AIRTIGHTNESS TESTING OF OCCUPIED, MULTI-UNIT RESIDENTIAL BUILDINGS (MURBS) - LESSONS LEARNED

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ABSTRACT

The research described in this paper was carried out to explore some of the unique problems associated with performing airtightness tests on occupied Multi-Unit Residential Buildings (MURBs). Current airtightness testing methods and standards are predicated on the assumption that the testing agency has complete control over the building and its operation during the test period. Current airtightness testing methods and standards also require that interior doors be kept open and exterior windows be kept closed. With unoccupied buildings, this is seldom a problem, however if the building is an occupied MURB then major issues arise. Testing an occupied MURB requires occupant access to be limited during certain critical portions of the testing, interior doors be kept closed (for security and privacy purposes) and suite windows kept closed. These last two issues (interior door and suite window positions) were the focus of this project.

Using two unoccupied and four occupied MURB's, ranging in size from 8 to 124 units, a series of airtightness tests were conducted to determine if reliable results could be obtained with interior suite doors closed and a limited number of windows partially open. The results of this work indicated that:

1) The error introduced into airtightness test results by closed suite doors is relatively small (2% to 6%) and can be reduced by applying a correction factor which is based on the average, measured pressure differential across the suite doors while the building is depressurized to a standardized value (75 Pa).

2) All windows in a MURB (and any other type of building) must be kept closed during airtightness tests. Despite the fact that MURB's are compartmentalized buildings, even a relatively modest amount of window operation will likely invalidate the results. However, the project experiences demonstrated that with proper test management, window operation can be controlled in an occupied MURB, thereby permitting a successful test.

3) Owner cooperation and participation are essential. This must begin long before the actual test takes place since the owner has to communicate with tenants, work around other scheduled events in the building, etc. During the test, the owner will have to control the HVAC system, access circuit breaker panels (often in several locations), answer numerous queries from the test crew and, most critically, be actively involved in tenant communication and cooperation.

INTRODUCTION

Project Background

In 2012, Red River College (RRC) embarked on a research program to study the airtightness characteristics of "commercial" buildings, i.e. those other than detached and semi-detached houses. One of the outcomes of this work has been the recognition of the special challenges involved with airtightness testing of MURBs, which are unique from those encountered testing other types of larger buildings. All airtightness testing standards in use today assume that the building is either vacant or that the test crew has control over the movement and actions of the occupants during the test (e.g., restricting entry and exit; keeping windows closed; not operating mechanical systems; etc.). This introduces a major problem when testing MURBs once they are occupied. As a result, airtightness testing of the over 3 million dwelling units in Canadian MURBs is rare.

Measuring the Airtightness of Occupied MURBs

There are three major issues which arise when airtightness testing occupied MURB's:

1) Is it possible to obtain accurate results if the interior suite doors (that is, doors between the units and the common corridor) are kept closed during the test, given that it is totally impractical to expect dozens or hundreds of tenants to cooperate (or be expected to cooperate)?

2) Is it possible to obtain accurate results if there is occasional opening of a "few" suite windows by the tenants, given (again) that significant tenant cooperation is required?

3) Is it possible to control access to the building by tenants and both essential and non-essential individuals for the several hours it takes to conduct the test?

The first and second issues are both quantitative while the last is purely qualitative.

To address the first issue - closed suite doors - a correction factor was developed to calibrate the error in the airtightness results to the average, measured pressure differential across the suite doors while the building was depressurized to a standardized value (of 75 Pascals). The correction factor was developed by measuring the airtightness of three, unoccupied MURB's in both the 'doors open' and 'doors closed' configurations and correlating the error in the airtightness results to the pressure drop across the suite doors. These suite doors required undercuts that allowed communication from the corridors. Note that one of these three MURBs was not part of this project, but was tested using the same protocol described herein.

The second issue – occasional window openings – was challenging. Although closed windows are an obvious requirement for all airtightness tests, MURB's are multi-zone buildings whose internal partitioning (and closed suite doors) can create considerable resistance to air leakage. We measured the effects of the multi-zones and if they will help to mitigate the impact of a partially open window.

We believed that the third issue – controlling access – basically involved proper test management of the building using personnel at every exterior door as well as significant cooperation by the building owner.

