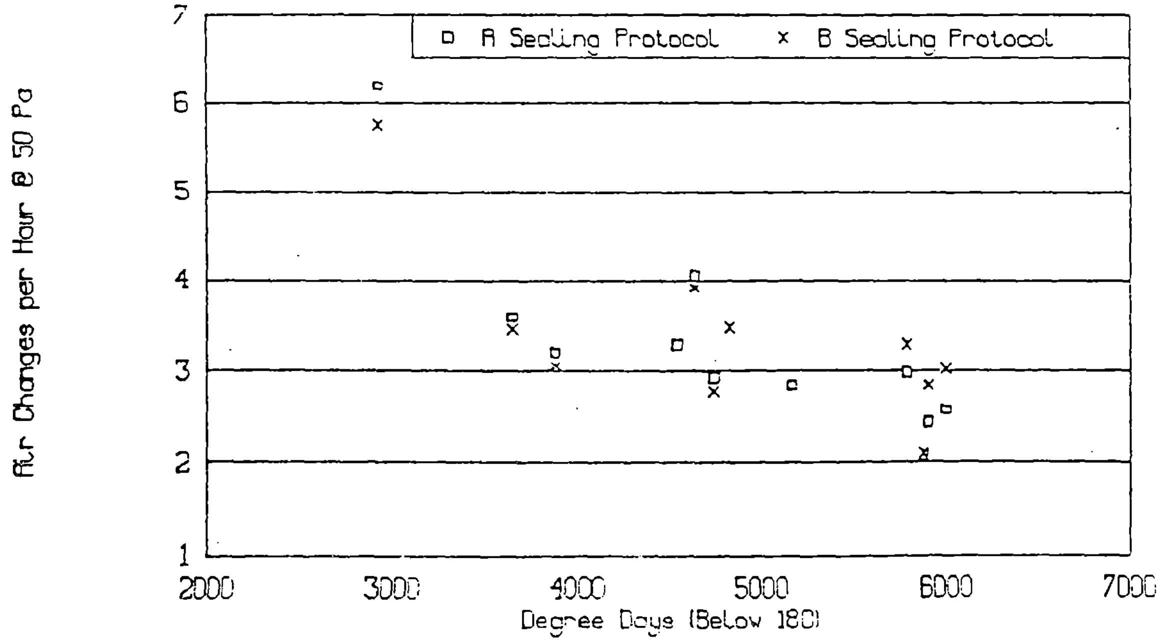
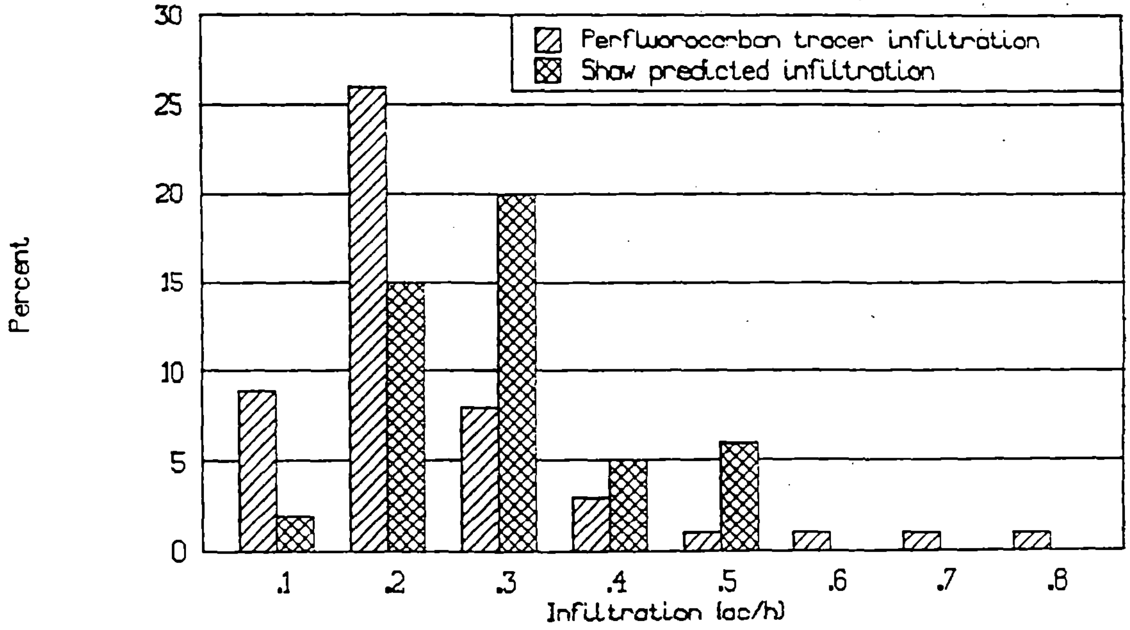


Fig.6

Infiltration Comparison
PFT Measured versus Shaw Predicted



Relative humidity and formaldehyde concentrations were measured in a subset of 50 houses from the "1989 Survey of Airtightness of New, Detached Merchant Builder Homes". At the same time, these houses were also tested using perfluorocarbon tracer (PFT) gas to determine their air change rates under normal operating conditions in March 1989. Table 3 summarizes the results of these tests. Data presented in Fig.6 shows that the distribution of air leakage rates measured by the perfluorocarbon tracer gas technique is similar to the distribution predicted by Haysom and supports their conclusion that natural air leakage is inadequate for ventilation.

Data shown in Fig.7 and 8 is consistent with that observed in the "Flair Homes Enerdemo Project" (9) and resembles the classical relationship between concentration and airchange rate for a constant source strength. This implies that maximum source strength is related to size of home. The ventilation rates greater than 0.3 ac/h have a decreasing effect on formaldehyde concentration suggesting that higher ventilation rates are not generally useful.

Fig.9 shows the distribution of relative humidity readings from 49 houses all taken in late winter/ early spring. Thirty four (69 %) of the houses had relative humidity levels of between 30 and 50 %, commonly referred to as the "comfort zone". Due to the variation in source strengths, no relationship was observed between ventilation rate and humidity.

Despite occasional introduction of new pollutant sources such as carpets, furniture, or paint, building pollutant sources are most often eventually exhausted. When this happens, the need for ventilation is usually dominated by occupant generated pollutants of which carbon dioxide a recognized indicator. The CSA F326 ventilation capacity requirement for a minimum typical 3 bedroom house is 55 l/s total. Coincidentally, the average air flow rate to produce 0.3 AC/H based on the volumes of 184 houses in the air tightness survey was 54.6 liters per second (Fig.10).

Eighty two percent of the houses for which PFT measurements were taken had natural air leakage rates below 0.3 volumes per hour during the sampling period (late winter/ early spring).

