PROGRESS AND TRENDS IN AIR INFILTRATION
AND VENTILATION RESEARCH

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AIR INFILTRATION IN CANADIAN HOMES — A DECADE OF CHANGE

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SYNOPSIS

This paper explores the results of air infiltration and ventilation research carried out in Canada over the last decade and specifically examines its application to low-rise residential buildings.

With Canada's cold climate, the reduction of space heating costs by dealing with air infiltration and ventilation issues in residential buildings is particularly important and has been the subject of government and industry initiatives. The results over the last decade have been gratifying. Not only has there been a large number of "innovative" houses built with exceptionally good control of air infiltration through the building envelope and well controlled space heating costs, but this information has been transferred to the general building industry. Current Canadian new house construction is showing significant improvement from the construction of ten years ago.

This paper outlines how this change has been brought about and how it is expected to continue.

1.0 INTRODUCTION

An examination of the evolution of house construction practices in Canada over the last decade is a study of the changes wrought by a concern over air infiltration.

The search to find methods of controlling air infiltration was driven by steep energy price increases in the 1970's. Canada's concerns were heightened by the fact that, due to our cold climate, a significant percentage of the energy used in our country is used to heat our homes. In 1973 it was estimated that:

- Approximately 20 per cent of the nation's energy was used for residential purposes[1]. and
- 77 per cent of this energy was used for space heating[2]. A large portion of this was heating infiltration air.

The control of air leakage in buildings is also particularly important in the cold Canadian climate due to a number of technical factors:

- In cold climates, the stack effect is the dominant driving force for air leakage. As a result, the highest air change rates occur during winter when the costs of heating that air are the greatest.
- In a cold climate, the exfiltration of indoor air can lead to condensation in the building envelope. Condensation can have a particularly negative impact on wood frame construction -- the typical type of construction in Canada.
- Virtually all Canadian houses have central heating with thermostatic temperature control. The most common "comfort problems" are due to drafts from air leakage.

The building industry and government agencies concerned with housing and energy reacted by stimulating research and development into reducing energy consumption for space heating. Researchers and experimental builders tackled the problems and initiated a variety of changes -- some unsuccessful, some very successful -- that have lead to significant modifications in the way houses are built in Canada. In recent years, many of the experimental techniques developed to control air leakage have been incorporated into the construction practices of tract and merchant home builders.

This has had an effect on residential energy use in Canada. In 1987, approximately 18 per cent of the total energy used was for residential purposes and, of that, space heating accounted for 68 per cent[2].

On average, energy use per household was estimated to have decreased by 32.5 per cent between 1973 and 1987. This 32.5 per cent decline in residential energy use intensity equates to a value of 50.8 GJ/household. Roughly half of the decline, 26 GJ/household, (which was approximately 15 per cent of the 1973 average residential requirement) was attributed to changes in tertiary energy demand (net of behavioral responses). About half of this was due to improvements in the old housing stock and the rest was from the greatly improved thermal efficiency of new housing stock.

Part of the improvement is due to better control of air infiltration.

A comparison of tested air change rates of the typical houses provides an indicator of the reductions in air infiltration that have occurred in the last ten years. The average air change rate for 200 houses built between 1980 and 1982 was in excess of 4.8 air changes per hour (ACH) when tested at 50 pascals pressure[3]. A recent test of merchant or tract-built houses across Canada has found that the average is now about 3.0 ACH at 50 Pa[4].

The process is not complete. Demonstration programs have shown that air tightness test results of 1.5 ACH at 50 pascals and further reductions in energy requirements are achievable. Home owners, builders, suppliers and regulatory agencies are working together to bring about continued improvements.

It is not surprising that there has been an impetus for controlling air leakage in Canadian homes. What, in retrospect, is surprising, is the extent of the change, the orderly process it has followed (considering the building science implications of the changes and the resistance to change of the building industry as a whole) and the fact that a building "philosophy" has developed. This philosophy could be stated as:

> *"Recognize the house is a system; build as tight a building envelope as practical and provide needed ventilation in a controlled, mechanical manner."*

Tracing the development of this approach and how it was accomplished is the subject of this paper.

