Airtightness in Existing Multi-Unit Residential Buildings: Field Trials of a New Test Protocol

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Executive Summary

The research project described in this report 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. With unoccupied buildings, this is seldom a problem. However, if the building is an occupied MURB, then major issues arise. Occupant access has to be limited during certain critical portions of the testing, interior doors must be kept open and suite windows have to be kept closed. These last two issues (interior door and suite window positions) were the main 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 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 standardized value (75 Pa).

2. 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 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 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.

Résumé

L'étude décrite dans le présent rapport a été entreprise pour explorer certains des problèmes uniques associés à la réalisation d'essais d'étanchéité à l'air dans des collectifs d'habitation occupés. Les méthodes et normes actuelles relatives à ces essais présupposent que l'organisme qui les réalise détient un contrôle entier sur l'immeuble durant l'essai, ce qui est rarement un problème lorsqu'il est vide. S'il s'agit d'un collectif d'habitation occupé, cependant, des problèmes importants peuvent se présenter. L'accès des occupants à l'immeuble doit être limité durant certaines étapes clés de l'essai, les portes intérieures doivent rester ouvertes et les fenêtres des logements, demeurer fermées. La présente étude porte principalement sur ces deux derniers éléments (portes intérieures et fenêtres des logements).

Une série d'essais d'étanchéité à l'air ont été réalisés sur deux collectifs d'habitation vides et quatre autres occupés, comprenant entre 8 et 124 unités, pour déterminer s'il est possible d'obtenir des résultats fiables si les portes intérieures sont fermées et si un nombre limité de fenêtres sont entrouvertes. Les résultats de ces travaux indiquent que :

1. L'erreur introduite dans les résultats de l'essai d'étanchéité à l'air créée par les portes fermées peut être corrigée en appliquant un facteur de correction fondé sur la moyenne du différentiel de pression mesuré pour l'ensemble des portes de logement lorsque l'immeuble est dépressurisé à une valeur standardisée (75 Pa).

2. Les fenêtres doivent rester fermées durant les essais d'étanchéité à l'air dans des collectifs d'habitation (ainsi que dans tout autre type d'immeuble). Bien que les collectifs soient des immeubles compartimentés, même une utilisation relativement modeste des fenêtres invaliderait vraisemblablement les résultats. Toutefois, les expériences réalisées dans le cadre de l'étude montrent qu'avec une gestion adéquate de l'essai, l'ouverture des fenêtres peut être restreinte dans un collectif d'habitation occupé, ce qui favorise la réussite de l'essai.

3. La coopération et la participation du propriétaire sont essentielles. Cette coopération doit débuter bien avant la réalisation de l'essai puisque le propriétaire doit communiquer avec les locataires, gérer d'autres événements prévus dans l'immeuble, etc. Durant l'essai, le propriétaire devra commander le système CVC, accéder au panneau de disjoncteurs, répondre à de nombreuses questions de la part de l'équipe chargée d'effectuer l'essai et, par-dessus tout, participer activement à la communication avec les locataires et s'assurer de leur coopération.

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1.0 Introduction

1.1 Project Background

In September 2014 Red River College (RRC) was contracted by Canada Mortgage and Housing Corporation (CMHC) to explore some of the unique problems associated with performing airtightness tests on occupied Multi-Unit Residential Buildings (MURBs). Current airtightness test 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. For unoccupied buildings, this is seldom a problem. However, if the building is an occupied MURB, then major issues arise. Occupant access has to be limited during certain critical parts of the testing, interior doors must be kept open and suite windows have to be kept closed.

Airtightness testing of larger buildings is a priority area of applied research at RRC. In 2010, the College's Applied Research and Commercialization Office commissioned a report to establish priority areas for research by its new Sustainable Infrastructure Technology Research Group whose mandate is to conduct applied research on improving the energy performance of new and existing commercial buildings.

Beginning in 2012, RRC embarked on a program to study the airtightness of commercial buildings in Manitoba. Ultimately, 26 buildings were selected and tested. Selection was based on size, style of construction, age, location and availability, with emphasis placed on buildings that were scheduled for major envelope retrofits - so that pre- and post-retrofit airtightness data could be obtained.

The RRC research project also focused on identifying barriers with current test protocols for large buildings. For example, environmental conditions, building occupancy schedules, human resource requirements needed to perform the tests and interpretation of current standards were considered. The findings have been instrumental in informing the development of ABAA/ASTM's new *Standard Method for Building Enclosure Airtightness Compliance Testing (ABAA – A*ir Barrier Association of America; ASTM – American Society for Testing and Materials).

