A Proposed Test Procedure for Separating Exterior Envelope Air Leakage from Interior Partition Air Leakage

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ABSTRACT

A new airtightness test procedure has been proposed that can be used to separate exterior envelope air leakage from interior partition air leakage when testing a single zone within a multi-zone building. The new technique does not eliminate partition leakage but permits it to be measured and then subtracted from the overall leakage of the zone, thus permitting the exterior envelope leakage to be quantified. Exact equalization of pressure differentials across interior partitions is not required, only modification of the pressure differentials. Further development is ongoing.

INTRODUCTION

Air leakage across the building envelope is a key factor in determining a structure's longevity, functionality, and future maintenance requirements. Excess air leakage can lead to accelerated envelope degradation (due to moisture deposition), increased energy costs, a less comfortable living space, as well as increased noise and dirt transfer from the outdoors. In Canada, the financial impact of envelope air leakage is estimated to be several hundred million dollars per year.

Over the last 20 years, the blower door test has emerged as a valuable tool for determining the airtightness characteristics of smaller buildings, such as single detached houses, and for identifying air leakage sources that may have been missed during the construction or retrofit process. Using protocols such as CGSB 149.10 (CGSB 1986) and ASTM E 779 (ASTM 1992), thousands of tests are performed each year in North America, most for commercial purposes. For houses, which are basically single-zone structures, the test procedure is straightforward: the house is pressurized or depressurized using a high-capacity fan and the air leakage rate is measured at various indoor-to-outdoor pressure differentials. A mathematical correlation is then developed that relates air leakage to the indoor-to-outdoor pressure differential. This permits the airtightness of different buildings to be compared using a suitable leakage parameter at a standardized pressure differential. For larger buildings, protocols such as CGSB 149.15 (CGSB 1996) have been developed, which use the structure's existing air-handling equipment to provide the necessary pressurization or depressurization.

However, if the test is performed on a multi-zone building, such as a duplex, row house, or apartment, or if only one zone of a building is of interest, these protocols cannot be used since the test is unable to distinguish the air leakage that occurs through the exterior envelope from that which occurs across the interior partitions. For these situations, other techniques must be used. The approach currently used to separate exterior envelope leakage from interior partition leakage involves the use of additional blower door(s) to provide simultaneous "pressure-masking" across interior partitions (Reardon et al. 1987). This requires the use of an additional fan(s) to eliminate partition leakage by exactly neutralizing the pressure differential across the partition. In large buildings this may be difficult since it could require a very large fan to provide the pressure-masking. As a result, the technique is seldom used other than for the occasional research project. The absence of a simple and inexpensive test method for multi-zone buildings has hampered the development of airtight construction methods in these types of structures. As a result, they are usually not

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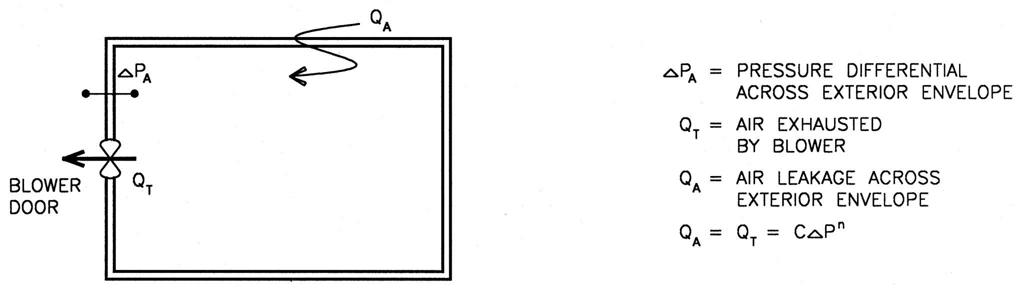

Figure 1 *Single-zone case.*

Figure 2 *Multi-zone case.*

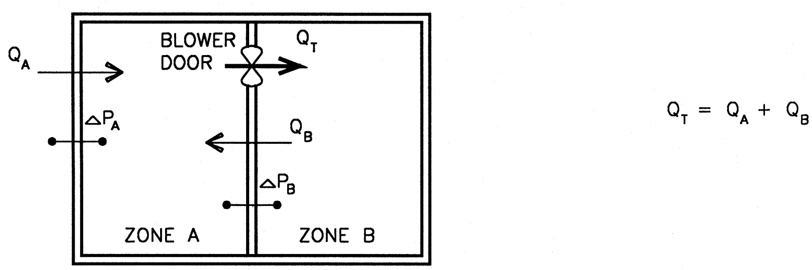

Figure 3 *Typical test configuration.*

constructed to the same level of airtightness routinely achieved in houses (Proskiw and Phillips 2001). Hence, envelope degradation is accelerated, energy costs are increased, drafts are more prevalent, and noise and dirt transmission from the outdoors is increased. To deal with this problem, a new test method is proposed that can isolate exterior building envelope air leakage from interior partition leakage in multi-zone buildings but does not require exact equalization of the partition pressure differentials—only that they can be modified by the second fan.