Airtightness Metrics

Two metrics are used in this paper to express building airtightness:

Air change rate at 50 Pascals:

$$ACH_{50} = \frac{Total\ Air\ Leakage\ Rate\ per\ hour\ at\ 50\ Pa}{Building\ Volume} \quad (1)$$

$$= (Q_{50} \times 60) / V$$

where:

Q_{50} = Air leakage rate at 50 Pa (m^3/min)

V = Building volume (m^3)

Normalized leakage rate at 75 Pascals:

$$NLR_{75} = \frac{Total\ Air\ Leakage\ Rate\ at\ per\ hour\ at\ 75\ Pa}{Envelope\ Area} \quad (2)$$

$$= (Q75 \times 60) / A$$

where:

Q_{50} = Air leakage rate at 75 Pa (m^3/min)

V = Building envelope area (m^2)

Project Overview

The project took place in two phases. Phase One consisted of various field trials on two unoccupied buildings to explore some of the issues involved with airtightness testing of MURB's, primarily the effect of interior door position (open or closed) and occasional window operation which might occur courtesy of the tenants.

In Phase 2, the knowledge gained on the first two buildings was applied to test four occupied MURB's. This provided a better quantitative understanding of the impact that tenant action can have on an airtightness test and also offered insight into some of the subtle factors which can have an impact on both the test and the results themselves.

PHASE 1 – FIELD TRIALS, UNOCCUPIED BUILDINGS

Overview of Testing on Buildings #1 & #2

Buildings #1 and #2 were both unoccupied MURB's which were used to measure the impact of interior suite door position (open or closed) on the overall airtightness of the structures. They were also used to determine if reliable results from an airtightness test could be generated if a small number of suite windows were left open during the test. While this is a departure from established testing procedures, there was the possibility

that reasonable results could still be obtained since the flow resistance between a suite and the rest of the building would mitigate (somewhat) the influence of the open window. The information gleaned from these two buildings was used to establish a modified airtightness testing protocol which could be used on occupied MURB's.

This revised testing protocol was then used to perform airtightness tests on Buildings #3, #4, #5 and #6, which were all occupied MURB's. All of the project buildings had suite windows operable by the tenants.

Building #1

This rural MURB was an unoccupied, 39-year old, single-storey building with a large central common area and 15 individual suites (each with two doors - one to the common area and one to the outdoors).

Building #1 was used to study the impact of interior door position on the measured airtightness of the structure and to gain some initial insight on the effects of open windows on airtightness.

Test #1-1 - The first test was conducted using the standard AABA/USACE protocol with the interior suite doors open and all windows closed. It was intended to provide the baseline airtightness of the structure using conventional testing procedures. This produced a mean normalize leakage rate at 75 Pascals (NLR75) of 1.44 l/s•m2 and an air changes per hour at 50 Pascals rate (ACH50) of 3.75.

Test #1-2 - The next test was the same as the first except that a single window on the southwest side of the building was left partially open in one of the suites. The window had a free area of about 368 cm2 (57 in2), although the mosquito screens were left in place which would have provided pressure drop. All interior doors were left open.

The NLR75 for Test #1-2 decreased in value from 1.44 l/s•m2 to 1.14 l/s•m2, while the air change rate at 50 Pa increased from 3.75 ACH50 to 4.18 ACH50. In other words, the ACH50 increased as expected while the NLR75 moved in the opposite direction from that anticipated.

Test #1-3 - This was basically a replicate of the previous test except that a single window on the opposite (southeast) side of the building was used, but with the same free area and mosquito screens. Once again, all interior doors were kept open.

The results of Test #1-3 indicated that the NLR75 decreased yet again (to 0.90 l/s•m2) while the ACH50 also decreased slightly from Test #1-2 to 4.00 ACH50. At first glance, these results appear to make little sense since the NLR75 and ACH50 values normally move in a similar manner. Looking closer at the results reveals the reason for this apparent anomaly. Although the final results (i.e. the NLR75 and ACH50) for the "window open" configuration were similar to the "window closed" case, albeit sometimes the results moved in a direction that was not expected, the flow coefficients (C), flow exponent (n) and correlation coefficients (r) were all radically different. In fact, according to any airtightness testing protocol, Tests #1-2 and #1-3 would all have been declared invalid. The flow coefficients (C) were dramatically higher than anticipated while the flow exponents (n) and correlation coefficients (r) were far below acceptable minimums. For example, the minimum acceptable correlation coefficient for an airtightness test is 0.99. Observed values for Tests #1-2 and #1-3 ranged from -1.54 to 0.33, well outside the acceptable range. Given this absence of correlation, the differences between the NLR75 and ACH50 values, for Test #1-1 compared to Tests #1-2 and #1-3 were as

much good providence as good experimentation. The borderline wind conditions encountered during Tests #1-1 to #1-3 may have also influenced the results.