One of the outcomes of RRC's research 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 test 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 with testing some types of buildings, such as MURBs, once they are occupied. As a result, airtightness testing of the over 3 million dwelling units in Canadian MURBs is rare.

Airtightness testing of various types of new and existing low-rise houses (e.g., single detached, semi-detached, duplex and row housing) has become an increasingly common practice in Manitoba and elsewhere and Canada. However, testing of larger buildings, especially multi-unit residential buildings (MURBs), is far less common. For example, approximately 30,000 to 35,000 homes in Manitoba have had their airtightness measured through initiatives such as the Natural Resources Canada (NRCan) ecoENERGY Home Retrofit Program, R-2000 New Home Program and Manitoba Hydro's Power Smart Program. In contrast, less than 40 larger buildings (including only five MURBs) have been tested in the province – and 80% to 90% of these occurred in the last three years as part of RRC's research.

Several barriers exist to wider-scale testing of MURBs and other larger buildings. They include:

- the increased complexity and cost of testing larger buildings;
- an absence of regulatory requirements or incentives to test;
- a lack of industry demand and capacity to test larger buildings; and
- inconsistent methods and standards for testing.

The development of whole building airtightness test methods and standards for larger buildings started in the mid-1990s and has continued to be refined over the years. As mentioned, a new standard has been developed by the Air Barrier Association of America, Inc. (ABAA). Titled the *Standard Method for Building Enclosure Airtightness Compliance Testing*, it addresses the requirement of large Industrial, commercial and institutional buildings. The standard has been approved by the ABAA membership; it has been passed on to American Society for Testing and Materials (ASTM) as a work item for a new standard within ASTM.

1.2 Project Objectives

The objective of this project was to capitalize on RRC's knowledge and experience in conducting airtightness tests on larger buildings to explore new procedures for testing occupied MURBs.

1.3 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.

Based on RRC's prior experiences over the last three years testing 26 commercial buildings (including MURB's), as well as related, prior work by team members, we believed that workable solutions could be developed for all three of these issues.

To address the first issue - closed suite doors - a correction factor could (theoretically) be 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 would be developed by measuring the airtightness of a few, 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.

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. These will help to mitigate the impact of a partially open window. But, will it be enough?

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

1.4 Airtightness Metrics

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

Air change rate at 50 Pascals:

$$ACH_{50} = \frac{\text{Total Air Leakage Rate at 50 Pa (expressed in building volumes)}}{\text{Building Volume}} \quad (1)$$

Normalized leakage rate at 75 Pascals:

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

1.5 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 which 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.

2.0 Phase 1 - Field Trials, Unoccupied Buildings

2.1 Overview of Testing on Buildings #1 & #2

Buildings #1 and #2 (see Figure 1 and Figure 2, below) 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.

All of the airtightness tests conducted as part of this project followed, for the most part, the draft ABAA/ASTM's *Standard Method for Building Enclosure Airtightness Compliance Testing* (refer to Appendix A). Any departures from the standard were made for experimental purposes and are noted below.

2.2 Building #1

FIG. 1: 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.

All tests performed on Building #1 used the "envelope" sealing schedule as defined in the draft ABAA/ASTM Standard, i.e. all intentional openings in the building envelope (two exhaust fans and one dryer vent) were sealed for the tests.

Tests #1, #2 and #3 were conducted during relatively strong wind conditions with average site-measured wind speeds of 15 to 22 km/hr. Note that the maximum wind speed permitted under the current AABA/ASTM protocol is 20 km/hr. Wind speeds exceeding 20 km/hr may cause errors and requires additional consideration to placement of reference pressure taps.

Test #1-1 - The first test was conducted using the standard AABA/ASTM 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 NLR_{75} of 1.44 l/s•m^2 and an ACH_{50} of 3.75. See Table 1.

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 cm^2 (57 in^2), although the mosquito screens were left in place which would have provided a relatively significant pressure drop. All interior doors were left open.

The NLR_{75} for Test #1-2 *decreased* in value from 1.44 l/s•m^2 to 1.14 l/s•m^2, while the air change rate at 50 Pa *increased* from 3.75 ACH_{50} to 4.18 ACH_{50}. In other words the ACH_{50} increased as expected while the NLR_{75} 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 NLR_{75} decreased yet again (to 0.90 l/s•m^2) while the ACH_{50} also decreased slightly from Test #1-2 to 4.00 ACH_{50}. At first glance, these results appear to make little sense since the NLR_{75} and ACH_{50} 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 NLR_{75} and ACH_{50}) for the "window open" configuration were similar to the "window closed" case, albeit sometimes moving in the wrong direction, 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 NLR_{75} and ACH_{50} 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.

