AIRTIGHTNESS TESTING AND AIR FLOW MODELLING OF A THREE-UNIT MULTIFAMILY BUILDING

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ABSTRACT

Older multifamily buildings offer a great opportunity for energy savings because they are typically poorly insulated and not airtight. Weatherization programs, such as Hydro-Quebec's *ISOLACTION* program, have recently targeted this building stock. These programs and the emergence of the renovation market have created a need for practical tools that can be used by the building industry to evaluate the impact of retrofits on energy and ventilation.

This paper presents a ventilation case study for a three-unit multifamily building. Both the external and the inter-unit air leakage characteristics of the building were obtained using a single-fan blower door method. This method produces significantly more valuable data than is currently obtained with the whole building depressurization technique. A steady state ventilation model was used with the in-situ test results to investigate the outdoor air distribution and the impact of exhaust ventilation on a unit-per-unit basis.

INTRODUCTION

Background

Energy use in housing has been the focus of numerous research studies in Canada. So far, the majority of Canada's energy efficiency initiatives have focused on new construction. However, the emergence of the renovation market has shifted interest to the energy efficiency potential of existing housing. This potential was the focus of the recent Hydro-Quebec weatherization program called *ISOLACTION*, which was completed in 1998.

Approximately 1000 low-rise multifamily buildings in the Montreal region were retrofitted as part of the *ISOLACTION* program. The Montreal region was targeted because of its urban environment, which is significantly different from that of other large Canadian cities. A large proportion of the urban building stock in Montreal consists of two and three unit buildings constructed prior to 1970. A distinguishing feature of these dwellings is that individual units usually have separate entrances and civic addresses, as detached houses do.

ISOLACTION brought to light the need for practical methods and tools, which can be used to evaluate the impact of energy measures on ventilation. A sponsoring agency, such as Hydro-Quebec, is responsible for the impact of work on the overall building performance. Ventilation is of particular concern due to the obvious link with occupant heath. A program sponsor must ensure that the retrofit work does not lead to inadequate ventilation.

To gauge the impact of energy retrofits on ventilation for multifamily buildings, both the airtightness of the building shell and of partitions between units must be considered. The performance of ventilation systems, particularly exhaust fans, also depends on the airtightness of both the exterior shell and the interior partitions.

Originally developed as research tools, fan pressurization doors (blower doors) have proven their worth as practical and effective tools for the housing industry. The blower door consists of a heavy-duty fan, pressure and airflow meters, and a supporting frame (figure 1). They have been used extensively to test the airtightness of detached homes in programs and research studies sponsored by agencies such as Natural Resources Canada (NRCan), the Canadian Mortgage and Housing Corporation (CMHC) and Hydro-Quebec. However, blower door testing of multifamily buildings is not widespread.

Standard CAN/CSGB-149.10, *A Method for Testing the Airtightness of Buildings by the Fan Depressurization Method*, provides a methodology for determining the airtightness of the exterior envelope. Other standards include ASTM Standard E779-87, *Test*

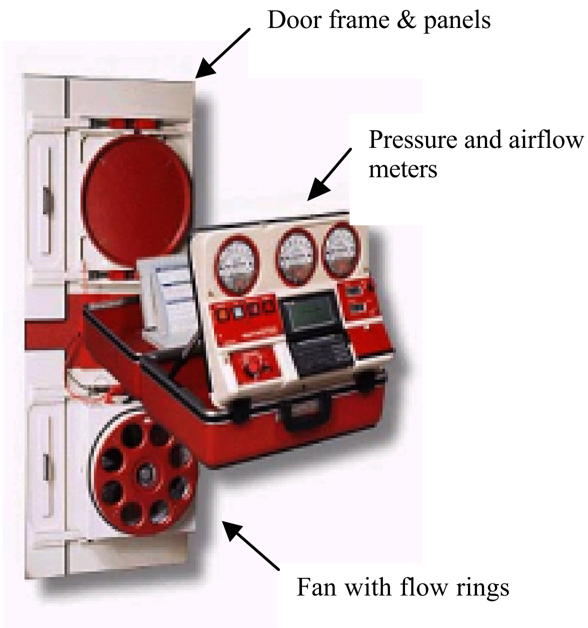

Figure 1. Retrotec Blower Door

Method for Determining Air Leakage by Fan Pressurization and ASHRAE Standard 119, *Air Leakage Performance for Detached Single-Family Residential Buildings*. These standards to not address the interior partitions of multifamily buildings. On a practical note, whole building depressurization of multifamily buildings is not cost effective within the scope of a weatherization program.