Test #1-4 - This was a repeat of Test #1-1, the only difference being that lighter winds were encountered during Test #4. Despite the difference in environmental conditions, the NLR75 and ACH50 results for Tests #1-1 and #1-4 were within 5% of each other (NLR75 of 1.37 l/s•m2 and ACH50 of 3.83).

Tests #1-5 - This test was conducted with the same environmental conditions and overall set-up as Test #1-4, except that the interior suite doors were closed, whereas in all the previous tests they were open (as per current testing protocols). Comparing results for these two tests, we can observe that the impact of closing the 15 interior suite doors was a reduction in the NLR75 of 7% (1.28 l/s•m2), while the ACH50 dropped by 6% (3.60).

In addition, the pressure differentials across the 15 interior suite doors were measured while the building was depressurized to 75 Pa. These ranged from 7 Pa to 25 Pa, meaning that between 9% and 33% of the induced pressure occurred across the interior suite doors and the balance (67% to 91%) across the exterior envelope. The relatively large variation in suite door pressure differentials is believed to be mainly due to differences in the door undercuts, which ranged from about almost zero to over 20 mm, and the roughness of the floor surface (vinyl or carpet). The application of this information is discussed below.

Table 1: Building #1 Test Results

Test	**Interior Doors**	**Open Window**	**Depressurization**			**Pressurization**		
			C (l/s•Pa^n)	n	r	C (l/s•Pa^n)	n	r
1-1	Open	No	189	0.6687	0.9972	97	0.8566	0.9919
1-2	Open	Yes	2282	0.0664	0.1315	5144	0.1380	0.2430
1-3	Open	Yes	1382	0.1957	0.3272	1,108,868	-1.5365	0.4298
1-4	Open	No	250	0.6043	0.9922	272	0.5960	0.9972
1-5	Closed	No	217	0.6223	0.9945	261	0.5924	0.9950

Building #2

This Winnipeg MURB was a 35-year old, six-storey structure which had just begun major renovations to modernize the suites. It contained 124 suites and a common area. At the time of the testing, the building was occupied by a single tenant and a small number of workmen.

Building #2 was used to again study the impact of interior door position on the measured airtightness of the structure and to further study the effects of open windows on airtightness. One unique feature of this building was that small transfer grilles were used between the corridors and individual suites to enhance ventilation.

Test #2-1 - The first test was a standard "envelope" test conducted with all interior doors open as per accepted protocols. This produced a mean NLR_{75} of 1.67/s•m^2 and an ACH_{50} of 1.40.

Test #2-2 - This was performed under the same conditions as Test #2-1, except that the 124 interior suite doors were closed, while the transfer grilles and stairway doors were left open. The transfer grilles were left open because this would be the normal building configuration if a test were conducted with the suite doors

closed. While it would have been possible to seal the transfer grilles, this would be time consuming in larger MURB's with one hundred or more suites.

Comparing results for Tests #2-1 and #2-2, the impact of closing the 124 interior suite doors was a reduction in both the NLR_{75} and ACH_{50} of 3%.

In addition, the pressure differentials across the interior suite doors were also measured while the building was depressurized to 75 Pa. These ranged from 3 Pa to 17 Pa, meaning that between 4% and 23% of the induced pressure occurred across the interior suite doors and the balance (77% to 96%) across the exterior envelope.

Tests #2-3 and #2-4 - These two tests were used to determine if reliable airtightness test results could be obtained if a small number of suite windows were left open during the test. While this is a departure from standard testing protocols, and is not a desired situation, these tests addressed the situation in which it was not possible to close every window because access could not be obtained to every suite or due to a lack of cooperation from some tenants.

However, this posed the question as to how many windows should be left open and how "open" each window should be. To answer this question, previous research performed for CMHC by Proskiw and Philips (2006) was used. This study characterized the air pressure/air movement patterns in two 15 and 17 storey Winnipeg MURB's, and also provided some insight into tenant usage of windows. One of its findings was that some MURB occupants routinely kept their windows open (partially or fully) - even at temperatures as low as -40 °C. Using site observations of window usage on one of the buildings, at three different outdoor temperatures, they established a simple correlation to relate window usage to outdoor temperature (8.8% open area at 20 °C, 7.0% open area at 4 °C and 2.3% open area at -25 °C). With this as a guide, a window schedule was developed for Building #2. Test #2-3 used 7.0% open window area while Test #2-4 used 2.3%. In addition, roughly the same vertical and horizontal distribution of open window area observed in the Proskiw and Phillips study was used.