Tests #1-4 and #1-5 were conducted the following day under calmer wind conditions. The site-measured wind speeds were 4 km/hr or less.

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 NLR_{75} and ACH_{50} results for Tests #1-1 and #1-4 were within 5% of each other.

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 NLR_{75} of 7%, while the ACH_{50} dropped by 6%.

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 application of this information is discussed below.

Table 1
Building #1

Description: Single-storey, 15-unit MURB
Envelope Surface Area: 2531 m^2 (27,238 ft^2)
Building Volume: 2566 m^3 (90,553 ft^3)

C- Flow Coefficient

Test	Intentional Openings Sealing Protocol	Interior Doors	Open Window	Depressurization			Pressurization			ACH_{50}	NLR_{75}	
				C ($l/s \bullet Pa^n$)	n	r^2	C ($l/s \bullet Pa^n$)	n	r^2		$l/s \bullet m^2$	cfm/ft^2
1-1	Envelope	Open	No	189	0.6687	0.9972	97	0.8566	0.9919	3.75	1.44	0.28
1-2	Envelope	Open	Yes	2282	0.0664	0.1315	5144	0.1380	-0.2430	4.18	1.14	0.22
1-3	Envelope	Open	Yes	1382	0.1957	0.3272	1,108,868	-1.5365	-0.4298	4.00	0.90	0.18
1-4	Envelope	Open	No	250	0.6043	0.9922	272	0.5960	0.9972	3.83	1.37	0.27
1-5	Envelope	Closed	No	217	0.6223	0.9945	261	0.5924	0.9950	3.60	1.28	0.25

n- Flow exponent
r- correlation coefficient

2.3 Building #2

FIG 2: BUILDING #2

FIG 3: BUILDING #2 Location of blower doors in the balconies

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.

The tests performed on Building #2 were conducted using both the "envelope" protocol (Tests #1 to #4) defined in the draft AABA/ASTM Standard in which all intentional openings are sealed and the "energy" protocol (Tests #5 to #8) in which the intentional openings are left unsealed.

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 be possible to seal the transfer grilles, this would be somewhat time consuming in larger MURB's with (say) 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 $l/s•m^2$ 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 to reduce 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

Description: Six-storey, 124-unit MURB.
Envelope Surface Area: 5362 m^2 (57,693 ft^2)
Building Volume: 17,583 m^3 (620,560 ft^3)

Test	Intentional Openings Sealing Protocol	Interior Doors	Open Window	Depressurization			Pressurization			ACH_{50}	NLR_{75}	
				C (l/s•Pa^n)	n	r^2	C (l/s•Pa^n)	n	r^2		l/s•m^2	cfm/ft^2
2-1	Envelope	Open	No	587	0.6298	0.9984	435	0.7006	0.9980	1.40	1.67	0.329
2-2	Envelope	Closed	No	633	0.5943	0.9985	386	0.7300	0.9952	1.35	1.62	0.319
2-3	Envelope	Closed	Yes	737	0.6656	0.9968	744	0.6679	0.9989	2.06	2.46	0.485
2-4	Envelope	Closed	Yes	533	0.6910	0.9969	336	0.7993	0.9919	1.60	1.98	0.390
2-5	Energy	Open	No	608	0.6411	0.9928	737	0.6542	0.9825	1.74	2.08	0.409
2-6	Energy	Closed	No	511	0.6729	0.9913	785	0.6273	0.9730	1.66	1.98	0.390
2-7	Energy	Closed	Yes	850	0.6263	0.9963				2.02	2.44	0.480
2-8	Energy	Closed	Yes	451	0.7486	0.9904				1.73	2.17	0.428
2-9	Energy	Closed	No	483	0.6815	0.9975	493	0.7132	0.9884	1.53	1.87	0.368