DESCRIPTION OF THE PROBLEM

The difficulty associated with measuring exterior envelope air leakage in multi-zone buildings can be better understood by examining Figures 1 and 2. In a single-zone structure with no significant internal partitioning, the airflow exhausted from the structure can be easily measured at the blower door. A sufficiently large indoor-to-outdoor pressure differential is chosen such that the entire envelope is subjected to air infiltration (assuming the CGSB protocol is being used—the ASTM procedure allows either pressurization or depressurization). Thus, the rate of envelope air leakage must equal the rate at which air is exhausted by the blower door. This can be correlated to the pressure differential across the envelope and the exercise repeated at various pressure differentials to characterize the envelope leakage.

In a multi-zone structure, the problem is more complicated if the exterior envelope of only one zone is of interest, such as one floor of a multi-story building, i.e., Q_A in Figure 2 cannot be isolated from Q_B.

PROPOSED TEST METHOD

The proposed method solves this problem by using a blower door between the two zones (or, in some cases, in only one zone) and the test setup shown in Figure 3 in which Zone A is of primary interest and Zone B is of secondary interest.

The blower door is used to achieve "initial" pressure differentials across the exterior envelope (ΔP_A) and the interior partition (ΔP_B), both of which are measured and recorded. The indoor-to-outdoor pressure differential in Zone B is then altered (by opening a window, turning on a high capacity exhaust fan, or by other means). This changes the pressure differential across the partition wall (ΔP_B) and, as a result, the flow rate through the blower door (Q_T). Next, the air flow rate through the blower door is adjusted until $\Delta P_{A\ initial} = \Delta P_{A\ final}$ to achieve the "final" condition. Since the flow rate across a flow restriction is proportional to the pressure differential across the restriction, $Q_{A\ initial}$ must equal $Q_{A\ final}$ and the resulting change in air flow through the blower door is due solely to the change in leakage across the partition wall. Expressed mathematically,

$$Q_T = Q_A + Q_B \tag{1}$$

where

Q_T = air flow rate measured at the blower door,

Q_A = air leakage through the exterior envelope in Zone A,

Q_B = air leakage across the interior partition between Zones A and B,

so

$$Q_{T\ initial} = Q_{A\ initial} + Q_{B\ initial}$$

$$Q_{T\ final} = Q_{A\ final} + Q_{B\ final};$$

thus

$$\Delta Q_T = Q_{T\ initial} - Q_{T\ final} = (Q_{A\ initial} + Q_{B\ initial}) - (Q_{A\ final} + Q_{B\ final})$$

but

$$\Delta P_{A\ initial} = \Delta P_{A\ final}$$

so

$$Q_{A\ initial} = Q_{A\ final};$$

thus,

$$\Delta Q_T = Q_{B\ initial} - Q_{B\ final}$$

since

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

$$Q_T = C_P P^n{}_{B\ initial} - C_P \mathrm{P}^n{}_{B\ final}$$

or

$$Q_T = C_P(P^n{}_{B\ initial} - P^n{}_{B\ final}) \tag{2}$$

where

C = flow coefficient of the partition,

n = flow exponent of the partition.

Of the five terms in Equation 2, three are known (ΔQ_T, $\Delta P_{B\ initial}$, $\Delta P_{B\ final}$) and two are unknown (C and n). By repeating the exercise for a different set of conditions (i.e., different values for ΔQ_T, $\Delta P_{B\ initial}$, and $\Delta P_{B\ final}$), the resulting values can be substituted into Equation 2 to yield two equations in two unknowns—i.e., a solvable expression. Thus, the airtightness of the partition can be determined.

Finally, a standard blower door test is performed on Zone A with a door or window open in Zone B thereby exposing all surfaces in Zone A (both interior and exterior) to the same pressure differential. Since Q_B is now known, and Q_T can be measured using the blower door, Q_A can be calculated using Equation 1. Similarly, the leakage characteristics of the exterior envelope of Zone B can be determined.