Using the results of Test #2-1 as the base case, the impact of 7% open window area, with the interior suite doors closed, was an increase in both the NLR_{75} and the ACH_{50} of 47%. With 2.3% open window area, the NLR_{75} and the ACH_{50} increased (relative to Test #2-1) by 18% and 14%, respectively.

Test #2-5 - As previously mentioned, Tests #2-5 to #2-8 were performed using the "energy" sealing schedule for intentional openings. Otherwise, they paralleled the first four tests.

Test #2-5 served as the base case configuration and was conducted with the interior doors open. The measured NLR_{75} from Test #2-5 was 2.08 $l/s \cdot m^2$ while the ACH_{50} was 1.74 ACH_{50}. Interestingly, these values were 25% and 24% larger than the values obtained when the intentional openings were sealed.

Test #2-6 - This was performed under the same conditions as Test #2-5, except that the 124 interior suite doors were closed, while the transfer grilles and stairway doors were left open.

Comparing results for Tests #2-5 and #2-6, the impact of closing the 124 interior suite doors was the reduction of both the NLR_{75} and ACH_{50} by 5%.

Tests #2-7 and #2-8 - These two tests also explored the impact of open windows using the same window

opening schedule described for Tests #2-3 and #2-4. Unfortunately, the airtightness tests could only be conducted using pressurization conditions (but not depressurization) since the building's awning windows (which had to be propped open during the tests) kept blowing shut. Although this problem was not encountered during tests 2-3 and 2-4, it became an issue during continued testing as the tape and props used to secure the windows in an open position were not staying in place anymore. Time constraints to complete the tests due to security issues in the building did not allow for this problem to be corrected.

Using the results of Test #2-5 as the base case, the effect of having 7% open window area, with the interior suite doors closed, was an increase in the NLR_{75} of 17% and the ACH_{50} of 16%. With 2.3% open window area, the increases in the NLR_{75} and the ACH_{50} were 5% and -1%, respectively.

Table 2: Building #2 Test Results

Test	Interior Doors	Open Window	Depressurization			Pressurization		
			C (l/s•Pa^n)	n	r	C (l/s•Pa^n)	n	r
2-1	Open	No	587	0.6298	0.9984	435	0.7006	0.9980
2-2	Closed	No	633	0.5943	0.9985	386	0.7300	0.9952
2-3	Closed	Yes	737	0.6656	0.9968	744	0.6679	0.9989
2-4	Closed	Yes	533	0.6910	0.9969	336	0.7993	0.9919
2-5	Open	No	608	0.6411	0.9928	737	0.6542	0.9825
2-6	Closed	No	511	0.6729	0.9913	785	0.6273	0.9730
2-7	Closed	Yes	850	0.6263	0.9963	-	-	-
2.8	Closed	Yes	451	0.7486	0.9904	-	-	-
2-9	Closed	No	483	0.6815	0.9975	493	0.7132	0.9884

The Impact of Closed Suite Doors on Building Airtightness Testing

By comparing the measured airtightness results, with the suite doors open and closed, for Buildings #1 and #2, it was possible to determine the impact of suite door position on the building's airtightness. For example, closing the suite doors in Building #1 reduced the NLR_{75} by 7%, while in Building #2, the reduction was 3% (using the envelope sealing protocol) and 5% (using the energy sealing protocol).

While these errors were neither unexpected nor desirable, it should be pointed out that their magnitude was relatively small. Given the paucity of reliable information on MURB airtightness, errors of 3% to 7% in an airtightness test can likely be tolerated in many situations.

However, the accuracy of testing a MURB with suite doors closed can be further improved by measuring the pressure drops across the suite doors while the building is pressurized or depressurized, and then applying a correction factor based on the measured pressure drop across the doors. By combining the single set of results for Building #1 and the two sets of results for Building #2 (i.e. determined using the envelope and energy protocols), the errors in both the NLR_{75} and ACH_{50} results as a function of the measured pressure drop across the suite doors was found. Using the resultant regression equations, corrections were developed for the NLR_{75} and ACH_{50}.