Several studies have focused on the measurement of interzonal and envelope air leakage in multi-unit buildings. Sheltair Scientific (1987) tested six different approaches for the R2000 Program and the British Columbia Home Builders Association. At the time of the report, a number of multifamily R2000 developments were under construction in British Columbia. Modera and Herrlin (1990) analyzed a two-fan pressurization technique for measuring the interzonal leakage in a multi-unit building. Love (1990) used a similar two-fan technique to test the airtightness of row houses in Calgary, Alberta. Blasnik and Fitzgerald (1992) present methods for diagnosing complex air leakage paths using blower door induced pressures. Tuluca and Sherman (1995) evaluated two single-fan methods and a two-fan method. This research focused on the applicability of these methods for New York State apartment buildings. DePani (1999) defined and evaluated three single-fan methods suitable for Montreal's multifamily building stock. The single-fan methods were benchmarked against a two-fan approach on four case study buildings. One of these compared favorably with the two-fan method.

Objectives

The objective of this paper is to present a ventilation case study for a low-rise multifamily building with three units, typical to Montreal's building stock. The paper aims to demonstrate how blower door test results can be used with a simple modelling tool to investigate ventilation as a function of outdoor temperature and wind speed, on a unit-per-unit basis.

METHODOLOGY

Single–fan Blower Door Method

The single-fan method used in testing the case study building was developed and tested by DePani (1999). The method can be used to test the three building configurations typical to Montreal low-rise multifamily buildings (figure 2).

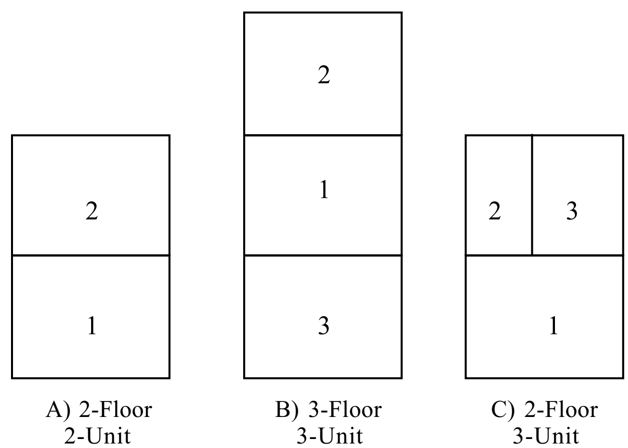

Figure 2 Typical Configurations for Montreal Low-rise Multifamily Buildings

The single-fan method uses a single blower door combined with pressure measurements in adjacent units to calculate the airtightness of the building envelope and of the interior partitions between units. Tests are performed with each unit depressurized in turn to 50 Pa pressure difference. Equations are obtained by balancing airflows through the exterior envelope and the interior partitions, using the power law airflow equation:

$$Q = CP^n$$

Where:

Q = airflow through the leakage path, l/s,
C = flow coefficient of the leakage path, l/(s*Pa^n),
P = pressure difference across the leakage path, Pa,
n = flow exponent of the leakage path, dimensionless.

The flow exponent is assumed to be 0.65, which is the value commonly used in industry for single point blower door tests. When fitting depressurization test data to buildings, the value of n generally lies between 0.6 and 0.7 (ASHRAE Fundamentals, 1993). It is assumed that the flow coefficient C does not vary with the leakage direction through a flow path (no directional valve effect). Current standards and blower door manuals do not specify the measurement of the directional valve effect when establishing the airtightness of buildings (Energy Conservatory, 1996).