Fig.7 Distribution of Formaldehyde Concentrations in 48 New Houses

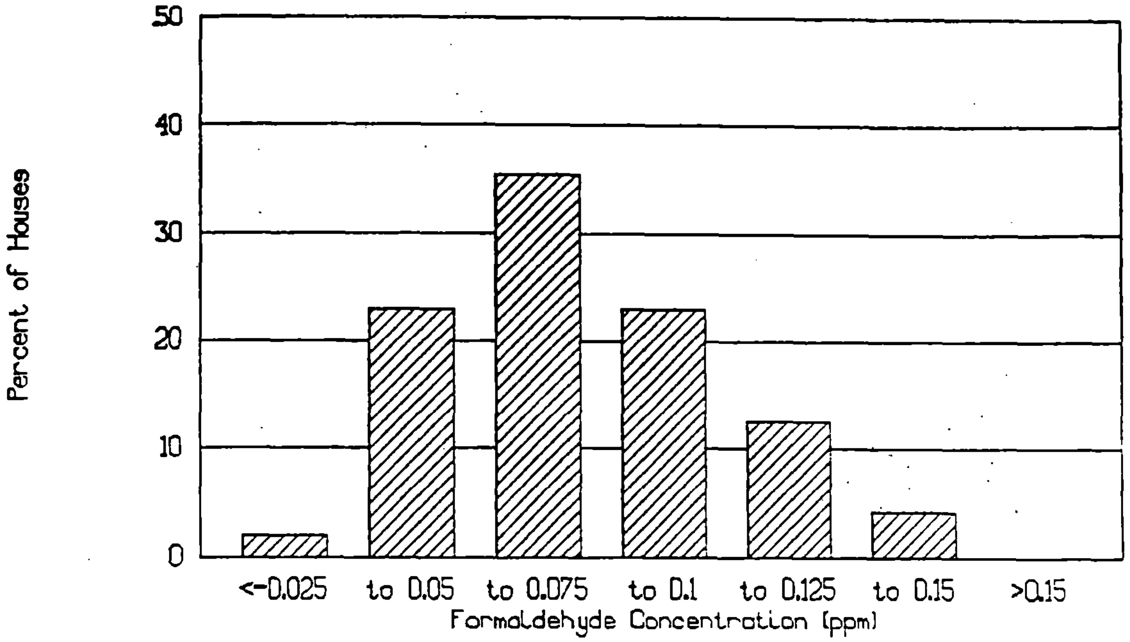


Fig.8 Formaldehyde Concentration versus Air Change Rate

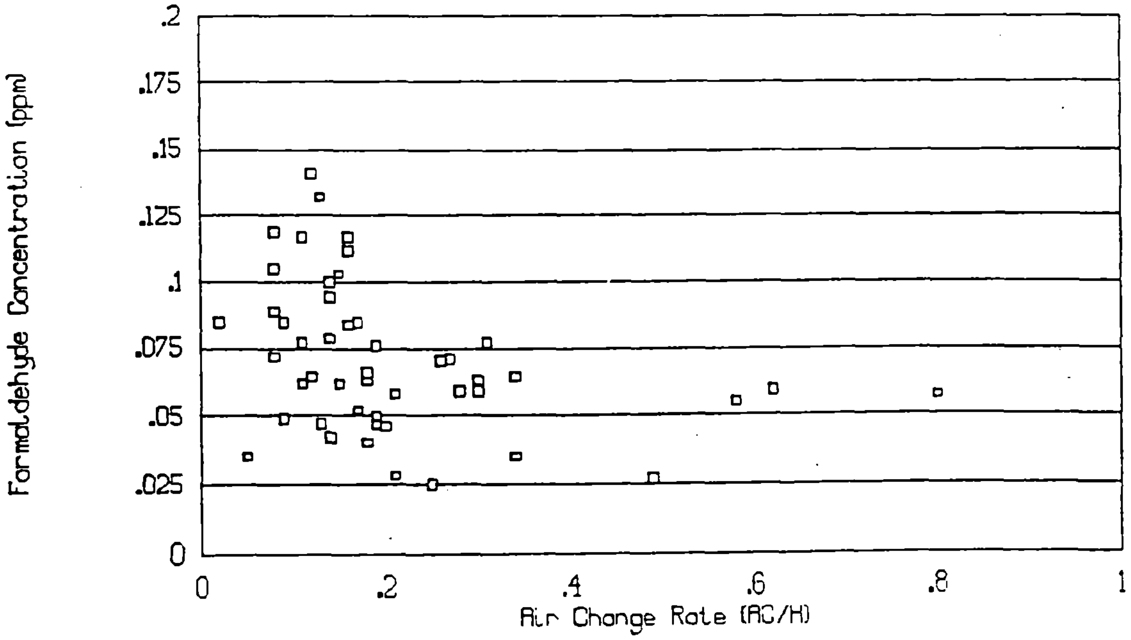


Fig.9 Distribution of Relative Humidity Readings for 49 Houses

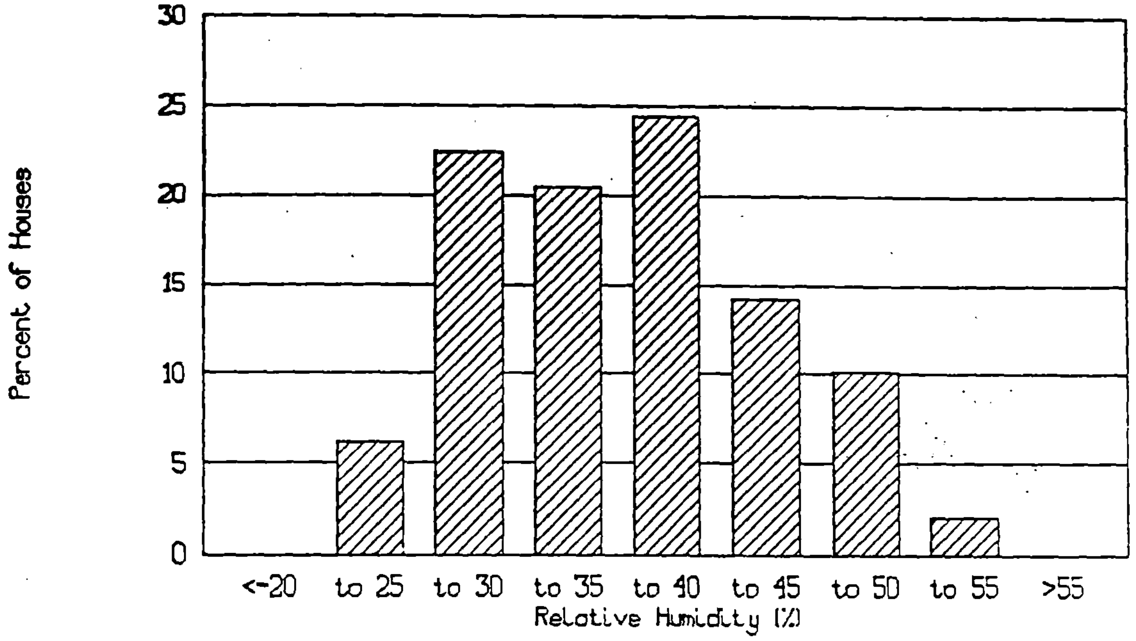
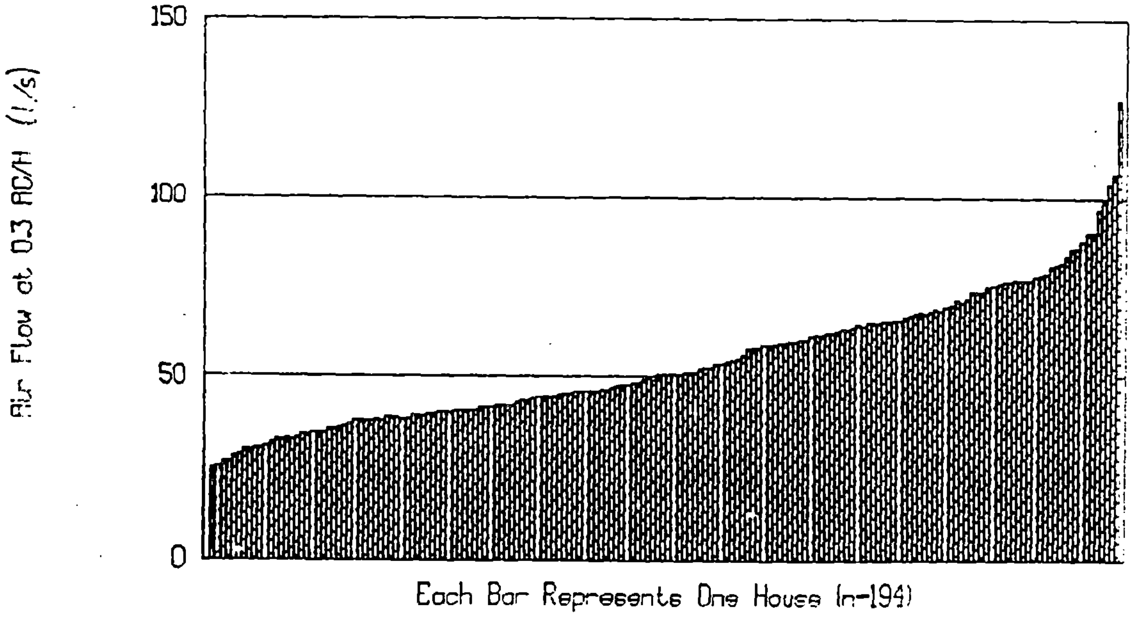


Fig.10 1989 Survey of Airtightness in New, Detached Merchant Builder Houses



2.3 Ventilation Performance

Observations on mechanical exhaust systems are based upon data collected during the "Canadian Residential Duct and Chimney Survey". This study was undertaken by Canada Mortgage and Housing Corporation (CMHC) in 1988/89. A consultant examined the field (installed) performance of various types of exhaust equipment and chimneys in 205 houses across Canada. The measurements were taken using a specially designed Duct Test Rig (DTR) and test protocols established as part of an earlier project. (10)

The DTR uses the principal of a compensated pressure difference across the duct opening to negate the effects of the measurement device. There is an internal fan capable of creating flows in a measurable range of 2 to 390 L/s. The DTR also includes both heat generating and temperature sensing devices to assess the thermal performance of chimneys. The fan can be used to generate the pressure versus flow characteristics of passive devices (combustion air supply duct), or aid in fan system flow measurement.

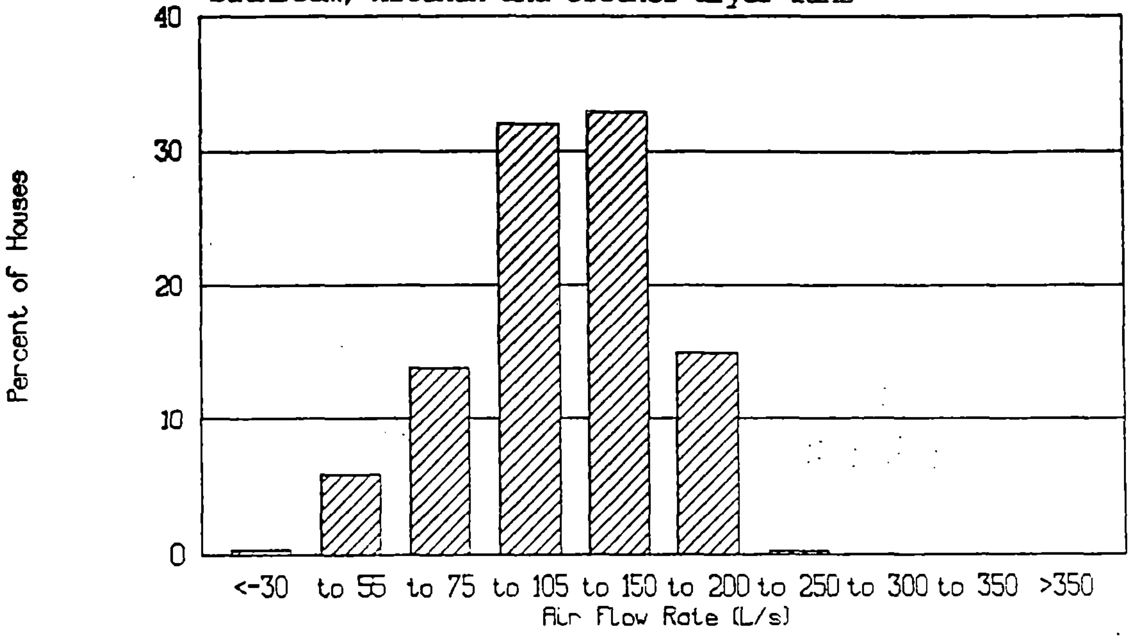
The data collected during the "Canadian Residential Duct and Chimney Survey" indicates that mechanical exhaust systems typically installed in new houses perform far below expectations. In a significant number of cases, bathroom exhaust fans and other devices provided almost no air flow. Where flow was measurable, it was generally far less than the rated flow for the device. The average measured flow rates for a variety of installed ventilation devices and chimneys is provided in Table 2. The flow rates for the chimneys were determined with the chimneys under a 10 pascal (Pa) pressurization, which is roughly equivalent to the pressure created by normal operation of the various combustion devices.