C- Flow Coefficient
n- Flow exponent
r- correlation coefficient

2.4 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), we arrive at Fig. 4. This shows the errors in both the NLR_{75} and ACH_{50} results as a function of the measured pressure drop across the suite doors. Using the resultant regression equations, the following corrections can be developed for the NLR_{75} and ACH_{50} results:

$$\text{Corrected } NLR_{75} = (\text{Measured } NLR_{75}) \times K1 \quad (3)$$

$$\text{where } K1 = 1 + [0.2911\ (\Delta P/75) + 0.0089]$$

$$\text{Corrected } ACH_{50} = (\text{Measured } ACH_{50}) \times K2 \quad (4)$$

$$\text{where } K2 = 1 + [0.1964\ (\Delta P/75) + 0.0192]$$

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

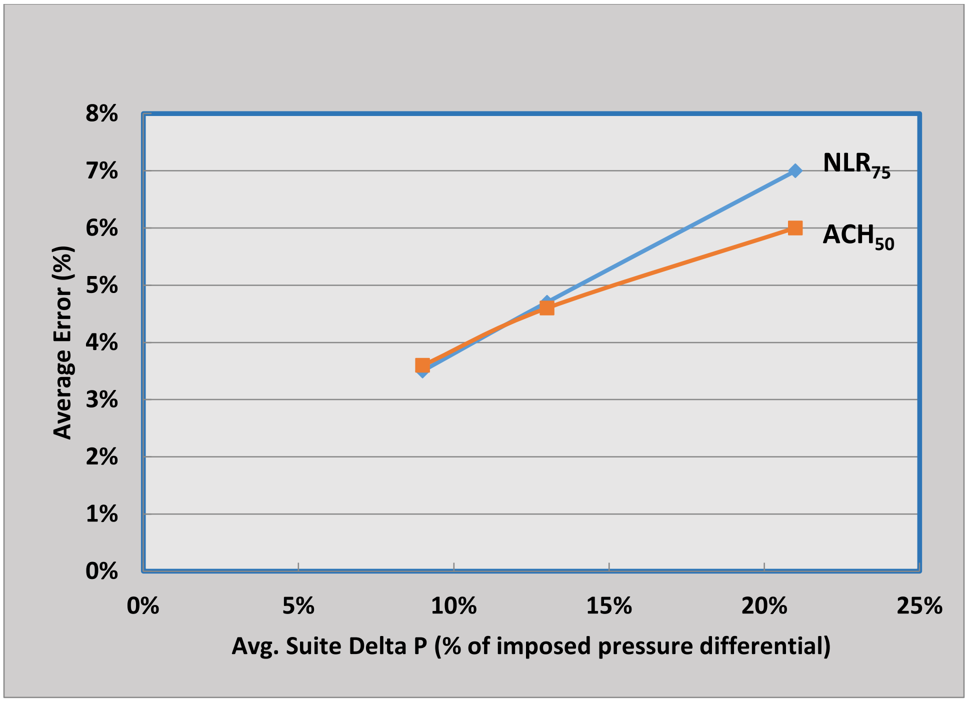

Fig. 4. Airtightness Results Error vs. Suite Delta P

Example: To illustrate how the correction would be applied, consider the results from Building #1. The measured NLR_{75} with the suite doors closed was 1.28 l/s•m^2 (see Table 1 above, Test 1-5). The average pressure differential measured across the suite doors when the building was depressurized to 75 Pa, was 16 Pa. Using the regression equation described above, calculating the true NLR_{75}, i.e. the result which would be attained had the test been conducted with the interior doors open, would be done by the following:

Solution: The average pressure differential across the suite doors was 16 Pa, or 16/75 = 21%. Using Eq. (3),

$$\text{Corrected } NLR_{75} = (\text{Measured } NLR_{75}) \times K1 \qquad (3)$$

$$K1 = 1 + [0.2911\ (\Delta P/75) + 0.0089]$$

$$K1 = 1 + [0.2911\ (16/75) + 0.0089]$$

$$K1 = 1.0709$$

So, the corrected NLR_{75} would be 1.28 x 1.0709 = 1.37 l/s•m^2.

Also, it should be appreciated that the correction factors described in Eqs. (3) and (4) were generated using data from only two buildings - a single-storey, 15 unit MURB and a six-storey, 124 unit MURB. 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 Eqs. (3) and (4) are proposed as a method for calculating the impact of closed suite doors on the measured airtightness of MURB's.

3.0 Phase 2 - Field Trials, Occupied Buildings

3.1 Planning and Coordination Issues

A pre-test site meeting was held with an owner's representative and building staff at each location to assess the building suitability and availability for the whole building airtightness tests. The three small rural buildings (#3, #4 and #5) posed few problems and only required limited planning to successfully complete the tests. In contrast, the sole high-rise structure (#6) required additional planning particularly to assess the extra personnel requirements required for the occupied tests. These extra individuals were recruited from within the college faculty and student body, Manitoba Hydro and Manitoba Housing. Pre-test orientation and training was provided to all non-core personnel.