The testing protocol for the single-fan method starts with the blower door installed in unit 1. The unit is depressurized to a pressure difference of 50 Pa and the change in pressure to the other units is measured (with respect to initial baseline pressures). The test is repeated with the blower door installed in unit 2 and then in unit 3. The protocol and the flow paths are illustrated in figure 3.

Balancing the flows for units 1,2 and 3, for test A,

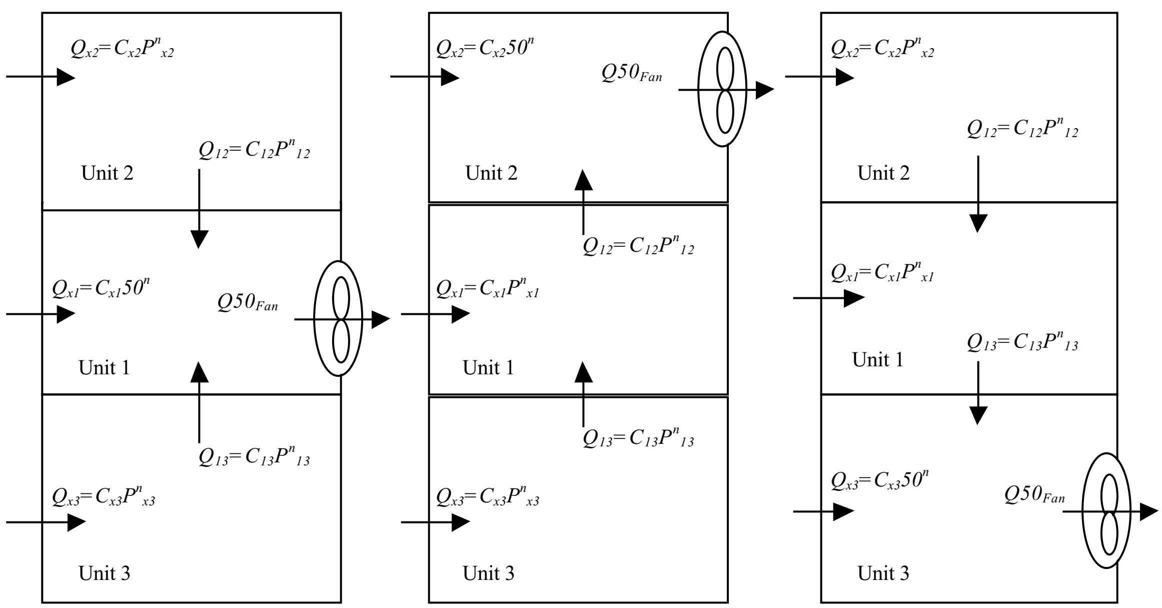

Figure 3 Single-fan protocol

gives us the following equations:

$$C_{x1}50^n + C_{12}P_{12}^n + C_{13}P_{13}^n = Q50_{Fan} \quad \textbf{(1)}$$

$$C_{x2}P_{x2}^n + C_{12}P_{12}^n = 0 \quad \textbf{(2)}$$

$$C_{x3}P_{x3}^n + C_{13}P_{13}^n = 0 \quad \textbf{(3)}$$

The 4th and 5th equations are obtained by balancing the flows in the unit with the blower door in tests B and C:

$$C_{x2}50^n + C_{12}P_{12}^n = Q50_{Fan} \quad \textbf{(4)}$$

$$C_{x3}50^n + C_{13}P_{13}^n = Q50_{Fan} \quad \textbf{(5)}$$

Equations 1 through 5 can be solved with linear algebra techniques to obtain the five unknown flow coefficients C.

The equivalent leakage area (ELA), normalized leakage area (NLA), liters per second at 50 Pa pressure difference (l/s50) and air change at 50 Pa pressure difference (ACH50) can be derived from the flow coefficients.

Computer model

A computer model was used in conjunction with the single-fan blower door test. Multi-unit airflow models are needed to analyze natural and mechanical ventilation rates on a unit-per-unit basis. Most existing airflow modelling tools were designed for research work and are not well suited for use by weatherization teams. The model presented in this paper has a simple graphical interface (figure 4), which requires limited data entry. With further development, this model could be used in-situ to evaluate ventilation in multifamily buildings.