A recent study (11) conducted by Allen Associates, of Toronto, found that:

- -more than 95 percent of new houses have clothes dryers;
- -more than 70 percent of new houses have bathroom or kitchen exhaust fans;
- -more than 50 percent of new homes utilize fuel fired (i.e.: vented) heating systems;
- -approximately 40 percent of new houses contain fireplaces; and
- -approximately 30 percent of new houses have central vacuum systems.

Based upon this information, it is reasonable to assume that a new house will contain at the minimum a clothes dryer, and a bathroom or kitchen exhaust fan. These exhaust devices, operating in combination under installed conditions, will provide an average air flow of 113 L/s (Fig.11). Houses are assumed to be depressurized 5 Pa during operation of these fans.

Fig.11 Installed Exhaust Capacity (Probability of Occurrence)



As shown in Fig.12, 64 % of houses exceed an airflow of 55 l/s with one bathroom fan and one kitchen fan as currently being installed. Since 55 l/s is the typical CSA F326 flow requirement for typical 3 bedroom houses and assuming larger houses would have more bathroom fans, the CSA F326 flow rates are nominally being met in 64 % of new houses. These fans may not have the durability nor quietness necessary for continuous operation.

Twelve percent of bathroom fans and 50 % of kitchen fans exceed the CSA F326 intermittent capacity requirements of 25 L/s and 50 L/s respectively. CSA F326 only requires these higher rates when exhaust equipment is not part of a continuous ventilation system design. The performance of fans did not show any significant variation with age of home (Fig.12a).

If there is also a central vacuum system installed in the house, the average exhaust air flow rises to between 78 and 137 L/s whe all of these devices are operating. The operation of a fuel fired heating appliance with a chimney causes the air flow to rise to between 121 and 180 L/s. An operating fireplace results in an exhaust air flow of 225 to 284 L/s.

174 houses from the 1989 airtightness survey show that 37 % are heated with electricity. The remainder (63 %) are heated with natural gas. Further, 36 % did not have an air circulation system. (See Table 6.) This agrees fairly well with the data collected by Allen Associates. They found that 43 % of new houses are heated with electricity, 45 % are heated with natural gas, and 12 percent use other fuels, such as wood or oil. They also found that more than 40 % of new houses in Canada do not have a means of circulating air throughout the living space.

Most of those which do have air circulation systems rely on the forced warm air (FWA) heating systems to distribute air around the house. FWA systems are often not operating when air leakage driving forces (temperature differences, wind, etc.) are low. Consequently, some areas of the house may receive no fresh air while other areas may be over ventilated.

In consideration that 64 % of new houses would meet continuous airflow requirements, 63 % have recirculation systems by virtue of them having FWA heating, and 10 % have whole house ventilatio systems (like heat recovery ventilators), about half of current practice would meet the CSA F326 airflow and distribution requirements. They may, however, fail depressurization limits.

2.4 House Depressurization

The Allen Associates study (11) found that approximately 10 % of new houses built in Canada are equipped with whole house ventilation systems. The remainder have point source exhaust devices in bathrooms and kitchens. These systems exhaust air from "trouble spots" and rely on air leakage through the buildin envelope to provide replacement (makeup) air. If the house envelope is not sufficiently leaky, the living space will be

Fig.12 Installed Exhaust Capacity
(Probability of Occurrence)
Bath and kitchen fan only

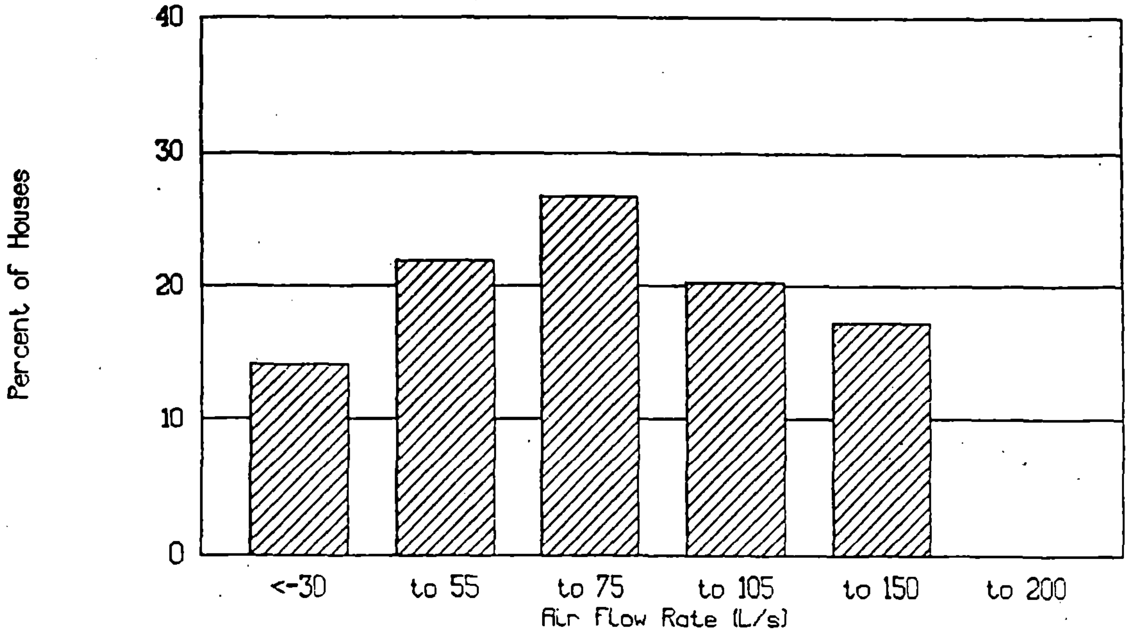
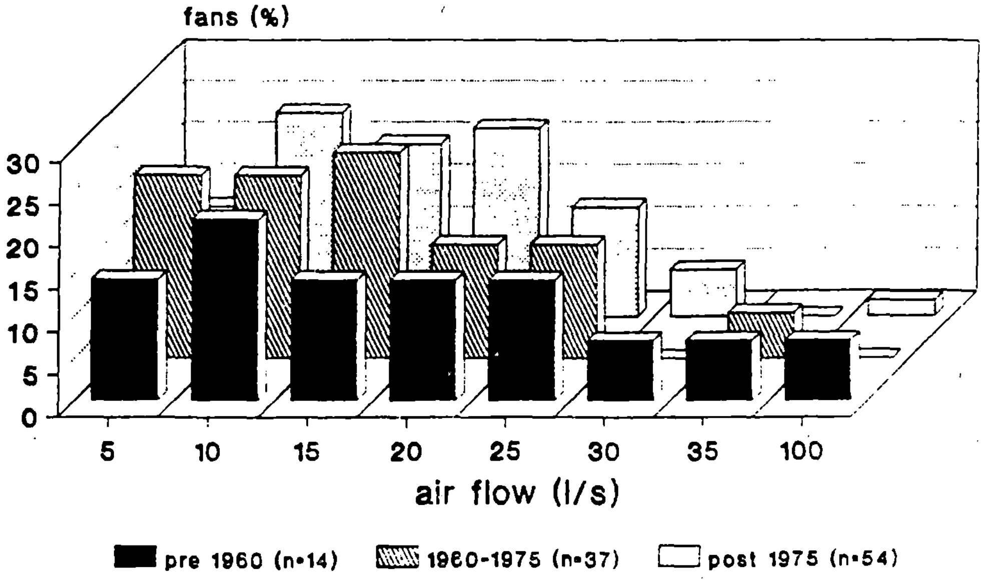


Fig. 12a **Bathroom Fans**
from the Duct and Chimney Survey



depressurized. The extent of the depressurization is proportional to the difference between the rate at which air is exhausted and the rate at which it leaks into the building through cracks and holes in the envelope.

The house depressurization levels of new detached housing were determined using the measured exhaust flows from the Duct and Chimney Survey and the airtightness measured in the Survey of the Airtightness of New Detached Housing.

This analysis is primarily concerned with exhaust devices which are quite commonly found in new houses. The air flow rates measured for these devices at a controlled depressurization of 5 Pa were examined to determine the distribution in air flow rates provided by exhaust equipment as installed in the field.

Since there was considerable variation in the air flow provided by each type of device, depending upon their location and installation, the distribution of results for each device was partitioned into eight equal occurrence bins and average flow rates determined within each bin. Individual averages were then added to develop a matrix of air flow rates provided by various combinations of a clothes dryer, a bathroom fan and/or a kitchen rangehood.

This matrix allowed the determination of the probability with which air flow rates falling between predetermined limits occur (installed ventilation capacity distribution). The results are shown in Figure 11. The frequency distribution of envelope air leakage rates at 5 Pa depressurization was then mapped onto the installed ventilation capacity distribution to determine the probability with which houses have a ventilation capacity which could depressurize the house to 5 Pa. The probability was calculated by multiplying the percentage of houses falling into each category of air flow rates on the depressurization graph by the percentage of houses of houses falling into each category of air flow rates on the installed ventilation capacity graph.