Based on our experiences conducting these tests, it was possible to identify some of the unique issues associated with testing an occupied building:

- Additional testing personnel are required compared to those needed if the building were unoccupied. Personnel are needed to monitor all: exterior faces with operable windows and doors, entrances and exits (to keep people from entering and leaving the building during the test) and exits with installed fan doors (for safety reasons). Personnel are also required to deal with tenants during the test (e.g. to request they close windows and exterior doors).

- An efficient and disciplined test schedule is needed to reduce inconveniences for the tenants. Additionally, the mechanical system may have to be disabled (depending upon the test being conducted). As a result, apartments may become too hot or cold for the tenants (especially if they are elderly). This can even become a health concern if the test duration is excessive.

- The computer/hardware operator must be very competent and experienced with the equipment and software. The operator must also be particularly diligent during the data collection phase of the test to identify potentially questionable data caused by tenant operation of a window or door. The operator should be capable of modifying the test parameters as well as overwriting results if individual test points have to be re-done.

- 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. And, of course, the cooperation of the tenants is essential.

- Some tenants may not be cooperative with the testing personnel and this will need to be monitored very carefully.

- 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.

3.2 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.

The results of the airtightness tests below on Buildings #3 to #6 illustrate the results when the technique is applied to actual MURB’s whose suite doors are closed, These show the measured airtightness (both the NLR_{75} and ACH_{50}), average suite-to-hallway pressure drop (measured while the building was depressurized to 75 Pa), the correction factors (calculated using Eqs. (3) and (4)), and the final, corrected airtightness.

Estimates of the time required to conduct each test are also shown for each building. These include: 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.

3.3 Building #3

Fig 5: Building #3

Description: Single-storey, 12-unit MURB.
Envelope Surface Area: 2276 m^2 (24,490 ft^2)
Building Volume: 3357 m^3 (118,478 ft^3)

This single-story building was constructed in 1982 and contains 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 centre. 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.

Two tests were conducted on this building: one using the "envelope" protocol for sealing intentional openings and one using the "energy" protocol. The results are summarized in Table 3.

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

Table 3
Measured and Corrected Airtightness Results - Building #3

Test	Sealing Protocol	Measured Value	Avg. Suite-To-Hallway ΔP (% of 75 Pa)	Correction Factor	Corrected Value
NLR_{75} (l/s•m^2)					
3-1	Envelope	0.60	5.8/75 = 7.4%	1.030	***0.62***
3-2	Energy	0.79	7.4%	1.030	***0.82***
ACH_{50}					
3-1	Envelope	1.01	7.4%	1.034	***1.05***
3-2	Energy	1.17	7.4%	1.034	***1.21***

3.4 Building #4

Fig. 6: Building #4

Description: Single-storey, 28-unit MURB.
Envelope Surface Area: 3600 m^2 (38,736 ft^2)
Building Volume: 4746 m^3 (167,500 ft^3)

This was also a single story 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 centre of the east wing. Each apartment had an exterior door (motel style). The main entrance is 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

Table 4
Measured and Corrected Airtightness Results - Building #4

Test	Sealing Protocol	Measured Value	Avg. Suite-To-Hallway ΔP (% of 75 Pa)	Correction Factor	Corrected Value
NLR_{75} (l/s•m²)					
4-1	Envelope	0.96	37/75 = 49%	1.152	***1.11***
4-2	Energy	1.03	49%	1.152	***1.18***
ACH_{50}					
4-1	Envelope	2.14	49%	1.116	***2.39***
4-2	Energy	2.32	49%	1.116	***2.59***

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 shown in Fig. 4.

3.5 Building #5

Fig. 7: Building #5

Description: Single-storey, 8-unit MURB.
Envelope Surface Area: 1465 m^2 (15,763 ft^2)
Building Volume: 2179 m^3 (76,903 m^3)

This single-story 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.