The configuration shown in figure 4 has 3 units, one of which is a basement apartment. Air movement is modeled with 13 nodes. Inter-unit leakage occurs through one direct leakage path between the units. The basement unit is connected to the outside via leakage paths at ground level. The other units have four leakage paths on the exterior walls, two located at one third of the floor height and two located at two thirds of the floor height. The top unit has an additional leakage path through the ceiling. Half of the leakage paths face the wind and the other half are opposite the wind. Each unit also has an exhaust fan. The program solves a set of three non-linear equations with 3 unknowns (unit pressures), using the Newton Raphson iterative approach (Kreyszig, 1983).

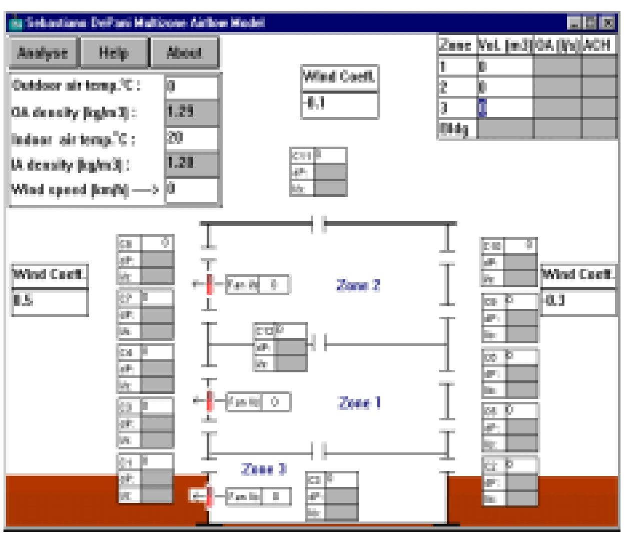

Figure 4 Multizone Airflow Model

CASE STUDY

Building description

The case study building is located at 8399 Dunant in Montreal. It is a semi-detached 3-unit building constructed in 1969 (figure 5). It contains one main unit, which occupies the ground floor and part of the basement. Another unit occupies the 2nd floor and a smaller 3rd unit is located in the basement. The floor areas, volumes and envelope areas are summarized in table 1.

Figure 5 Case Study Building

Table 1 Building Takeoffs

	Unit 1	Unit 2	Unit 3	Total
Floor Area (m^2):	170	135	50	355
Envelope Area (m^2):	165	248	35	448
Volume (m^3):	440	329	122	891

Single-fan blower door test results

The single-fan blower door method was used to obtain the flow coefficients C. These coefficients are presented in table 2, along with other derived data.

Table 2 Flow Coefficients and Derived Data

Leakage Path	*C* $l/(s*Pa^n)$	l/s50	ELA (cm^2)	ACH50
Exterior - Unit 1	101.2	1286	1808	10.5
Exterior - Unit 2	113.7	1446	2031	15.8
Exterior - Unit 3	30.6	389	547	11.5
Unit 1 - Unit 2	38.7	492	691	-
Unit 1 - Unit 3	26.2	333	467	-
Total Envelope	245.5	3121	4385	12.6

The results indicate that the building is quite leaky, with 12.6 air changes per hour at 50 Pa pressure difference. The top unit was the leakiest, which was expected since it is directly below the attic space. The results also show that the units are relatively well connected, meaning that air movement between units will have an important influence on ventilation.

SIMULATIONS

Simulations were performed to demonstrate how the blower door test results could be used with a computer model to provide information on the following relationships:

1. Outdoor air change as a function of outdoor temperature and wind conditions.
2. Outdoor air change following weatherization work, which reduces the air leakage through the roof.
3. Outdoor air drawn through the envelope of each unit by an exhaust fan installed in the top unit.

Simulations were carried out at outdoor temperatures of -20, -10, 0 and 10°C. Two wind conditions were simulated: calm (no wind) and light wind (10 km/h) conditions.