Fig.13 Air Flow Rates Required to Create 5 Pa Depressurization

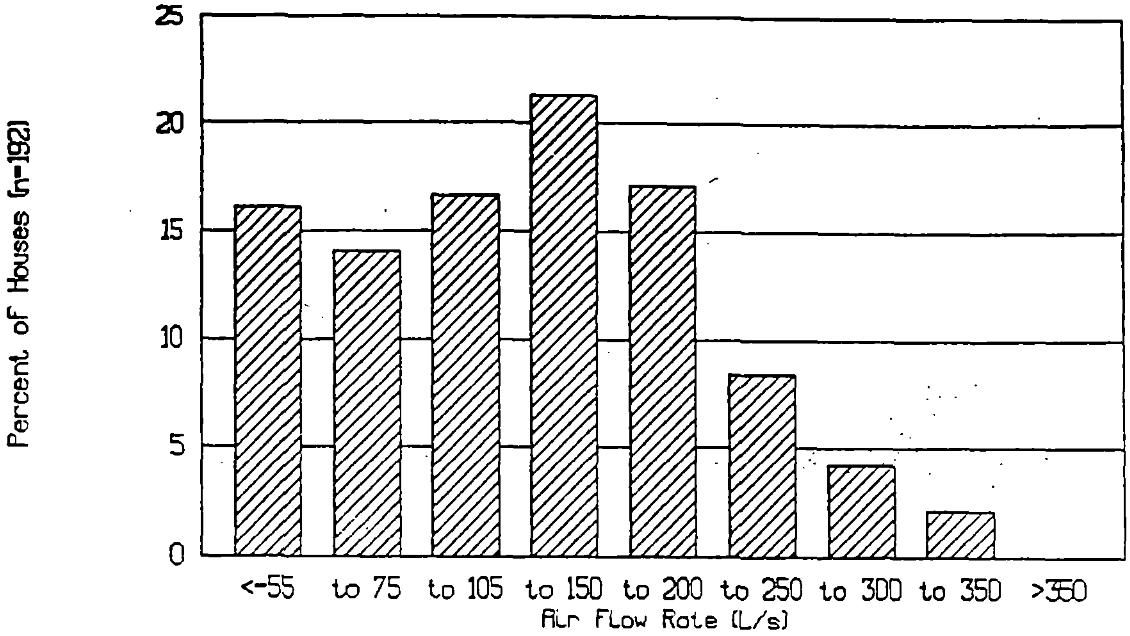
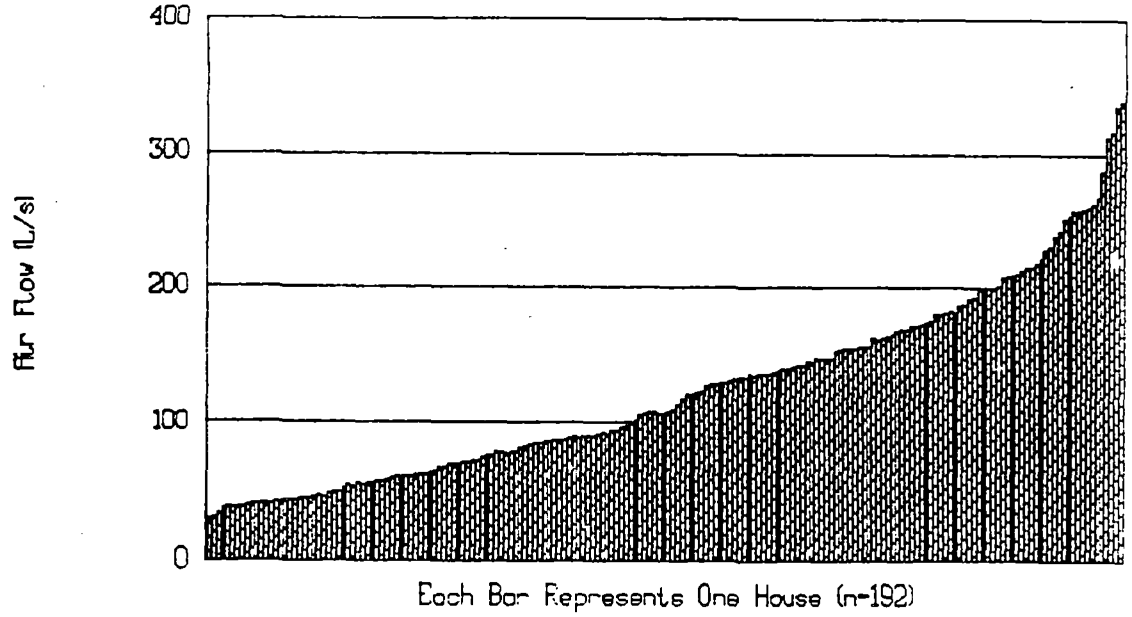


Fig.13a Exhaust Air Flow Resulting in 5 Pa Depressurization

(Excludes Combustion Equipment)



The data collected using the B test schedule was used to determine the envelope air leakage rates that would be required to depressurize the houses to 5 and 10 pascals (Pa). The power function

$$Q = C \times P^n$$

was used to calculate the rate of air flow required to depressurize the houses. The variables are defined as follows:

Q = volumetric flow rate (L/s);
C = flow constant (L/s x Pa^n);
n = flow exponent; and
P = pressure difference (Pa).

Depressurization to 5 Pa may lead to combustion spillage if naturally aspirated, fuel fired heating appliances are used in the house. Table 7 provides the average, minimum and maximum air flow rates required to create a pressure difference of 5 Pa across the building envelope.

The results of combining the ventilation capacity distribution with the air flow rates at 5 Pa depressurization (Fig.13) indicate that more than 18 percent of new homes are in danger of being depressurized such that the potential for combustion spillage from naturally aspirating, fuel fired heating equipment is increased. Spillage is also influenced positively and negatively by all of the following; wind, outdoor temperatures, and opening of windows in the house.

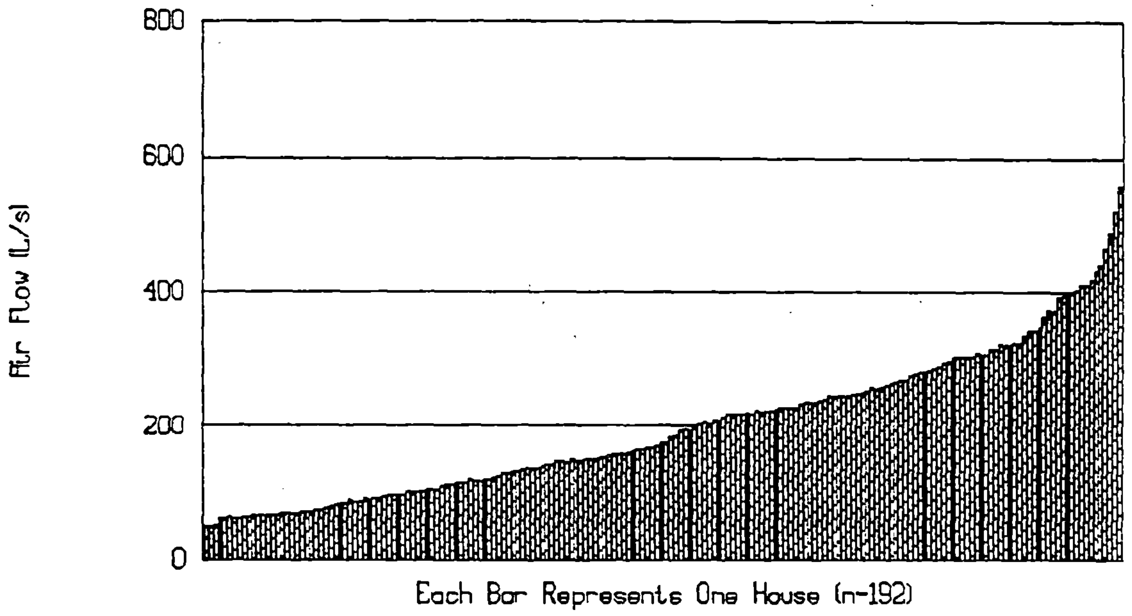
Assuming that minimum typical houses have an installed exhaust capacity of 55 L/s and a clothes dryer which achieves 55 L/s air flow, the intermittent or depressurization reference air flow capacity would be 110 L/s. Figures 8 and 9 show that almost 50% of the houses tested would be depressurized to 5 Pa by an air flow rate of 110 L/s. These results are very significant because the improvement of air flow capacity in houses will result in a significant increase in occurrences of combustion spillage from most naturally aspirating, fuel fired furnaces, releasing combustion by products such as carbon dioxide, oxides of nitrogen, and possibly carbon monoxide into the house. In 174 of the homes sampled, 109 (63 %) contained gas-fired furnaces, of which 101 (93 percent) were naturally aspirating. (See Table 6.)

Depressurization also increases the likelihood that soil gases will be drawn into the house. This may result in higher levels of relative humidity, and increased concentrations of radon and other components of soil gas (e.g., methane) in the house.

Table 8 provides the average, minimum and maximum air flow rates required to create a pressure difference of 10 Pa across the building envelope. A continuous air flow rate of 55 L/s provided by exhaust only equipment (such as a bathroom fan, and/or a kitchen fan) would result in a 10 Pa depressurization for no

Fig.14 Exhaust Air Flow Resulting in 10 Pa Depressurization

(Excludes Combustion Equipment)



houses (0%) in the air tightness survey when the C schedule (normal operating condition) is used (Fig.14). Two or three houses exceeded 10 Pa if the A or B schedules were used but these are inappropriate as flues were sealed for these tests.

2.5 Energy Impact

A building description suitable for energy analysis was completed for the majority of homes (174 of 194) in the 1989 air tightness survey. The air tightness data was used by Haysom (NRC) to simulate the natural air leakage rates and provided this study with a base case for ventilation improvements. The energy impact analysis was performed using a modified batch version of HOT2000. HOT2000 is a month by month energy simulation model (13) capable of predicting solar and internal gains utilization. This effect was expected to be important in spring and fall when mechanical ventilation would be required.