Table 5
Measured and Corrected Airtightness Results - Building #5

Test	Sealing Protocol	Measured Value	Avg. Suite-To-Hallway ΔP (% of 75 Pa)	Correction Factor	Corrected Value
NLR_{75} (l/s•m^2)					
5-1	Envelope	0.14	8.5/75 = 11%	1.042	***0.15***
5-2	Energy	0.18	11%	1.042	***0.19***
ACH_{50}					
5-1	Envelope	1.24	11%	1.041	***1.29***
5-2	Energy	1.62	11%	1.041	***1.69***

3.6 Building #6

Fig. 8: Building #6

Description: 13-storey, 107-unit MURB.
Envelope Surface Area: 4276 m^2 (46,010 ft^2)
Building Volume: 17,207 m^3 (607,283 ft^3)

This 13-story, high-rise building was constructed in 1975 and contains 107 apartments producing a total floor plan area of 6458 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-ridged 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: 118 man-hours

Table 6
Measured and Corrected Airtightness Results - Building #6

Test	Sealing Protocol	Measured Value	Avg. Suite-To-Hallway ΔP (% of 75 Pa)	Correction Factor	Corrected Value
NLR_{75} (l/s•m^2)					
6-1	Envelope	1.10	9.5/75 = 13%	1.037	***1.14***
6-2	Energy	1.48	13%	1.037	***1.54***
ACH_{50}					
6-1	Envelope	0.77	13%	1.038	***0.80***
6-2	Energy	1.04	13%	1.038	***1.08***

4.0 Site Observations - Testing Occupied Buildings

During testing of the six buildings, some general observations were made relating to the practical issues involved in testing fully occupied MURB's. Given that these buildings were fairly typical of their genre, testing similar types of buildings would likely produce similar experiences. Some of these observations are discussed below.

4.1 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, 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 (although for the most part, unintentionally). They continually opened windows and needed constant monitoring and on numerous occasions, the test had to be paused. 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.

4.2 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 insure that no windows are opened during the test.

4.3 Operator and Software Requirements

All airtightness tests conducted on large buildings require considerable knowledge, skill and experience on the part of the test crew. However, testing an occupied building also introduces some unique requirements than normally encountered on unoccupied structures.

Operator Requirements:

- The operator controlling the blower door equipment must be diligent when collecting data to watch for suspicious data which could be produced by unplanned window operation. With care, the operator should be able to identify spurious data points even if the rest of the crew misses unplanned window operation.

- The operator should be competent and experienced with the equipment to comfortably solve software and hardware issues. Further, they must be capable of controlling the software to account for unplanned test stoppages.

Software Requirements:

- The software must be flexible and should permit modifications to the normal, automated test process. For example, it should permit modification to the time period over which the data is sampled.

- The software should be capable of allowing a semi-automated test to be conducted whereby the operator sets the test pressure differential and manually activates the data sampling process.

- The software should permit re-testing of individual data points where erroneous data caused by unplanned window operation has been collected (the erroneous data can be kept in the raw output file, but should not be included in the test results within the software).

- The software should provide complete control over the blowers so that the test can be immediately stopped should problems arise.

- The software should permit all raw data to be collected, including any excluded from the final results.

- The software should provide individual and group fan control (the fans should be capable of being controlled with different speed/power settings since fans at different locations may have different requirements, as well as a software setting that sets all fan equipment to the same speed/power setting).

- The software should be capable of maintaining relatively constant conditions so that the pressure differentials across suite doors can be measured under the same indoor-to-outdoor pressure differential.

Hardware Requirements

- The hardware should permit immediate shut-down of the fans if a window or door is inadvertently opened.

- The hardware should be easily removed from the doors in the event of an emergency situation.

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.

5.0 Discussion

5.1 Overview of the Proposed Protocol for Testing Occupied MURB's

The results of this project have demonstrated that it is possible to conduct an airtightness test on an occupied MURB, even if the interior suite doors are closed:

1. Perform the airtightness test using an established protocol such as the AABA/ASTM "*Standard Method for Building Enclosure Airtightness Compliance Testing" (draft)*. The test can be conducted with interior suite doors closed. However, windows ***must*** be kept closed when measurements are being performed. If a window is opened at some point, the test must be halted and the window closed before the test can be resumed.

2. Determine the average pressure differential across the interior suite doors when the building is depressurized to a stable 75 Pa. Ideally, the pressure differentials across all closed suite doors should be measured. However, in a larger building this may not be practical, so as large a sample as possible should be used. The selected suites should be well distributed both vertically and horizontally in the building.