FIELD TRIALS

Mathematically, the new test procedure is relatively simple. However, to gain better insight into its functionality under field conditions, a series of trials were carried out on actual buildings. Tests were performed on a single detached house and on an indoor swimming pool that formed part of a larger recreational complex.

Single Detached House

The single detached house was configured to function as a two-zone structure with the first zone consisting of the main floor and the second zone consisting of the basement. The proposed procedure was used to measure the total leakage of the exterior envelope in each of the two zones, which were then added and compared to the total exterior envelope leakage measured using CGSB 149.10 (with the house configured as a single-zone building, i.e., with the door between the main floor and the basement open). As shown in Figure 4 four airtightness tests were performed.

Test 1, the standard airtightness test, measured the overall airtightness of the house's exterior envelope. Test 2 used the new technique to measure the airtightness of the partition separating Zones A and B. Tests 3 and 4 measured the combined airtightness of the exterior envelope and the partition for Zones A and B, respectively. By subtracting the partition leakage (Test 2) from the results of Tests 3 and 4, the airtightness of the exterior envelope of Zones A and B was determined. The exterior envelope leakage for Zones A and B was added to give the total envelope leakage for the house, as determined using the new technique. This was compared to the results of Test 1. The results, expressed using the leakage rate at a pressure differential of 50 Pa, are summarized in Table 1.

If the results had been in complete agreement, the envelope leakage rate measured using Test 1 would have been the same as the sum of the envelope leakage rates measured for Zones A and B, as determined using the new method. In fact, the observed difference between the two procedures was –9% (at 50 Pa), suggesting reasonable agreement between the two independent estimates of the envelope leakage.

St. James Civic Center, Winnipeg

The test method was then used to perform before and after airtightness tests on an indoor swimming pool that had received an extensive retrofit to its building envelope to reduce air leakage. The objective of this exercise was to deter-

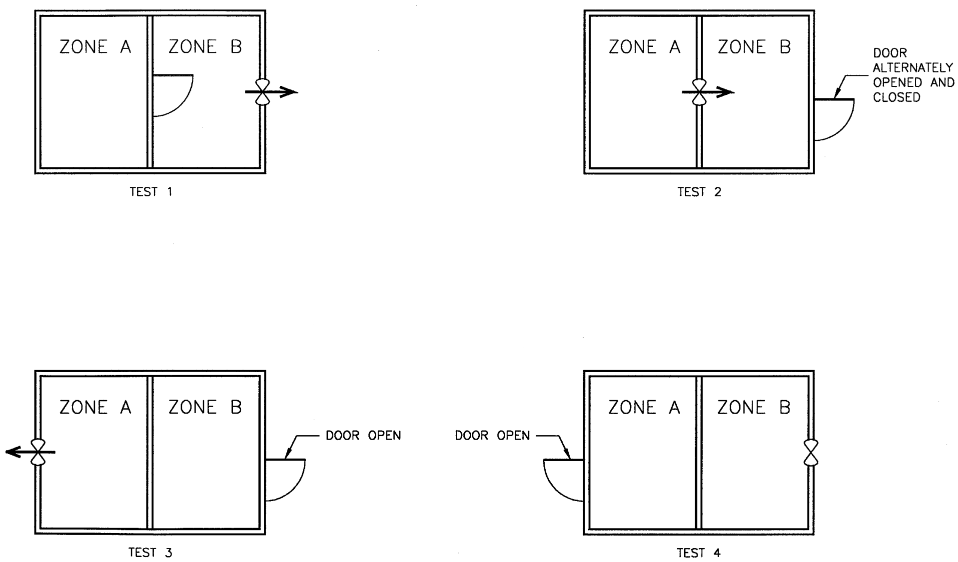

Figure 4

mine the practicality of the new technique when used on a building significantly larger than a house. The test was performed using two commercial blower doors with flow capacities of about 2,500 L/s.

The building used for the evaluation was the St. James Civic Centre located in Winnipeg, Manitoba. This is a recreational complex that contains an indoor swimming pool, auditorium, hockey rink, and other ancillary spaces. The swimming pool portion of the building is attached to the rest of the complex on three sides (two interior walls and the floor). The pool room has a floor area of 492 m^2 and volume of 2,730 m^3. The remainder of the complex is roughly ten times the size of the swimming pool, which would have made it too large to depressurize using the pressure-masking technique and the available equipment. Built approximately 25 years ago, the swimming pool underwent a major renovation in 1999. All of the masonry in the two above-grade walls had to be replaced because of severe structural degradation caused by repeated freeze-thaw cycling, corrosion of metal fasteners, and general degradation of all but the structural steel framework. The retrofit included application of a new, self-adhesive membrane air barrier on the new exterior wall system that was constructed. The new membrane was examined and qualitatively inspected during the construction phase using a blower door and smoke wand. All air leaks that were identified were then repaired. As a result of these extensive measures, it was felt that the air leakage of the new building envelope should be very low.