The air tightness data was further processed by the Institute for Research in Construction of the National Research Council (IRC/NRC). This analysis incorporates neutral pressure plane level data to more accurately simulate infiltration and exfiltration. Hourly, 8 hour average and monthly air leakage rates were determined for each house using the Shaw model and hourly weather data for a typical meteorological year (TMY) for each location. Appendix B provides a summary of the data generated by IRC/NRC. The Shaw hour by hour generated monthly average air leakage rate was expected to provide a better estimate of air air leakage losses than the current application of the Shaw model in HOT2000. Therefore, a procedure to enter the hourly generated monthly average Shaw air leakage rates into HOT2000 was developed. In the energy analysis component of this study the monthly air leakage rate generated by IRC/NRC corresponding to fan test schedule A was input to the HOT2000 program.

A series of transformations referred to as cases were investigated. Each case investigated a different ventilation rate, operation, system or envelope airtightness scenario to determine the energy impact of ventilation improvements.

The analysis used a mechanical ventilation capacity rate of 0.3 air changes per hour. This was chosen because it corresponds to the minimum rate required by CSA F326.1M-1989. This rate is not expected to under predict typical ventilation system operation.

Ventilation improvements will have an impact upon the ventilation load and the resulting space heating load. The main contributing variables in assessing the impact of ventilation improvements are climate, building size, ventilation rate, system selection, and operation. The data is normalized by heating degree days (1985 10 year averages) and to total floor area (living space, plus heated foundations) to isolate the ventilation variables. This also allows distinct comparison of the energy consumptions of various ventilation and air tightness improvement options.

In the sample (174 homes), 15 homes (8.5%) were already equipped with a whole house heat recovery ventilation system. These were removed from the simulation to provide consistent reference conditions to complete the analysis.
The sample is further divided into two subsets of airtightness to allow a comparative analysis. The Vancouver homes on average represent the leakiest region and the Prairies (Winnipeg, Saskatoon, Regina) represent the tightest region. The remaining locations (Edmonton, Toronto, Ottawa, Montreal, Quebec City, Halifax, St. John's) are similar to the average national airtightness. Table 9 provides the characteristics of each category. These characteristics differ slightly from those presented in section 3.2 due to missing HOT2000 data for the entire Fredericton sample and a few houses within the other zones.

2.5.1 As Built Condition

The air leakage rates for the "As Built Condition" and the relationship of air leakage to space heating load (Mj/m2/DD/yr) is indicated in Fig. 15.

The monthly air leakage rate as estimated by Shaw for an average nationally representative house is presented in Fig. 16.

2.5.2 As Built Condition with Mechanical Ventilation

Mechanical ventilation was added to indicate the energy impact of ventilation under uncontrolled and controlled ventilation strategies.

In the uncontrolled ventilation strategy, a rate of 0.35 ac/h was entered and the air leakage rate was estimated. For balanced supply and exhaust, Hot2000 combines these by adding all the larger and one half the smaller of these rates. This method was not considered appropriate for balanced equipment but was considered appropriate for exhaust only or unbalanced equipment as it accounts for reduced exfiltration of air when the house is under depressurization. Figure 15 provides a monthly indication of this for the average national house.

In the controlled ventilation strategy, the monthly ventilation rate is assumed to be controlled by turning down or turning off fans to achieve a monthly minimum house air change rate of 0.3 ac/h. If the monthly natural air leakage rate was greater than 0.3 ac/h, then the monthly ventilation rate was set to zero and the overall ventilation rate for the month would be the air leakage rate. In a number of homes in Vancouver, monthly air leakage rates were in excess of 0.3 ac/h, which is why the sum of the air leakage rate and mechanical ventilation rate is greater than 0.3. Figure 15 provides a monthly indication of this for the average national house.

Fig.15 Infiltration/Space Heating Comparison

Infiltration vs. Space Heating Load: No Improvements

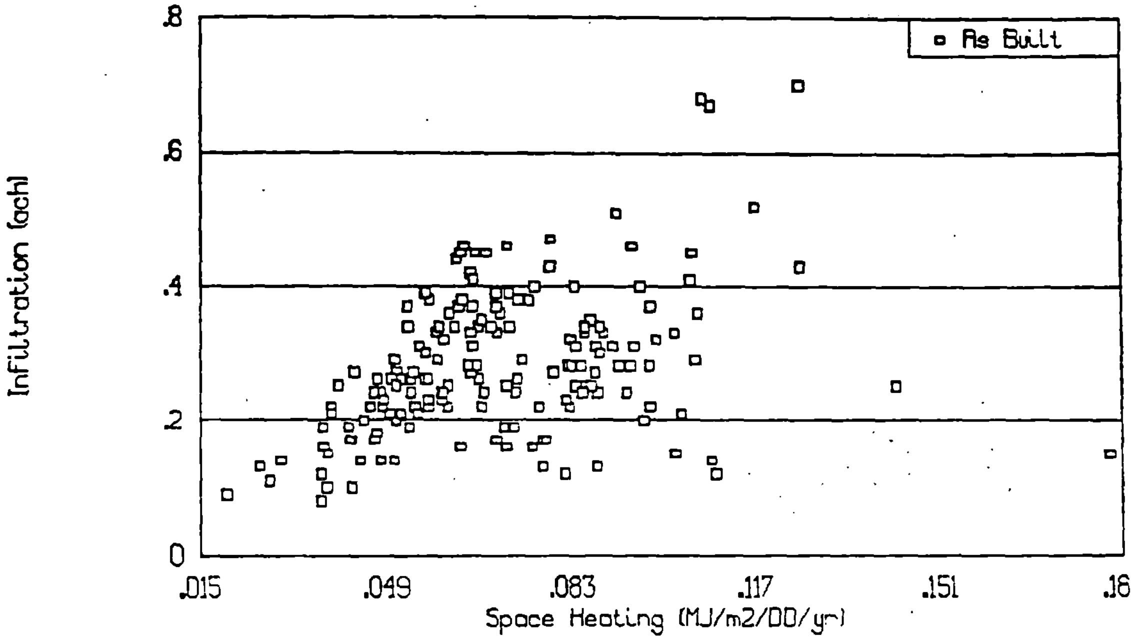
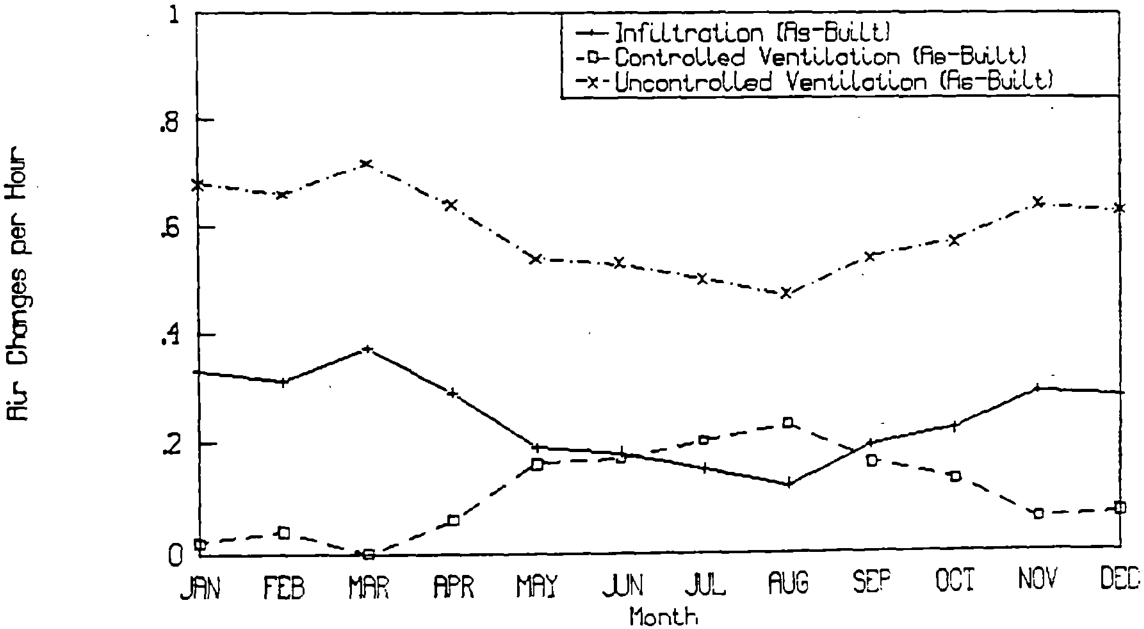


Fig.16 National Average Infiltration and Ventilation



Uncontrolled Ventilation = Infiltration + 0.35 ACH
Controlled Ventilation = 0.3 ACH - Infiltration

Uncontrolled ventilation increased the national space heating load from the As Built Condition (no ventilation) by 22.2 Gj per year or 29 percent. The space heating load was increased by 13.8 Gj (20 %)in Vancouver and 28.3 Gj (32 %) in the Prairies. The overall house ventilation rate in Vancouver has increased by 90% to 0.73 ac/h. Comfort problems in addition to substantial energy cost increase can be anticipated with such a high air change rate. It is very unlikely that uncontrolled ventilation would be used in any climate.

If the ventilation rate is controlled at 0.3 ac/h minimum (air leakage plus ventilation), the national space heating load is only increased by 6.4 Gj/yr (8 %) from the As Built Condition. The space heating load increased by 2.0 Gj (3 %) in Vancouver and 12.6 Gj (14 %) in the Prairies.

Fig.17 illustrates the distribution of space heating load (Mj/m2/DD/yr) of the As Built condition and the controlled ventilation scenario. This shows the increase in space heating as a result of incorporating a controlled ventilation system nationally. There is a shift to higher heating loads. The appearance of two groups of performance indicates that the sample contains some poorly insulated but airtight houses.

Fig.18 also illustrates the space heating load for each location in the sample according to ventilation provided by air leakage only, air leakage plus uncontrolled mechanical ventilation, and air leakage plus controlled mechanical ventilation. The uncontrolled ventilation scenario substantially increases the space heating loads in all locations. The Regina cases indicate loads about double the next worse case. This is due to the sample size of 6 homes, in which 2 homes are very poorly insulated. In these homes, the basements are uninsulated and the envelope insulation is substantially lower than any other home in Regina. Their level of air leakage (3.41 and 4.36 ac/h @ 50 Pa.) is substantially higher than the average for the Prairies (2.27 ac/h @ 50 Pa.). These two homes have annual space heating loads of 0.15 and 0.19 MJ/m2/DD, mainly attributable to a lack of insulation.