Also, it should be appreciated that the correction factors were generated using data from only three buildings

- a single-storey, 15 unit MURB, a six-storey, 124 unit MURB and a six-storey, 55 unit MURB (not part of this project). Obviously, it would be desirable to have a larger data set of equivalent information which could be used to further refine these correction factors. But, in the absence of this, the procedure described above along with developed corrections are proposed as a method for calculating the impact of closed suite doors on the measured airtightness of MURB's. Refer to Table 3 for the air leakage data used in developing the correction factors. The correlation between the airtightness test error and the average suite door pressure differential shown in Fig. 1.

Table 3: Air Leakage Data

Building	**NLR75**		**NLR75 Reduction**		**ac/hr50**		**ac/hr50 Reduction**		**ΔPdoors/ ΔPtotal**
	Doors Open	Doors Closed	Absolute	Percent	Doors Open	Doors Closed	Absolute	Percent	
Building #1	1.37	1.28	0.09	6.6%	3.83	3.60	0.23	6.0%	20.5%
Building #2	1.67	1.62	0.05	3.0%	1.40	1.35	0.05	3.6%	8.8%
55 unit MURB	1.32	1.30	0.02	1.5%	1.40	1.32	0.08	5.7%	12.8%

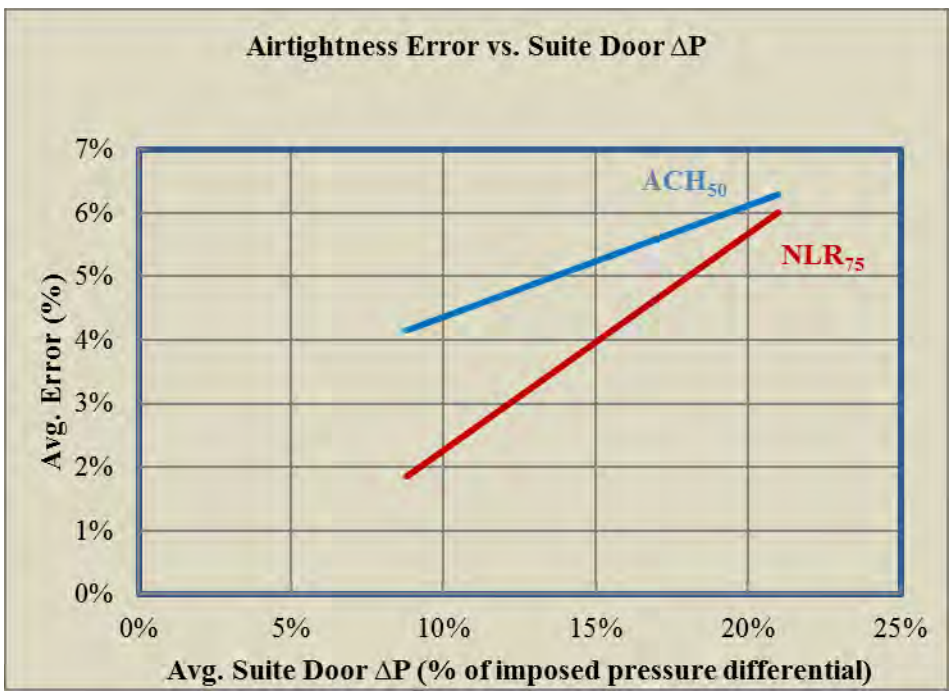

Figure 1: Correlated airtightness test error and the average suite pressure differential

The correction factors using the three buildings:

$$corrected\ NLR_{75} = (measured\ NLR_{75}) \times K1 \quad (3)$$

Where $K1 = 1 + [0.341\ (\Delta P/75) - 0.0115]$

$$corrected\ ACH_{50} = (measured\ ACH_{50}) \times K2 \quad (4)$$

Where $K2 = 1 + [0.1752\ (\Delta P/75) + 0.0261]$

and ΔP = average pressure differential across the suite doors (in Pascals)

PHASE 2 – FIELD TRIALS, OCCUPIED BUILDINGS

Planning and Coordination Issues

An efficient and disciplined test procedure is needed to minimize tenant inconvenience. The test requires the cooperation of the property manager to facilitate communications with the tenants regarding the test date and times, the requirement to keep all windows and doors closed during actual test, and the need to restrict movement during the testing. Cooperation of the tenants is essential, however some tenants may not be cooperative with the testing personnel and this will need to be monitored very carefully.