The test method used the general protocol described above. A blower door was mounted in one of the doorways separating the pool room from the rest of the complex. This blower door was then used to perform a standard CGSB 149.10 airtightness test on the pool room. By opening the main exterior doors to the complex, the pool room could be treated

TABLE 1
Results of Field Trial on Single Detached House

Test	**Leakage At 50 Pa (L/s)**			
	A + B	**Partition**	**A + Partition**	**B + Partition**
Test 1	474			
Test 2		401		
Test 3			648	
Test 4				670
A (Test 3 - Test 2)	648 - 401 = 247 L/s			
B (Test 4 - Test 2)	670 - 401 = 269 L/s			
A + B	247 + 269 = 516 L/s			
Difference: Test 1 - (A + B)	474 – 516 = –42 L/s (–9%)			

TABLE 2
Summary of Results (Initial)

Data Pairs		n	C_p (L/sCPa^n)	Q_{10} (L/s)	Q_{50} (L/s)	Q_{75} (L/s)
a)	b)	0.53	29.8	–7	38	65
a)	c)	0.44	48.6	–40	3	34
a)	d)	0.36	78.9	–85	–44	–10
a)	e)	6.7	?	?	?	?
a)	f)	0.04	?	?	?	?
b)	c)	0.39	61.9	–58	–10	26
b)	d)	0.18	255	–292	–241	–196
b)	d)	0.91	5.39	50	85	85
b)	f)	4.3	?	?	?	?
c)	d)	0.62	22.2	1	24	36
c)	e)	0.58	26.2	–6	22	38
c)	f)	0.64	20.5	5	24	34
d)	e)	0.57	27.5	–8	19	37
d)	f)	0.65	19.5	7	27	36
e)	f)	0.48	44.6	–41	–17	5

as a separate, detached space for the purposes of the initial airtightness test. A second blower door was then mounted in the main entrance door of the building. It was then cycled on and off to produce the "initial" and "final" pressure differential conditions across the common partitions separating the pool room from the rest of the complex. Both blower doors were standard, residential models, which is significant because to use the pressure-masking technique, the second blower door would have required significantly greater capacity since the non-pool portion of the structure was considerably larger, and leakier, than the pool room.

The procedure was then applied with various pressure differentials across the exterior envelope to generate six sets of equations, labeled a) through f), of the form shown in Equation 2. This resulted in six equations in two unknowns (*C* and *n*). By combining any two of the six equations, solutions for *C* and *n* could theoretically be found. This meant that the test produced 15 different combinations of results in which any two of the six equations could be combined to solve for C and n. Once the leakage characteristics of the interior partitions were defined (i.e., *C* and *n*), the partition leakage was subtracted from the overall six-sided leakage of the pool room calculated using the standard CGSB 149.10 airtightness test to give the leakage of the exterior envelope.

Table 2 summarizes the results of the trial. The column headed "Data Pairs" identifies which two of the six equations were used to calculate the results. The "n" and "C" columns show the calculated results for the interior partitions, while the Q_{10}, Q_{50}, and Q_{75} give derived air leakage rates through the exterior envelope of the pool, computed using the derived *n* and *C* values and the standard CGSB 149.10 airtightness test results. The Q_{10}, Q_{50}, and Q_{75} values are expressed in liters per second.

Initial examination of the data in Table 2 shows significant variation in the results. For example, in some instances the flow exponent (*n*) is clearly outside the physically possible range of 0.5 to 1.0. This is reflected in the final results for these cases. However, closer examination of the data shows that all of the "impossible" results (with one exception) are associated with Equations a) or b). If the nine sets of results calculated using these two equations are removed, along with the single set of results calculated using Equations e) and f) (since their *n* value was slightly outside the acceptable range), then five sets of results are left. These are shown in Table 3.