2.0 CONTROLLING AIR INFILTRATION -- THE STATE OF AFFAIRS AT THE END OF THE 70'S

The federal and some provincial governments initiated a number of programs designed to reduce energy consumption in residential buildings in the late 1970's. These programs included:

- CHIP -- Canadian Home Insulation Program
- COSP -- Canadian Oil Substitution Program
- The Heatline, a phone-in information service for consumers
- Research activities demonstrating "energy efficient" homes

These programs did not directly deal with controlling air infiltration and tended to focus on specific components of the building system.

By the end of the 1970's, building researchers and innovative builders were experimenting with reducing air leakage in houses to control energy costs. A number of well documented projects, such as the National Research Council of Canada's Mark XI houses[5] and the Saskatchewan Conservation House[6], as well as many individual projects, illustrated that achieving air change rates of 1.5 ACH at 50 Pa was possible and that energy could be conserved without loss of comfort.

2.1 Early Problems

Unfortunately, another major lesson of the early learning process was that, if the air sealing was not done properly, serious problems could result. Problems encountered with some "energy-efficient" homes built during the late 70's included:

- Poor ventilation and high humidity levels caused because needed ventilation was not being supplied. Associated with this was the possible build up of air contaminants that had been dissipated at higher levels of air infiltration.
- Condensation related water damage inside the building envelope. Even small amounts of leakage of humid air into areas where condensation could occur can result in damage or rot to structural parts of a building. Increased insulation levels could exacerbate the problem.
- Negative pressures developing in the house as a result of exhausting appliances operating in conjunction with a tighter building envelope. This could cause combustion appliances to spill combustion gases into the house.

As a result of the early research and developmental work on air infiltration, a number of conclusions were drawn:

- There is a need to positively control ventilation rather than allow it to occur accidentally through natural forces. Natural ventilation results in too much ventilation occurring at some times and inadequate ventilation occurring at other times.
- There is a need to address all locations of air leakage, not just the total amount. Small amounts of leakage into inaccessible areas can lead to serious rotting problems.
- The location of the air and/or vapour barrier is critical. Moisture damage can be exacerbated rather than reduced if the barrier is incorrectly located. To correctly locate and install the air and/or vapour

barrier requires a sound understanding of the building science principles involved -- a knowledge not previously required of builders.

- The combustion air and venting pressure requirements of fuel-burning appliances had to be recognized.

One important outcome was a general recognition that the house operates as a system in which changes in one component can affect the functioning of other components. With building envelopes in particular, it was recognized that they were a series of barriers to heat flow, air flow and vapour flow and, while each has its own requirements, they did interact.

The early problems proved to be surmountable and the successful efforts at controlling air infiltration demonstrated that, if it was done right, a better, more energy-efficient house could be built. To encourage such construction required more research and the overcoming of two major factors: the lack of knowledge on the part of most builders of the building science issues involved and the limited availability of equipment, tools and materials to do the job correctly. In Canada, government and industry chose to work together to overcome these factors and demonstrate that well-sealed, cost-effective homes could be built on a routine basis.

3.0 GOVERNMENT AND INDUSTRY WORKING TOGETHER IN THE 1980'S

Overcoming the early problems and transferring the knowledge to the building community was not a simple, pre-defined process. It required a co-operative, integrated process of research and development, demonstration and monitoring, education and legislative initiatives -- a process that is still ongoing.

3.1 Research

Various Federal government agencies, including Energy, Mines and Resources Canada (EMR), the Canada Mortgage and Housing Corporation (CMHC), the National Research Council, Canada (NRC); the Provincial ministries of Energy and Housing; industry groups such as the Canadian Home Builders' Association (CHBA); and manufacturers of relevant products sponsored or undertook research into the mechanisms of air infiltration, how to reduce it and the impact of reducing it. Specific research included:

- studies to understand the movement of air and vapour through the building envelope[7 8 9];

- the development of techniques which provided the necessary air barrier without compromising the other functions of the building envelope. The range of techniques developed included methods which used a combined polyethylene air/vapour barrier and ones which separated the functions, such as the "Airtight Drywall Approach"[10];
- the development of products such as spun bonded oleofin membranes which act as an air barrier but not a vapour barrier;
- modelling of air infiltration in houses[11] and heat loss from houses[12];
- studies on the prevalence, impact and causes of combustion product spillage from fuel-fired appliances[13 14 15];
- the development of heat recovery ventilators and other controlled ventilation systems.