Since the uncontrolled strategy will result in comfort problems in addition to a very high energy penalty, a controlled type strategy is assumed to represent realistic mechanical ventilation operation. The occupants will likely turn off the ventilator during times of the year when natural ventilation is sufficient (summer non-airconditioned and winter months). Therefore, if a ventilation system is installed, a controlled strategy will be employed resulting in a space heating load increase ranging from 2.0 Gj/yr (3%) in Vancouver to 12.6 Gj/yr (14%) on the Prairies.

This energy penalty could be reduced by installing a ventilation system incorporating exhaust air heat recovery. Four types of heat recovery ventilator options were compared to a whole house mechanical ventilator to indicate potential space heating savings. The characteristics of the four heat recovery ventilators are outlined in Table 10. It was assumed that heat recovery would be accompanied by air tightening.

2.5.3 Envelope Air Leakage Reduction of 50 Percent with Low Efficiency Heat Recovery Ventilation

The option of envelope air leakage reduction in conjunction with heat recovery ventilation was investigated to assess the energy impact of this scenario. This was achieved by reducing the natural air leakage rates in the As Built condition by 50 percent. It is assumed that this would correspond to improved envelope air sealing which would reduce the air leakage rate by 50 percent. It must be noted that in reality this leakage reduction is not equivalent for all homes.

For instance, a 50 percent improvement in the airtightness of the Vancouver sample should be relatively easy to accomplish with minimal expenditures. This is due to the leakiness of the As Built condition in Vancouver (see Tables 6,7). In Winnipeg, a 50 percent reduction in envelope leakage would require more effort since these homes are already well sealed (see Tables 6,7).

An example of a low efficiency HRV would be a single pass cross flow air to air heat exchanger. Poor installation would involve ducts longer than 2.5 m between the HRV and outdoors, RSI 0.7 or less duct insulation, 2 mil vapour barrier with pin holes or torn, or duct leakage. These often result in heat recovery efficiencies less than one half the laboratory rating.

Controlled ventilation imposed an additional average load of 6.4 Gj from the As Built condition. Fifty percent air leakage reduction and a low efficiency HRV with poor installation achieved space heating savings of 8.4 Gj which more than offsets the additional load imposed by controlled ventilation. Good installation saved 10.7 Gj.

On the Prairies (Table 11), the energy penalty imposed by a controlled ventilation system are offset only by better installations of HRVs. The net space heating savings range from 7.7 Gj for a low efficiency HRV (poorly installation) to 13.4 Gj (good installation).

2.5.4 Envelope Air Leakage Reduction of 67 Percent and High Efficiency Heat Recovery Ventilation

A further envelope air leakage reduction with a ventilation system was investigated to assess the energy impact of a controlled ventilation system with high efficiency heat recovery.

This improvement was achieved by reducing the natural air leakage rates in the As Built condition by 67 %. This is the highest level of airtightness practically possible for the Prairie homes by current techniques. A 67 % improvement in the airtightness of the Vancouver sample is still relatively easy to accomplish with minimal effort.

Fig.17 National Space Heating Distribution
As Built Condition

Space Heating Load: Infiltration vs. Ventilation

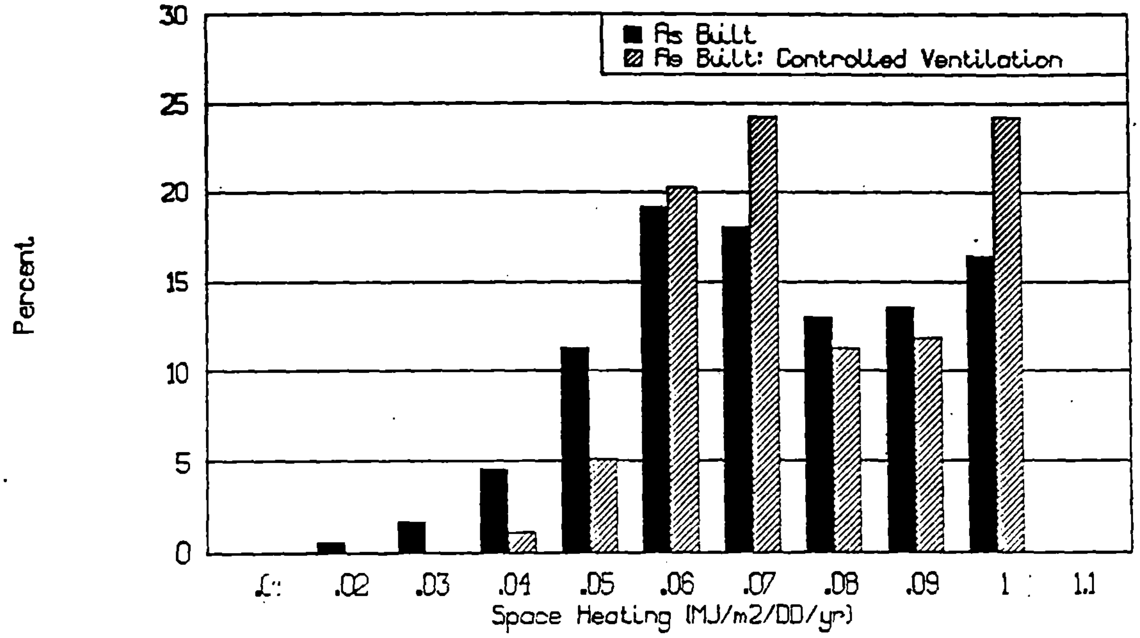


Fig.18 Space Heating Comparison
As Built Condition

Infiltration vs. Controlled vs. Uncontrolled Ventilation

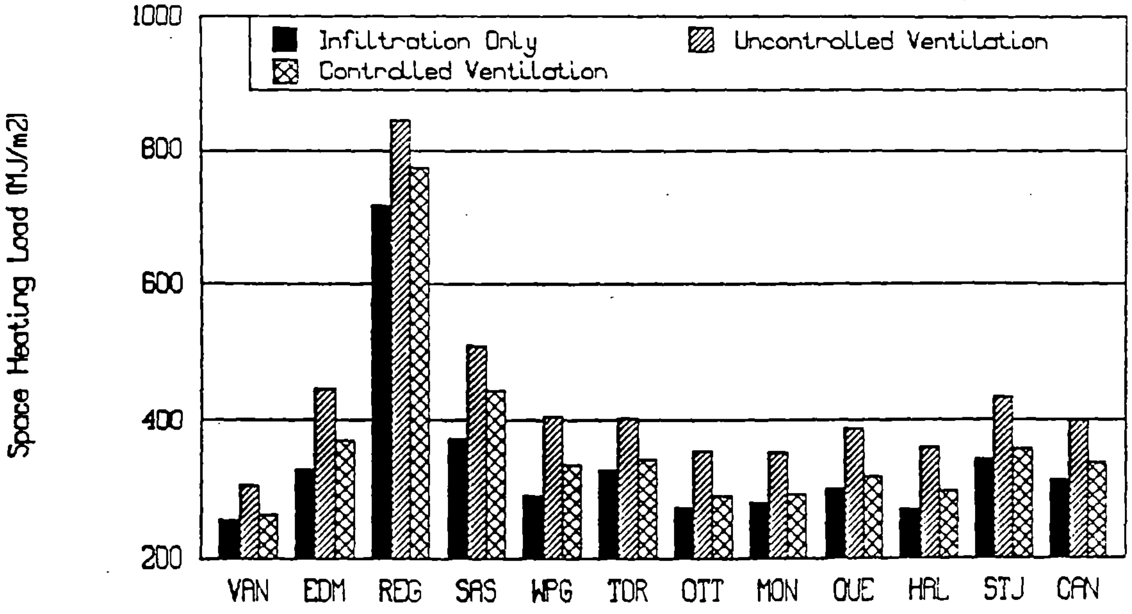
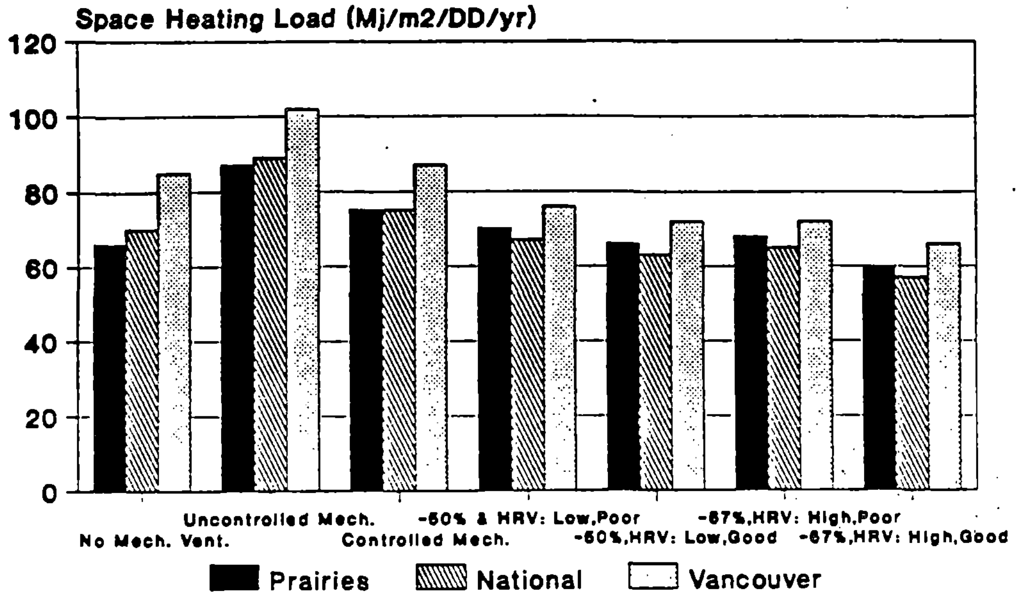


Fig.19 Energy Impact of Mechanical Ventilation
ventilation/ airtightness scenarios



Air leakage As Built, -50% or -67%
Controlled Mechanical Ventilation is 0.3 ac/h Minimum
HRV: High/Low Efficiency, Good/Poor Installation

Controlled ventilation imposed an additional average load of 6.4 Gj from the As Built condition. A high efficiency HRV, with good installation in a 67 percent tighter home achieved annual space heating load savings of 29.8 Gj, or a net space heating savings of 23.4 Gj from the As Built condition. In Vancouver (Table 11), the entire energy penalty of controlled ventilation is offset by both HRV installations. The net space heating savings are 21.4 Gj for a high efficiency HRV (poor installation) to 29.8 Gj for a high efficiency HRV (good installation). These savings are not difficult to achieve given the leakiness of the Vancouver sample. On the Prairies (Table 11), the energy penalty imposed by a controlled ventilation system are also completely offset if the envelopes are tightened by 67 percent. The net space heating savings range from 8.8 Gj for a low efficiency HRV (poorly installed) to 22.9 Gj for a high efficiency HRV (well installed). This level of savings may be difficult and costly to achieve since these houses were initially well sealed.