The most obvious question is why were problems encountered with Equations a) and b)? No conclusive reason could be found. The remaining five sets of results in Table 3 show good consistency, particularly at higher pressure differentials. This is encouraging given that the exterior envelope leakage was typically less than 10% of the partition leakage, i.e., the exterior leakage was calculated as the difference between two large numbers, which is not a desirable situation from an experimental perspective.

As a final step, the mean Q_{75} results shown in Table 3 were used to calculate the exterior envelope leakage in units of liters per second per square meter. This is the benchmark referenced in the Appendix and Commentary of Part 5 of the *1995 National Building Code of Canada* for the recommended maximum air leakage rates for air barriers (NRC 1995). Using

TABLE 3
Summary of Results (Final)

Data Pairs		n	C_p ($L/sCPa^n$)	Q_{10} (L/s)	Q_{50} (L/s)	Q_{75} (L/s)
c)	d)	0.62	22.2	1	24	36
c)	e)	0.58	26.2	-6	22	38
c)	f)	0.64	20.5	5	24	34
d)	f)	0.57	27.5	-8	19	37
d)	f)	0.65	19.5	7	27	36

the pool room's exterior envelope area of 828 m^2, this gave an air leakage rate of 0.044 $l/s{\cdot}m^2$ at 75 Pa, whereas the NBC's maximum recommended value for an air barrier system (excluding windows, which were present in the pool room) is 0.05 $l/s{\cdot}m^2$ at 75 Pa for buildings with warm side relative humidities exceeding 55% (such as a pool). As an aside, one of the authors recently completed a literature survey of airtightness data on larger buildings. The retrofitted St. James Civic Centre Pool had the lowest measured leakage rate of the 192 buildings identified in the survey.

The total time on site to set up and complete the tests was approximately seven hours, although the vast majority of this was devoted to sealing approximately two dozen ductwork penetrations into the pool room plus several doors and other openings. Once this had been completed and the equipment set up, the time to perform all of the airtightness tests was approximately one hour.

The experience with the new test method was encouraging. While much of the collected data had to be rejected, the remaining data gave results that were both consistent and believable.

FURTHER DEVELOPMENTS

To further develop the procedure and better identify its capabilities and limitations, a laboratory facility has been constructed to evaluate the test method under controlled conditions. Known as the Building Air Leakage Simulator (BALS), the rig consists of two interconnected chambers designed to replicate two interconnected zones in a building (see Figure 5). Both chambers are lined with an air barrier membrane to control air leakage (other than that which is intentionally introduced through the ductwork). Chamber A represents Zone A in Figure 5, while Chamber B represents Zone B. Two ducts connect the two chambers. The first duct contains a variable speed blower that replicates the blower door that would be installed between the two zones of the real building. The second duct replicates the leakage area that would exist between the two zones. To simulate various leakage conditions, an adjustable damper is installed in this section of ductwork. Likewise, ductwork with adjustable dampers is

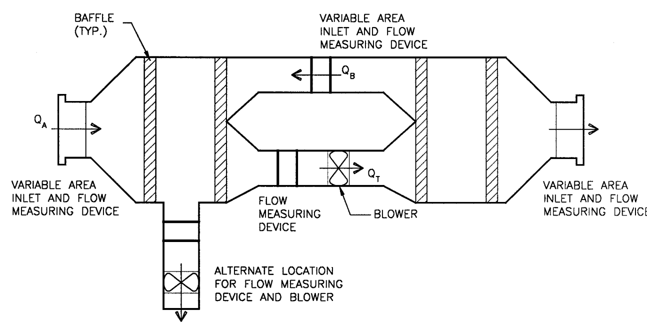

Figure 5 *Building air leakage simulator.*

connected to Chambers A and B to simulate the normal envelope leakage area between Zones A and B and ambient. Finally, a variable speed blower is connected to Chamber B to replicate Blower B in Figure 5. Further investigations of the new airtightness test method, using the BALS, are now underway.

Additional refinements to streamline the analysis procedures are also ongoing. This will include an analysis of the experimental uncertainty of the method, particularly as it compares to the pressure-masking technique.

CONCLUSIONS

A new airtightness test procedure has been proposed for isolating exterior envelope air leakage from interior partition leakage for use when testing a single zone within a multi-zone structure. Initial field trials conducted on a house, configured into a two-zone structure, and on an indoor swimming pool attached to a much larger recreational complex, have been encouraging. The procedure appears to be suited for field work and seems to offer advantages, in terms of time and equipment requirements, over those of the pressure-masking technique.

ACKNOWLEDGMENTS

Support for this project was provided by Natural Resources Canada.

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