As knowledge of the appropriate techniques for sealing building envelopes became available and suitable building products came onto the market, experimental and innovative builders began promoting low-energy construction. The Federal and provincial governments established programs to encourage further developmental research, educate builders and demonstrate to the public and builders the advantages of building energy-efficient homes which included infiltration control.

3.2 Demonstration Activities

It was observed that the Canadian building industry has tremendous inertia and did not readily embrace the concept of the energy-efficient house. To encourage more energy-efficient construction, education and promotion programs were needed. One prime example is the R-2000 Program established in 1982 by the Federal Government through Energy, Mines and Resources Canada. The goal of the Program was to demonstrate that building safe, comfortable, energy efficient housing was practical and affordable.

The R-2000 Program set a standard for houses based on the performance of the house. The key elements of the performance standard were:

- The house must be built by an approved R-2000 builder who has attended a special training course offered by the Program.
- The house must meet an energy budget established through the use of a simulation program. HOTCAN, developed by the National Research Council, Canada, was the simulation program used at first. It was later modified and refined for use by the R-2000 Program and renamed HOT2000[12].
- The plans for the specific house must be examined by a certified Plans Evaluator.
- The house must have a continuously operating mechanical ventilation system[16].

- The house must be tested for air leakage when complete and have an air leakage rate of less than 1.5 ACH at 50 Pa.

The focus of this performance standard has not changed since 1982, however, the standard has not remained static -- it has evolved as more knowledge has became available. For example, the use of the HOT2000 simulation program has expanded the range of house construction techniques and equipment that can be modelled and the ventilation standard has evolved based on actual monitored data.

The R-2000 Program has incorporated a wide array of functions, from validating early assumptions to developing an extensive training program. The Program has had to deal with quality assurance issues and has undertaken research into wide areas of building science to provide the considerable technical backup required.

The Program has taken an active roll in the development of new standards for the construction industry. As well, in conjunction with other agencies and groups, the Program has undertaken a comprehensive marketing plan to raise the public's awareness of the Program and its benefits.

The Program did not function in a vacuum -- other groups and agencies worked with and complemented the efforts of the R-2000 Program. The Canadian Home Builders' Association administers the program and ventilation training courses have been developed for them by the Heating, Refrigerating and Air Conditioning Institute of Canada[17]. Valuable research and program direction has been provided by CMHC and NRC.

A number of complimentary demonstration programs were undertaken as well. The Flair Homes Demonstration Program[18 19] is one notable example involving twenty homes which were built using different techniques to achieve tight building envelopes, energy-efficient and comfortable environments with good air quality.

3.3 Monitoring and Evaluation

Confirming that energy-efficient homes, such as R-2000 homes, work as advertised was an important facet of the improvement process. An extensive monitoring program was undertaken of the first 300 R-2000 homes registered to the Program and a number of conventionally built homes[20]. A dossier is maintained for all registered R-2000 dwellings. The information gathered forms one of the best data bases available on the performance of low-energy homes. Many other organizations have undertaken monitoring activities, as well.

The monitoring has contributed valuable feedback on the products and techniques used to build low-energy homes. The early manufactured heat recovery ventilators (HRVs) for example, had problems that were, in part, detected through monitoring the early R-2000 homes. It turns out that a major factor in HRV failures was inconsistency in the installation of the HRVs. The outcome has been the introduction of the HRV Installers' Course[17] by the HRAI with a resulting significant improvement in their field operation.

Through the monitoring programs and the ongoing analysis undertaken by various research groups, a number of concerns were raised and addressed.

One concern was the impact of well-sealed dwellings on the operation of combustion appliances. With the well-sealed house, it was suggested that, under certain conditions, combustion gases could spill into the house rather than go up the chimney due to the depressurization of the house. Simulation models have been developed by CMHC[13] and a number of field studies were conducted[14]. It has been found that the incidence of actual venting failure is low but significant, particularly when natural venting appliances are used in well-sealed houses. To avoid this problem, the current gas code requires the provision of outside combustion air for gas burning appliances.[21] Naturally aspirating appliances are not allowed under the R-2000 Program.