The space heating savings (in percent) of the different heat recovery ventilator options, in conjunction with a 67 percent envelope air leakage reduction, as compared with a whole house mechanical ventilator have been graphed in Fig.19.

The annual space heating average savings and corresponding standard deviations in kilojoules per square meter of total floor area per heating degree day (KJ/m2/DD/yr) for the reference zones Vancouver, Prairies, and nationally are presented in Table 11 and Fig.19.

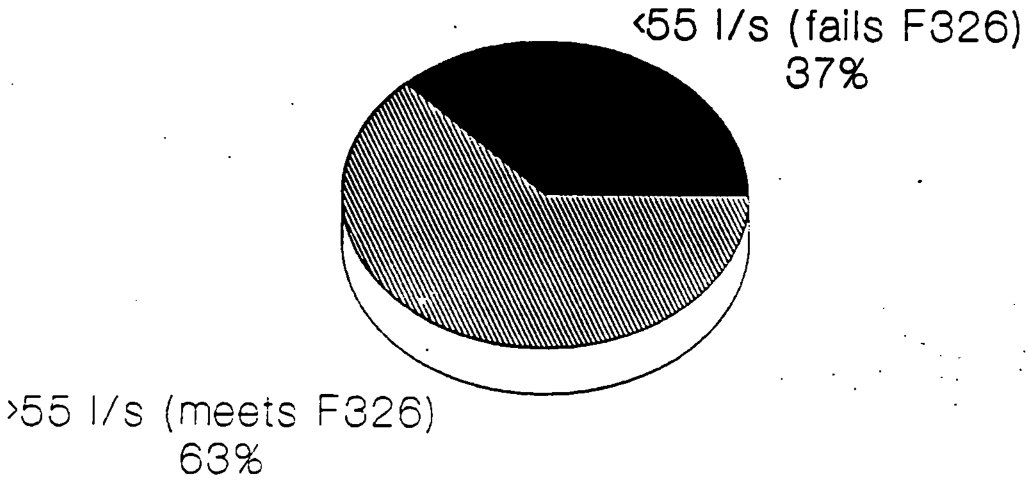
3.0 CONCLUSIONS

There is a trend to more air tight housing in Canada. Tightness has increased 30% since 1982/83. As the variation in tightness can be correlated to severity of climate, this trend is probably influenced by comfort and energy cost. As requirements in both areas are expected to increase due to an aging population and environmental concerns as well as requirements for durable envelope construction, preparations must be made to deal with the consequences of this trend.

Indoor air quality monitoring indicates that new housing is experiencing formaldehyde levels above the Health and Welfare long term goal of 0.05 ppm in 50 % of housing and above the short term limit of 0.1 ppm in 17% in new housing. Because levels are known to decay over time, the long term goal will probably be met over the majority of the building lifetimes. A minimum air change rate of 0.3 ac/h appears to control this pollutant in detached housing. Research by Haysom (12) and confirmed in this study indicates that the capacity required to control occupant generated pollutants such as carbon dioxide and odors (ASHRAE and CSA F326) is not being provided by natural air leakage for extended periods in new houses.

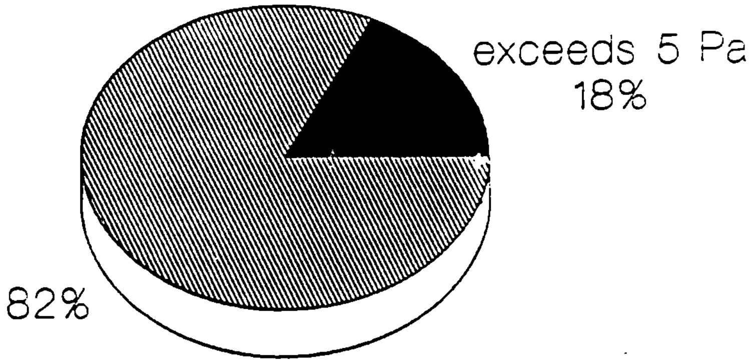
Current ventilation practice as measured in the Duct and Chimney Survey indicates that much of the ventilation equipment is

Fig.20 Ventilation Capacity
Existing Houses



– assuming at least
One Bathroom and One Kitchen Fan

Fig.21 Depressurization Probability
Percent of Houses



with a Dryer, Bathroom ~~and~~ Kitchen fan operating below expectations. Only 12 % of bathroom fans and 50 % of kitchen fans would meet CSA F326 intermittent flow requirements of 25 and 50 l/s respectively. Much of the existing equipment used is not suitable for continuous use due to noise and durability characteristics. However 64 % of current practice would meet the air flow requirements of CSA F326 (Fig.20). Upgrading to slightly better sound rated and airflow rated fan units (such as per CSA C260 Residential Ventilation Equipment) would be required.

Despite the poorer performance of exhaust equipment, 18 % of new houses if assumed to have one bathroom fan, one kitchen fan and/or a dryer in operation will depressurize below the 5 Pa limit recommended for naturally aspirated combustion appliances (Fig.21). As well, 20 % of new houses would be depressurized by more than 10 Pa by the average dryer, bathroom plus kitchen fan. Ventilation requirements for new houses should not be implemented without consideration of depressurization effects.

Inconsideration of air flow rates, distribution requirements (Fig.22), and house depressurization limits approximately 40 % (+/- about 10%) of houses tested would meet CSA F326 with current practice (Fig.23). This is based on the assumptions that 63 % are gas fired forced warm air systems, 90 % of which are naturally aspirated. 18 % of these are subtracted as those with better air flows are more likely to depressurize excessively. Of the remaining 10% gas fired houses none are assumed sensitive to depressurization levels. Of the 63% gas fired forced warm air systems 35% meet CSA F326 requirements. Assuming 50% of electric baseboard heated houses have solid fuel fired appliances which are sensitive to more than 5 Pa depressurization only half of the electric heated houses with whole house ventilation systems meet CSA F326. This results in a total of 40 % meeting CSA F326 with current practice. It is recommended that these assumptions be reviewed in light of any further data available but it is not expected that percentages would change significantly (more than 10 %). If mid efficiency with draft induction becomes a mandatory minimum for all gas fired appliances before the introduction of CSA F326 about 15 % more of these houses could meet the standard. The use of whole house ventilation systems (including through the wall units and distributed exhaust systems) in convection heated (electric and hydronic baseboard) houses and the use of depressurization tolerant solid fuel fired devices (such as those certified for use in mobile homes ULC S627) would be necessary for the balance of houses to meet CSA F326 requirements.

The energy cost of introducing controlled ventilation to housing is predicted to be 8%. The assumed controlled minimum air flow rate for this study was 0.3 ac/h however demand control and source control could reduce this substantially. These average rates do not support the conclusion that individual houses may not require a higher ventilation capacity due to designed occupancy (room by room calculations) or natural air leakage Capacity must be available on demand to satisfy health and thermal comfort in a controlled manner. Mechanical heat recovery

Fig.22 **Ventilation Distribution**

Percent of Houses

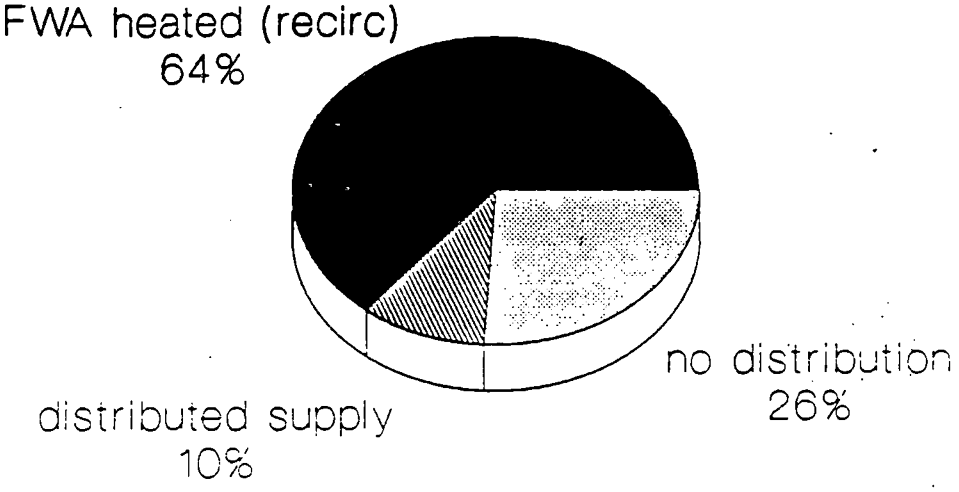
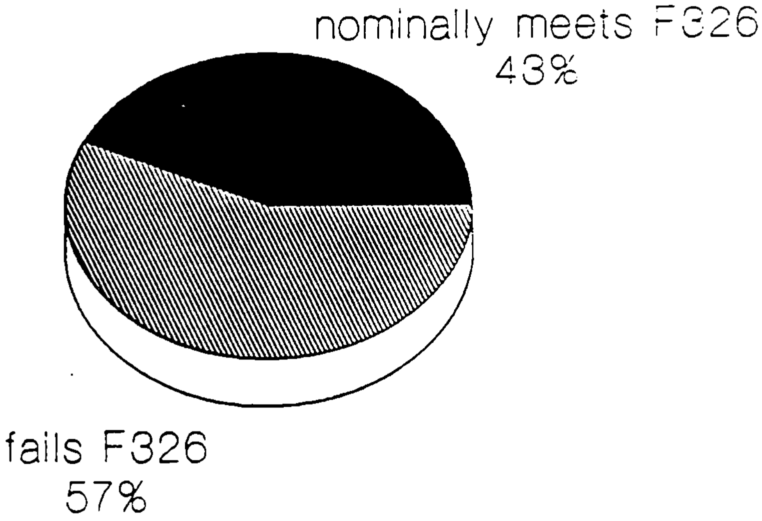