Leakage distribution

The blower door test data provides the flow coefficients of the exterior walls and interior partitions. However, the tests don't indicate how the leakage area is distributed within the units. Leakage distribution is important when modelling natural and mechanical ventilation because the pressure gradient due to stack and wind pressures is not constant. For the purposes of the simulations, the leakage area was distributed as follows:

- In unit 3 (basement), the exterior leakage area was split evenly between the two leakage paths to the outside.
- In unit 1 (first floor), the exterior leakage area was split evenly between the four exterior leakage paths to the outside.
- In unit 2 (2nd floor), half the exterior leakage area was located at the ceiling node, the remaining leakage area was split evenly between the four leakage paths on the exterior walls.

Simulation Results

The first set of simulations demonstrated natural ventilation trends on a unit-per-unit basis for the existing building (figures 6 and 7).

The second set of simulations demonstrated the impact of sealing the attic space (figures 8 and 9). A common retrofit used in the *ISOLACTION* program consisted of insulating and sealing the attic space with high-density cellulose fiber. In most cases, this technique reduced air leakage through the attic space by 85-95%. For the purposes of this study, it was assumed that the leakage area through the attic space was reduced by 90%.

A third set of simulations demonstrated the impact of a 50 l/s exhaust fan placed in unit 2 of the retrofitted building (figure 10). Exhaust fans are often used in these older buildings for ventilation purposes.