As energy consumption values and air quality statistics became available in the mid 1980's, the R-2000 Program, along with other interested parties, (for example, the Ontario Ministry of Energy, manufacturers and electrical utilities) began to actively promote R-2000 concepts to builders and the general public.

3.4 Education and Training

By the mid 1980's it was obvious that a good "product" (a variety of mechanisms and building techniques) had been developed to build tight, energy-efficient houses. However, there was a need to get the information on that product out to builders and establish a market with the general public. Again, government agencies took the lead in co-operation with industry.

In 1985, to more heavily involve builders and increase their awareness of the Program, the mandate for managing the implementation of the R-2000 Program was transferred to the Canadian Home Builders' Association from Energy, Mines and Resources Canada. A series of nation-wide Builder Workshops was instituted.

To date, this course has been attended by more than 12,000 people representing all facets of the building industry. The two or three day training course is important. The topics covered include the appropriate and best techniques for air/vapour sealing and the concept of the controlled supply of air through the use of mechanical ventilation equipment. By enforcing a high level of competence on the part of the builder, many of the earlier problems encountered with the construction of well-sealed houses could be avoided -- along with any negative publicity.

Energy, Mines and Resources Canada also developed courses for renovators[22] and for instruction in community colleges and trade schools.

The Canada Mortgage and Housing Corporation also sponsored training courses for builders of new buildings and for renovation contractors[23 24] They also publish a great number of publications on good construction practice. These are targeted at both builders and homeowners.

The Department of Building Research (DBR) of the National Research Council, Canada was also active. DBR sponsored a series of seminars called "Building Science Insight" and provided a great deal of information in the form of research reports and other various series-type publications.

As well, industry was encouraged and financially supported to offer training and education programs. The Heating, Refrigerating and Air Conditioning Institute of Canada, for example, conducted courses to train the correct procedures to installers for installing and commissioning HRVs[17].

Educating the builder about the features of the energy-efficient, well-sealed house was not a simple process due to the fragmentation and inertia of the building industry. An integral part of the process was to educate the consumer -- the home-buying public -- to request an energy-efficient, well-sealed product.

Advertising campaigns sponsored by the R-2000 Program, home builders, product manufacturers, provincial agencies and utilities promoted the concept of the energy-efficient, well-sealed house. The provincial home builders' associations presented annual home tours. Energy, Mines and Resources Canada, in conjunction with TV Ontario, produced a series of programs entitled "R-2000 The Better Built House". Newspaper and magazine articles documented the merits of living in a well-sealed house and R-2000 homeowners recommended R-2000 houses to their friends.

The proof of the success of the process has been in the demand by home purchasers for the concepts promoted through the advertising campaigns. The current Canadian home buyer is much more conscious of the levels of insulation used in construction, how well sealed the house is and the quality of the windows and doors.

Further proof of the success of the education and training campaign is the broad range of equipment and products available to control air leakage and, therefore, energy costs, and to provide needed ventilation. Equipment, such as prepackaged HRVs and high efficiency furnaces, and materials such as spun bonded oleofin membrane air barriers, gasketing, electrical box enclosures and other assorted products for both polyethylene and air tight drywall approaches (ADA) to air sealing are all readily available across Canada.

3.5 Codes and Standards

As the demand for a well-sealed, energy-efficient housing product has increased, so has the concern that the public be provided with safe habitation. Air and vapour barriers must be installed correctly and in the appropriate location, combustion appliances must receive adequate supplies of outside air and mechanical ventilation equipment must be installed correctly.

In a number of instances, the requirements and standards developed and instituted for projects such as the R-2000 Program have been, or are in the process of being, incorporated into national and provincial building codes and standards. In a sense, the voluntary standards of these programs provided a breeding ground for producing national standards and regulations for the building industry as a whole.