3. Using the average, measured pressure differential across the suite doors, apply Eqs. (3) and (4) to determine the corrected NLR_{75} and ACH_{50} results.

$$\text{Corrected } NLR_{75} = (\text{Measured } NLR_{75}) \times K1 \quad (3)$$
where $K1 = 1 + [0.2911\ (\Delta P/75) + 0.0089]$

$$\text{Corrected } ACH_{50} = (\text{Measured } ACH_{50}) \times K2 \quad (4)$$
where $K2 = 1 + [0.1964\ (\Delta P/75) + 0.0192]$

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

5.2 Interior Doors Open or Closed - What Are The Appropriate Conditions For Expressing MURB Airtightness Results?

The primary objective of this project has been to determine if an airtightness test can be successfully conducted on an occupied, Multi-Unit Residential Building - if the interior suite doors are closed. The results of this project suggest that, in fact, this is quite possible and further, that the errors introduced by the closed doors can be mathematically accommodated and corrected. However, this raises an interesting issue: what are the appropriate conditions for expressing airtightness results for a MURB?

Virtually every airtightness testing standard in use today requires the test to be conducted with all of the building's interior doors open, thereby turning the structure into a single large zone. In this way, the entire envelope is subjected to relatively uniform pressure differentials during the test - other than those created by wind and stack action. While MURB's may be similar to other types of buildings in the design and construction of the envelope details, their normal operation is somewhat unique. Unlike most commercial, institutional or industrial structures, MURB's are normally, in fact almost always, operated with their interior doors closed. These function as obstructions to air flow and, along with other flow restrictions (such as floors, interior partitions, etc.), result in the pressure differentials across the building envelope being less than they would otherwise be if the doors were kept fully open.

From a building science perspective, this can be better understood using the concept of the Thermal Draft Coefficient (TDC). The ASHRAE Handbook of Fundamentals defines the TDC as the actual pressure differential across the envelope divided by the theoretical pressure differential which would occur if there were no floors, partitions, etc. - in other words, if the structure were a single-zone building. The difference between the theoretical and actual pressure differentials is a measure of the internal flow resistance created by the floors, partitions, etc. A TDC of 1.0 would represent a single-zone structure while a value of 0.0 would represent a structure whose internal partitioning was perfectly airtight.

Although data is limited, some measurements by Tamura and Wilson of the National Research Council of Canada (NRC) found TDC values ranging from 0.8 to 0.9 for a three storey building (1967) - although the position of the interior doors is unknown. With the financial assistance of CMHC, Proskiw and Phillips (2006) measured winter TDC values of two Winnipeg MURB's (15 and 17 storeys, respectively) over week-long periods and observed values which ranged from about 0.5 to 0.8. All measurements were performed with the interior suite door closed. In other words, up to half of the total resistance to air flow across the building envelope was created by the internal partitions, not by the building envelope.

As a building becomes more compartmentalized (i.e. sub-divided into separate physical zones which have appreciable levels of airtightness between each other), the numerical value of the TDC will decrease. Increasing levels of compartmentalization reduce the pressure differential across the building envelope since a greater portion of the driving force (which causes air leakage) is assumed by the interior partitions, floors, etc. For this reason, compartmentalization is now being suggested, and occasionally used, as a means of reducing air leakage since it moderates the envelope pressure differentials.

Which leads to the following question - even if it were possible to test an occupied MURB with all interior doors open, would this be the most representative test configuration to express the operational airtightness of the building. In other words, should MURB's be tested with their interior doors open or closed? The argument for testing with doors open is simple: consistency with all established airtightness testing standards and protocols. This permits direct comparisons to test results from other types of buildings (which are also tested with their interior doors open). The argument against testing with the interior doors open is that the doors-closed configuration more accurately reflects normal building operation. Remember, the most critical issue an airtightness test attempts to answer is simply this: how tight is the building? Consider a hypothetical MURB which had a very leaky building envelope but whose interior partitions, floors and interior doors were perfectly airtight. An airtightness test conducted with the interior doors open would show the building (or more correctly the building envelope) to be very leaky. However, the same test conducted with the interior doors closed would indicate totally different results - a very airtight structure. The issue then becomes - which test configuration most accurately represents the building as it normally operates? Given that the doors-closed scenario is most reflective of normal building operation, a strong argument can be made for using this testing configuration. After all, this hypothetical building would be expected to operate with very low levels of natural infiltration - not because of the airtightness of the building envelope, but rather due to the airtightness of the internal partitioning.

Now, what are the implications of this argument from the perspective of this project? First, the experiences and results from the field testing clearly show that it is possible to test an occupied building, although additional planning, preparation, time and patience (sometimes in copious quantities) are required. Second, the "error" introduced by closed interior suite doors can be estimated by measuring the average pressure differential across the suite doors while the building is depressurized which can then be used to apply a mathematical correction which effectively returns the building to the "open door" configuration. Depressurization is preferred to pressurization since the former will help to keep hinged windows closed and provide more consistent measurements.