Fig.23 **Air flow/ Distribution/ Depressurization**

Estimate for New Houses



and further airtightening can result in energy cost reductions easily exceeding the increased cost of ventilation. Heat recovery system energy performance is highly influenced by installation although thermal comfort would be achieved regardless of installation quality. Heat recovery is most feasible economically when accompanied by increased air tightening and good installation practice.

4.0 REFERENCES

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Table 1: Minimum Ventilation Air Requirements as per "CSA F326.1 M1989, Residential Mechanical Ventilation Requirements"

	Column 1	Column 2	Column 3
Space Classification	Base Flow Rate (L/s)	Intermittent Exhaust (L/s)	Continuous Exhaust (L/s)
Category A			
Double/Master Bedroom	10		
Basement*	10		
Single Bedrooms	5		
Living Room**	5		
Dining Room**	5		
Family Room	5		
Recreation Room	5		
Other+	5		
Category B			
Kitchen**	5	50	30
Bathroom	5	25	15
Laundry	5		
Utility Room	5		

Either intermittent or continuous exhaust is required.
Flow rates based on air density of 1.204 kg/m3.

* Each area in a basement that is separated by a wall and doorway shall have a minimum ventilation requirement of 5 L/s. This does not include furnace rooms, storage rooms, and closets.

** Ventilation requirements for any combined living room, dining room, and kitchen shall be determined as if they were individual rooms.

\+ Other habitable rooms not listed shall have a minimum ventilation requirement of 5 L/s. This does not include spaces intended solely for access, egress, or storage, such as vestibules, halls, landings, and storage rooms.

Table 2: Air Flow Rates for Exhaust Equipment and Chimneys

Device	Number Tested	Mean Flow (L/s)	Range (L/s)	
Bathroom Fans	103	17	2	98
Kitchen Fans	62	59	3	155
Clothes Dryers	61	37	10	83
Central Vacuums	24	24	10	41
Chimneys (@ 10 Pa)				
Furnace	120	43	10	176
Fireplace	35	104	23	229
Woodstove	28	50	9	160

Table 3: Summary of Indoor Air Quality Measurements

	PFT ac/h	Relative Humidity (%)	Formaldehyde Concentration (ppm)
No. of Readings	50	49	48
Average	0.20	36	0.071
Standard Deviation	0.15	7.5	0.028
Minimum	0.02	23	0.025
Maximum	0.80	54	0.141

Table 4: Average Air Change Rates for New Houses

Location	Number of Houses	Air Change Rate (@ 50 Pa) Average	Minimum	Maximum
Winnipeg	20	2.08	0.98	3.46
Regina	10	2.44	1.22	3.88
Saskatoon	10	2.58	1.79	3.77
Quebec City	20	2.86	1.86	3.83
Fredericton	10	2.93	1.51	5.34
Edmonton	10	3.00	1.35	5.04
Halifax	14	3.22	1.71	5.96
Montreal	20	3.30	1.71	5.51
Toronto	30	3.60	2.47	5.35
St. John's	10	3.63	2.70	5.34
Ottawa	20	4.06	2.50	5.99
Vancouver	20	6.19	2.86	11.13
Canada	194	3.44	0.98	11.13

Table 5: Normalized Leakage Areas for New Houses

Location	Number of Houses	Normalized Leakage Area (cm2/m2) Average	Minimum	Maximum
Winnipeg	20	0.91	0.42	1.47
Regina	10	1.05	0.55	1.69
Quebec City	20	1.17	0.78	1.93
Saskatoon	10	1.20	0.67	2.01
Montreal	20	1.31	0.65	2.36
Edmonton	8	1.32	0.47	2.33
Halifax	14	1.36	0.70	2.32
Fredericton	10	1.49	0.81	3.08
St. John's	10	1.75	1.31	2.24
Toronto	30	1.92	1.18	2.69
Ottawa	20	2.07	1.34	2.79
Vancouver	20	2.87	1.27	4.79
Canada	192	1.61	0.42	4.79

Table 6: Heating Systems in New Houses (%)

System Type		Number in Sample
Electric		
Baseboard		56
Radiant Panel		7
Forced Air Furnace		2
	Subtotal	65
Natural Gas		
Naturally Aspirating with Pilot Light		82
Naturally Aspirating with Spark Ignition		19
Induced Draft Fan		7
Condensing		1
	Subtotal	109
	TOTAL	174

Table 7: Air Flow Required to Depressurize New Houses to 5 Pa

Location	Number of Houses	Air Flow (L/s) Average	Minimum	Maximum
Quebec City	20	62.3	39.1	161.1
Winnipeg	20	69.0	30.5	156.4
Montreal	20	74.2	31.7	128.1
Regina	10	89.0	41.2	131.9
Saskatoon	10	102.7	64.7	141.6
Halifax	12	109.2	39.2	256.5
Fredericton	10	104.0	60.4	162.6
Edmonton	10	119.0	61.3	212.9
St. John's	10	120.6	70.1	197.6
Ottawa	20	168.9	89.4	238.4
Toronto	30	178.7	81.9	315.8
Vancouver	20	221.3	97.5	338.5
Canada	192	123.5	30.5	338.5

Table 8: Air Flow Required to Depressurize New Houses to 10 Pa

Location	Number of Houses	Average	Air Flow (L/s) Minimum	Maximum
Quebec City	20	99.3	62.2	256.6
Winnipeg	20	111.6	49.4	244.0
Montreal	20	118.2	50.5	204.0
Regina	10	147.6	67.4	209.4
Saskatoon	10	165.0	102.5	307.1
Fredericton	10	167.8	96.5	268.8
Halifax	12	180.2	66.7	415.5
Edmonton	10	189.0	102.4	307.1
St. John's	10	189.5	112.7	280.1
Ottawa	20	268.9	148.5	373.4
Toronto	30	286.7	148.5	466.3
Vancouver	20	353.1	159.1	558.1
Canada	192	197.9	49.4	558.1

Table 9: House Characteristics: Energy Simulations

	Number of Houses	Total Volume (m3)		Total Floor Area (m2)	
		Ave.	S.D.	Ave.	S.D.
Vancouver	20	692	150	266	58
Prairies *	34	589	140	226	67
Remainder+	120	660	225	254	86
Canada	174	650	207	250	80

* Prairie sample includes:

10 Saskatoon houses
6 Regina houses
18 Winnipeg houses

\+ Remainder sample includes:

8 Edmonton houses
29 Toronto houses
20 Ottawa houses
20 Montreal houses
20 Quebec City houses
13 Halifax houses
10 St. John's houses

Total floor area equals liveable floor area plus heated foundation floor area, or total house volume (m^3) divided by 2.6.

Table 10: Heat Recovery Ventilator Characteristics

Type	Sensible Efficiency		Power Inputs (W)		Field Efficiency	
	0C	25C	0C	25C	0C	25C
High Eff., Good Installation	80	70	150	150	72	63
High Eff., Poor Installation	80	70	150	150	40	35
Low Eff., Good Installation	55	45	150	150	49.5	40.5
Low Eff., Poor Installation	55	45	150	150	27.5	22.5

Notes: 1. No preheaters installed
2. Field efficiencies are calculated as 90 percent of the sensible efficiency for the good installation and 50 percent of the sensible efficiency for the poor installation.

Table 11: Space Heating Load Required: Airtightness/ Ventilation Scenarios

Case Analyzed	Kilojoules per Square Metre of Total Floor Area Per Heating Degree Day							
	Vancouver		Prairies		Remainder		National	
	Ave.	s.d.	Ave.	s.d.	Ave.	s.d.	Ave.	s.d.
no ventilation	85	16	66	36	68	18	70	23
0.3 ac/hr uncontrolled vent.	102	16	87	36	88	18	89	23
0.3 ac/hr controlled vent.	87	15	75	36	73	18	75	23
50% air leakage reduction, controlled vent. low efficiency HRV, good installation	72	14	66	36	61	16	63	20
same as above except Poor Installation	76	14	70	36	65	16	67	20
67% air leakage reduction, controlled Vent. high efficiency HRV Good Installation	66	13	60	36	55	15	57	21
same as above except poor installation	72	14	68	36	63	16	65	21

Notes:

1. Remainder includes homes in Edmonton, Toronto, Ottawa, Montreal, Quebec City, Halifax and St. John's
2. no ventilation is the as built condition
3. The controlled ventilation and HRV options simulate a mechanical ventilator operating at a monthly ventilation rate required for the house to achieve 0.3 air changes per hour as a minimum. The field performance efficiencies are in the previous table.