Some of the most significant codes and standards developed over the last decade that relate to the control of air leakage through the building envelope include:

CAN/CGSB-149.10-M86
Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method
Canadian General Standards Board
This standard details the procedure for using a fan to determine the equivalent leakage area of the building envelope through the use of a calibrated fan test apparatus.

CAN3-A440-M84
Windows - Building Materials and Products
This standard defines the performance of windows, regardless of the material of construction. It addresses performance tests and outlines the standards for air leakage, water leakage and wind load resistance.

CAN/CSA-C444-M87
Installation Requirements for Heat Recovery Ventilators
Canadian Standards Association
This standard applies to the installation requirements for self-contained ducted heat recovery ventilators for new and existing buildings. It applies to equipment selection, minimum installation requirements and the information to be provided to the purchaser.

CAN/CSA-C439-M88
Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators
Canadian Standards Association

This standard documents a procedure developed for testing and rating the ventilation and energy performance of heat recovery ventilators under standard conditions including a cold weather test (to -25°C and, more recently, to -40°C). The most important output of this standard is the independently produced design information for designers and builders.

CAN/CGSB-51.34-M86
Vapour Barrier, Polyethylene Sheet for Use in Building Construction
Canadian General Standards Board

A revision of the previous standard outlining the minimum criteria polyethylene sheet must meet to be acceptable as a vapour barrier. It now incorporates provisions for resistance to thermal decay.

CAN/CGA-B149.1-M86
Natural Gas Installation Code
National Standard of Canada

This standard contains a specific requirement for the provision of combustion air to gas burning appliances. The standard specifies the free area of the outdoor air supply required according to the rating of the total appliances in the structure or enclosure.

CSA Preliminary Standard F326.1-M1989
Residential Mechanical Ventilation Requirements
Canadian Standards Association

This preliminary standard defines the requirements for mechanical ventilation systems whose purpose is to provide the minimum controlled rates of ventilation air to the habitable spaces of self-contained single-family dwellings. Research and findings from the R-2000 Program provided important background to the development of the standard.

National Building Code of Canada
(the model for provincial codes)
Associate Committee on the National Building Code, National Research Council, Canada

The 1985 version of this code required that the vapour barrier be sealed. This, in effect, made it as air barrier, as well.

Three proposed revisions to the 1990 version of the code will have an impact on the control of air leakage through the building envelope. These include:

- Revised wording which recognizes the different functional requirements of the air and vapour barrier systems in the building envelope and requires a continuous air barrier.

- A requirement that a ventilation system capable of operating at an average continuous rate of 0.3 air changes per hour be installed in houses.
- Radon protection measures which include the sealing of all below grade entry points, a membrane under the floor slab and a gravel layer under the slab.

4.0 THE FUTURE

Although the various segments of the Canadian building industry have made a great deal of progress over the last decade in understanding and controlling unwanted air leakage in buildings, significant further advances are expected. Demonstration programs have proven that air tightness levels of 1.5 ACH at 50 Pa and space heating energy savings of 50 to 75 per cent after 1980 levels are achievable. As many of the developed concepts and techniques are incorporated into existing building codes and standards, all new housing will achieve the benefits of air leakage control.

Already the difference between regular, tract-built housing and energy-efficient homes, such as the R-2000 homes, is diminishing. It is not unusual to find tract built houses which meet R-2000 air tightness standards. It is logical to project that the average difference will continue to diminish to the point where it will be insignificant.

The changes in new building stock have already made a significant improvement in Canada's energy future. There is still room, however, for future developments in controlling air leakage, particularly in dealing with the existing housing stock. The lessons that have been learned about the importance of controlling air leakage and how best to do it can equally be applied to existing houses with some modifications. This process has already started in a significant fashion. Other concepts are also being explored including the "dynamic wall" approach[25] in which air leakage is not eliminated but rather controlled and used to advantage.

Continued development is expected in improved, cost-effective ventilation systems which meet the needs of consumers and Canada's harsh climate.

Probably the most important element in this transformation is the fact that a large and growing pool of engineers, architects, builders and trades contractors have been part of the process and have received the benefits of the improved knowledge and training in building energy-efficient houses. These people are ultimately the group which will have the greatest impact on the future of the Canadian housing industry.

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