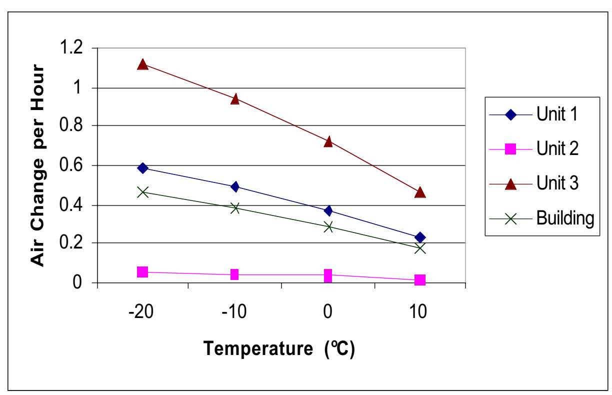

Figure 6 Natural Ventilation - No Wind

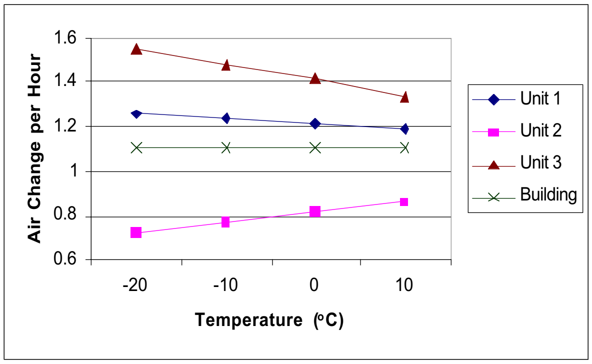

Figure 7 Natural Ventilation - 10 km/h Wind

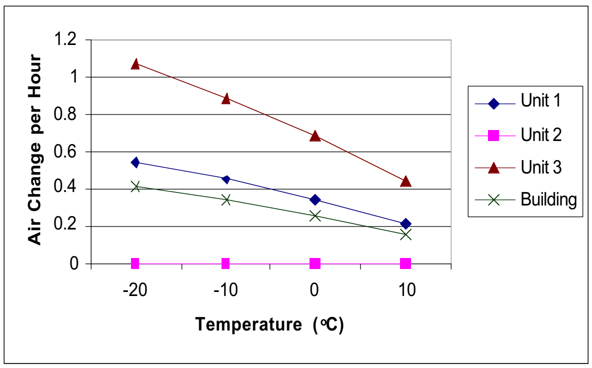

Figure 8 Natural Ventilation - Post-retrofit No Wind

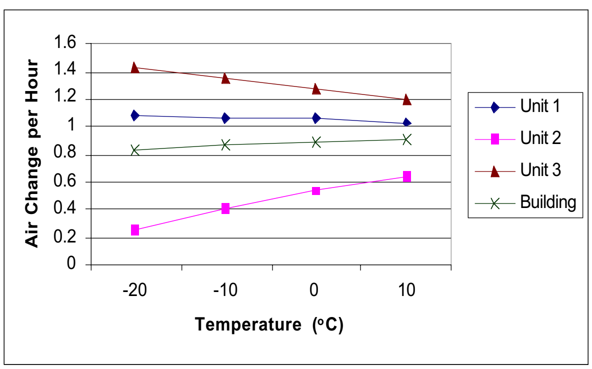

Figure 9 Natural Ventilation - Post-retrofit 10 km/h Wind

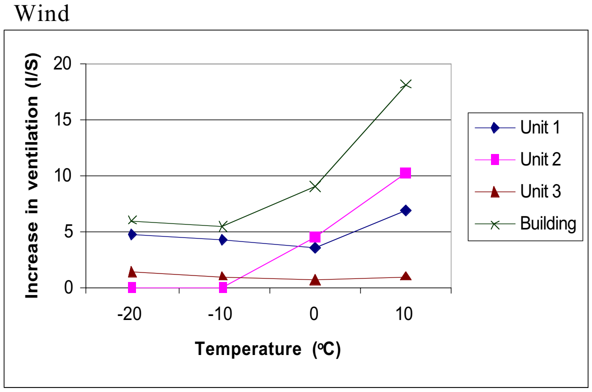

Figure 10 Increase in Ventilation with 50 l/s Exhaust Fan in Unit 2 - Post-retrofit No Wind

Discussion of Results

The key findings are summarized below:

- **A unit's location within the building will influence its ventilation rate.**
  Where units are relatively well connected, the stack effect will affect how outdoor air is distributed. In the absence of wind, ventilation rates for unit 2 were below the 0.35 ACH required by the National Building Code (figure 6).

- **The relationship between ventilation and outdoor temperature is influenced by the unit's location within the building.** With a 10 km/h wind, ventilation for units 1 and 3 decreases as outdoor temperature rises but the opposite occurs in unit 2. Ventilation rates converge as the outdoor temperature approaches the indoor temperature (figure 7).

- **Sealing the attic has an important impact on the outdoor air supplied to the top unit.**
  Weatherization work in the attic lowers the neutral pressure plane. In the absence of wind, unit 3 (top unit) experiences only exfiltration when the neutral pressure plane is lowered below the level of the leakage paths in the top unit (figure 8). Even with a 10 km/h wind, unit 3 may receive much less fresh air than the other units (figure 9).

- **For buildings with well connected units, exhaust fans are ineffective in bringing outdoor air to the top unit.** When the units of a building are well connected, as was the case with the case study building, exhaust fans draw little or no outdoor air directly through the envelope of the top unit. As the outdoor temperature approaches the indoor temperature, the exhaust fan draws more outdoor air into the building. With an outdoor temperature of 10°C, the exhaust fan draws only 10 l/s of additional outdoor air through the envelope of unit 2 and 18 l/s through the envelope of the entire building (figure 10).

CONCLUSIONS

This paper presented a case study where the leakage characteristics of both the exterior envelope and the interior partitions of a three-unit building were obtained with a single-fan blower door method. This method relies on airflow measurements using one blower door, combined with pressure measurements in adjacent units.

This paper also presented a graphical airflow model developed for multifamily building configurations typically found in the Montreal area. The model can be used with the results of the single-fan blower door test to investigate ventilation trends on a unit-per-unit basis. The model can also be used to study the impact of retrofit measures on natural ventilation, the need for mechanical ventilation and the potential for energy savings.

The simulation results showed that ventilation depends on both the exterior envelope and the interior partitions. In cases where the partitions are relatively leaky, the tendency is for the top floor unit to receive much less outdoor air then the other units. Even though the building-has-a-whole meets code requirements for air-change rate, the top unit may only receive air from adjacent units, leading to local indoor air quality problems.

ACKNOWLEDGEMENTS

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