Another coordination issue is visitors to the building who are providing essential services (such as nursing or home care staff, cleaning personnel, postmen, food services workers or repair and maintenance staff). In many cases, they cannot be easily re-scheduled nor can they be easily notified in advance of the test.

The mechanical system may have to be disabled (depending upon the test being conducted) so individual, apartments may become too hot or cold for the tenants (especially if they are elderly) and this can become a health concern if the test duration is excessive.

Overview of Testing on Buildings #3 To #6

Buildings #3, #4, #5 and #6 were all occupied MURB's located in or around Winnipeg and were used to evaluate the practicality of using the modified airtightness procedure (testing with closed suite doors) on occupied buildings. Since these were all fully occupied buildings, there was no opportunity to conduct any tests with the suite doors open.

Estimates of the time required to conduct each test are also shown for each building. These included: on-site meetings, testing, clean-up, data analysis and reporting. Travel, mobilization and demobilization times are not included since these vary for each test location.

Building #3

This single-storey building was constructed in 1982 and contained 12 apartments. It used a double, wood-frame wall assembly (consisting of two 2x4 frame walls spaced apart with insulation between), stucco and wood siding, a gable roof, and a combination of fixed and casement, double-glazed windows. The floor plan area was 931 m^2 (10,024 ft^2) and consisted of two wings with central corridors and a common area in the center. The main entrance was located on the west elevation with a secondary door on the east side leading to a garden area. Two emergency exits were located at the north and south elevations. The building also has a screened porch on the west elevation with a door to the common area. The blower fans were installed in the door located in the porch area.

For these tests, four personnel were required (including the owner): one blower door/computer operator, one outside observer to monitor visitors and window operation by the tenants, one interior observer to monitor

the occupants and one observer to watch the main entrance.

The test duration from arrival on site to departure was 4.5 hours with four personnel. The pre-test site visit (by one individual and the owner) was 1.5 hours. The time required for calculation of the building geometry, analysis of the test data and reporting was about 5 hours.

Total time: 26 person-hours

Building #4

This was also a single-storey building constructed in 1973 with 28 apartments. It used a wood-frame wall assembly, stucco, vinyl and Tyndal stone (limestone) cladding, a gable roof and a combination of fixed, awning and casement double-glazed windows. The floor plan area is 1478 m^2 (15,907 ft^2) with two wings, central corridors and a common area at the center of the east wing. Each apartment had an exterior door (motel style). The main entrance was located on the north side with a patio door on the south elevation. Two emergency exits are located on the east and north elevations. The emergency exit door on the east elevation was used for the installation of blower door, leaving all the other doors operable.

For this building, five personnel were required (including the owner): one blower door/computer operator, two outside observers to monitor visitors and window and door operation, one interior observer to monitor the occupants who wished to leave the building and one observer to watch the main entrance.

The test duration from arrival on-site to departure was 6 hours with five personnel. The pre-test site visit (by one team member and the owner) was 1.5 hours. The time required for calculation of the building geometry, analysis of the test data and reporting was about 6 hours.

Total time: 38 person-hours

This building displayed comparatively high pressure drops across the suite doors. As a result, the correction factors ranged from 11.6% to 15.2% - which required significant extrapolation beyond the range of buildings #1 and #2.

Building #5

This single-storey building was constructed in 1987 and contains eight apartments. It was built with a stucco-clad, double wood-frame wall, gable roof and combination fixed and awning, double glazed windows. The floor plan area is 591 m^2 (6356 ft^2) with a central corridor and a common area at the south end of the building. The main entrance is located on the south elevation. One emergency exit is located on the north elevation. A screened porch is located on the south elevation with a door to the common area. The porch door was used for the blower door installation, leaving all the other doors operable.

For this test, four personnel were required (including the owner): one blower door/computer operator, one outside observer to monitor visitors and window operation, one interior observer to monitor the occupants and one observer to watch the main entrance.

The test duration from arrival on-site to departure was 4 hours with four personnel. The pre-test site visit (by

one team member and the owner) was 1.5 hours. The time required for calculation of the building geometry, analysis of the test data and reporting was about 5 hours.

Total time: 24 person-hours

Building #5 was added at the request of Manitoba Housing due to its high heating costs. During the pre-test review, the outdoor temperature was -2 °C yet four of the apartments had their windows completely open. This is believed to be due to poor ventilation provided by the central air make-up system which supplies air to the suites via the corridor. The door undercuts and through-wall corridor transfer vents were inadequate, requiring the tenants to keep their windows open and the baseboard heaters on.

Building #6

This 13-storey, high-rise building was constructed in 1975 and contains 107 apartments producing a total floor plan area of 6,458 m^2 (69,492 ft^2). The original construction used a structural concrete frame with pre-cast floors, steel stud framing, flat built up roof, and metal siding. According to the building records and the owner's personnel, the structure received two major retrofits. The first took place in 1982 and consisted of removal of the metal siding and installation of additional wall insulation and re-cladding with stucco. In 1999, the stucco was removed and the wall system was re-built with a concrete sheathing board over the steel studs, a bitumen air barrier membrane, semi-rigid batt insulation, building wrap and metal siding. New vinyl horizontal sliders and fixed windows plus a new two-ply roofing system were also installed at the time of the second retrofit.

The main floor vestibule entrance and ground floor patio door (opening to a small garden area) are both located on the west elevation. The emergency exit doors are located on the east and north elevations. The East and South emergency exit doors were used for the blower door installation during the test, and were manned at all times throughout the test, leaving all other doors operable. Emergency exits were located at the bottom of each stairwell.

For this test, up to 12 personnel were required (including the owner). This included: two senior managers/engineer, one blower door/computer operator, two outside observers to monitor the windows and one to control visitors coming to the building, one interior observer to monitor the occupants at the main vestibule and one in the common area to monitor the patio door and communicate with the tenants. Finally, two observers were positioned on the roof to monitor the HVAC equipment and their seals and one floor runner to communicate with tenants regarding the opening of windows.

The test duration from arrival on-site to departure was 8.5 hours with 12 personnel. The pre-test site visit (by two team members and the owner) required 4 hours. The time required for calculation of the building geometry, analysis of the test data and reporting was about 8 hours.

Total time: 114 man-hours

SITE OBSERVATIONS – TESTING OCCUPIED BUILDINGS

Field Experiences

Building #3

During the pressurization test, all windows were visually checked from the outside and appeared to be fully closed and locked. However, as the test pressure was increased, many of them began to open - either uniformly along the hinge axis or at a single corner. Typical crack size was about 13 mm (½") at 75 Pa. Some tenants had not closed and locked their windows, some were not physically capable of closing them while other window units had broken hardware and were no longer capable of being locked at both corners. Windows left open by the tenants were closed and locked. Faulty windows were left as-is (this was considered the normal operating condition of the building) and the test re-run. No other building related issues were encountered.

Overall, the tenants fully co-operated with the test crew. Although some essential services needed to enter the building during the test (nurses, Meals on Wheels and Handi-Transit), they were relatively easily accommodated and produced minimal disruption.

Building #4

Prior to conducting the test, the windows and doors were checked and many were found not to be closed, despite every suite receiving a written notice about the test. Several tenants had to be asked to close their windows or the owner had to enter the apartments to close windows if the tenants were away. As in Building #3, several windows which appeared to be closed and locked, opened during the pressurization test.

Some problems were also encountered with circuit breakers supplying power to the test blowers. These tripped several times and had to be re-set. While not a major issue, it was annoying and probably added 15 to 30 minutes to the overall time-on-site. No other building-related issues were encountered.

The majority of the tenants co-operated during the test, although three tenants repeatedly opened windows or doors and needed constant monitoring. The tenant population included independent living, assisted living and special needs individuals. This required careful coordination with the owner, whose assistance was critical. There was also regular disruption from essential services personnel who needed to enter the building (nurses, Meals on Wheels and Handi-Transit). No problems were encountered with non-essential personnel who patiently waited until the test was completed.

Building #5

During the pressurization test, two windows that appeared to be closed and locked opened. These were closed, locked and the test continued with minimal disruption. No other building related issues were encountered. The tenants fully co-operated with the test crew.

Building #6

Prior to conducting the test, the windows and doors were checked and many were found not to be closed, despite every suite receiving a written notice about the test. Several tenants had to be asked to close their windows or the owner had to enter the apartments to close windows if the tenants were away. As in Buildings #3 and #4, several windows which appeared to be closed and locked were opened during the pressurization test.

Some problems were also encountered with circuit breakers supplying power to the test blowers. These tripped several times and had to be re-set. While not a major issue, it was annoying and probably added 15 to 30 minutes to the overall time-on-site. No other building-related issues were encountered.

In general, the vast majority of the tenants co-operated with the test crew, although a small number were repeatedly disruptive (for the most part, unintentionally). They continually opened windows and needed constant monitoring with the test having to be paused on numerous occasions. In fact, to complete the pressurization and depressurization tests, the process had to be paused roughly 15 to 20 times because of tenants opening windows. A small number of tenants ignored all requests to wait for the test to be completed. This was particularly problematic with those wishing to access the outdoor smoking area.

Perhaps because this was the largest *occupied* building in the project, as well as being in an urban setting, there were also more problems with tenant communication. For example, some could not speak or write English.

As with most of the buildings, there were regular disruptions from essential services including nurses, Meals on Wheels and Handi-Transit. However, because Building #6 contained the most people, the number of these types of disruptions was also the greatest.

A new issue encountered (or perhaps first recognized) in Building #6, was that some of the tenants suffered from early-onset Alzheimer's which produced serious degradation of their short-term memory. Even though the tenants received written notification, and in several cases, were verbally reminded about the test, the fact that it lasted for an entire working day may have taxed their memory capabilities.

Window Operation during Tests

The tests conducted on Buildings #1 and #2 revealed some interesting information about the impact of open windows on the test results. First, even a small amount of window usage (i.e. a relatively small area of open windows) can have a significant impact on the measured airtightness of the building. The tests performed on Building #1 were conducted with site-measured winds at the upper limit permitted for airtightness tests. Even though only a single window was open, the results were unusable since values for both the correlation coefficient (r) and the flow exponent (n) were well outside acceptable ranges. In hindsight, it would have been desirable to repeat one of the “window-open” tests with the suite doors closed since that might have mitigated the effects of the window leakage.

Reviewing the results for Building #2, the impact of opening a "typical" number of windows was to skew the results significantly. For example, during the envelope tests, the open windows increased the NLR_{75} by 19% to 47%, while for the energy tests, the increase in the NLR_{75} ranged from -5% (i.e. the building got tighter) to 17%. The ACH_{50} results behaved similar.

It should be noted that the number, distribution and free area used for these tests were selected based on observed window usage patterns in an occupied MURB, under winter conditions. They were as similar to typical occupant usage as could be achieved in the building.

Given the magnitude of these errors, the results from this testing program suggest that, for the types of buildings encountered in this project, the windows will have to be kept closed. Further usage will have to be

carefully monitored and controlled during the test to ensure that no windows are opened during the test.

Other Issues

During testing of the occupied buildings, some tenants and less experienced testing personnel did not always inform core testing personnel when entering or exiting of the building. This was due to a simple misunderstanding since they were not aware that testing may still be underway even when the fans were not operating (i.e. when collecting baseline/bias pressures differentials). A possible solution might be the use of remote activated signal lights (red or any bright obvious colour) that can be controlled by the operator. This allows for a simpler explanation to tenants and staff that if the light is on, no one can enter or leave the building.

On-site communication between team members was occasionally an issue, particularly in the larger buildings since they required the largest number of team members and were the easiest for an individual to get "lost" in. Cell phones were used extensively but do encounter the following problems:

The need to share phone numbers between team members;

The time delay in identifying a problem, finding the appropriate phone number, connecting and relaying the information;

Signal problems due to location (location within the city or location within the building); and

Battery life (one tester for Building #6 had to charge their phone).

One potential solution to these issues might be the use of two-way radios.

CONCLUSIONS

The error introduced into airtightness test results by closed suite doors in a MURB can be corrected by conducting the airtightness test and then applying a correction factor based on the average, measured pressure differential across the suite doors while the building is depressurized to a stable value (75 Pa). Since the correction factors are based on a sample size of just three buildings, it is strongly recommended that additional buildings be tested in both the interior doors "open" and "closed" configurations to increase the sample size and develop revised correction factors.

Windows must be kept closed during airtightness tests on MURB's (and any other type of building). Despite the fact that MURB's are compartmentalized buildings, even a modest amount of window operation will likely invalidate the results. However, experiences with testing four, occupied MURB's ranging in size from 8 to 107 units demonstrated that with proper test management, window operation can be controlled thereby permitting a successful test.

Owner cooperation and participation is essential. This must begin long before the actual test since the owner has to communicate with tenants, work around other scheduled events in the building, etc. During the test, the owner will have to control the HVAC system, access circuit breaker panels, answer numerous queries from the test crew and, most critically, be actively involved in tenant communication and cooperation.

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