However, since buildings such as MURB's are normally operated with their interior doors closed, it is recommend that the results for both the "doors closed" and the corrected, "doors open" configuration be reported. With increased understanding of this issue and more test results become available, time will tell which configuration is most representative of the true airtightness of an occupied building.

In any event, the results of a single investigation - such as this study - do not provide sufficient information from which to draw a firm conclusion. However, *consideration should be given to using both the "doors closed" and the corrected, "doors open" test configurations in air tightness test protocols to express the airtightness of buildings such as Multi-Unit Residential Buildings in which the building is normally operated with most of its interior doors closed.*

6.0 Conclusions

1. 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).

2. 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.

3. 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.

Nomenclature:

ACH_{50} - The air leakage rate of a building, expressed as the number of air changes per hour at an indoor-to-outdoor pressure differential of 50 Pa.

NLR_{75} - Normalized Leakage Rate; the air leakage rate of a building, expressed as the air leakage per square metre of building envelope area at an indoor-to-outdoor pressure differential of 75 Pa.

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Appendix A – ABAA/ASTM Standard Method for Building Enclosure Airtightness Compliance Testing

The ABAA/ASTM test method was derived from the U.S. Army Corps of Engineers (USACE) standard for testing large buildings and reflected some of the lessons learned using the USACE protocol in the field. Since most readers of this report will be familiar with CGSB 149.10 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method", Table A-1 has been prepared to summarize some of the key features, and differences, between the ABAA/ASTM and CGSB 149.10 protocols. While the two are basically similar, there are some important differences which reflect the intended applications of the two documents.

Aside from the explicit differences between the two documents, their hardware and personnel requirements are radically different - although this is largely due to the types of buildings they are designed to test. The vast majority of airtightness tests conducted using CGSB 149.10 are performed by a single individual using a blower door which is small enough that it can be easily transported with a compact car. Commercial building tests performed using the ABAA/ASTM protocol are much more challenging from a logistics perspective. For example, the total equipment kit weighs in excess of 500 kg. (1000 lb.) and typically requires a truck with a 3 m to 6 m (10' to 20') box for transport. Further, the number of personnel required will range from as low as 3 to over a dozen, depending on the building, its complexity and occupancy.

Table A-1

Comparison Between ABAA/ASTM and CGSB 149.10

	ABAA/ASTM	CGSB 149.10
Primary application	Large, commercial-style buildings	Houses
Typical air flow capacity required	25,000 l/s (50,000 cfm)	2500 l/s (5,000 cfm)
Test pressure range	up to 75 Pa	15 Pa to 50 Pa
Number of test points	≈10	8
Positive or negative pressurization	Positive and negative	Negative only
Sealing schedules for intentional openings	Two (Energy and Envelope)	One (Envelope)
Reference pressures normally used to express results	50 Pa and/or 75 Pa	10 Pa and/or 50 Pa
Minimum acceptable correlation coefficient (r) for test data	0.99	0.99

APPENDIX B – MURB Types

Multi-Unit Residential Buildings come in a variety of sizes and designs and can be constructed using almost any type of construction material including wood framing, steel, masonry, etc. The following describes the most common building configurations used by MURB's.   Notice they are grouped into two categories - those MURB types which can be tested using the new protocol and those not covered by the protocol. Brief descriptions of the test setup for the first category are also included.

MURB's Which Can Be Tested With the New Protocol

Mid and High-Rise Apartments

A tall structure that typically has at least six floors, common entrances, areas and corridors. These buildings have centralized HVAC systems (with many intentional openings) which have to be carefully studied to prepare them for the test.

An airtightness test on a high-rise apartment requires care to ensure the building is properly prepared (verifying and correctly sealing the building's intentional openings) and that proper control is exercised over the mechanical system. Since it is a multi-storey structure, the testers must verify that the desired pressure differential is attained across the building envelope. The equipment setup should allow for at least one operable exterior access to the corridor, preferably the entrance closest to the elevator(s). If possible, the test equipment can be set up in the emergency exits to minimize disruption and keep the main entrances operational.

Low-Rise Apartments

This type of MURB typically has two to four floors, and is usually provided with elevator service. They usually have common entrances, although individual suite doors which open to the outdoors are frequently included. The HVAC systems can be either fully centralized or a mix of centralized and suite-located.

Low-Rise, Walk-up Apartments

A building that is typically between two and four floors without elevator service. They usually have common entrances, corridors and centralized HVAC systems.

Maisonette

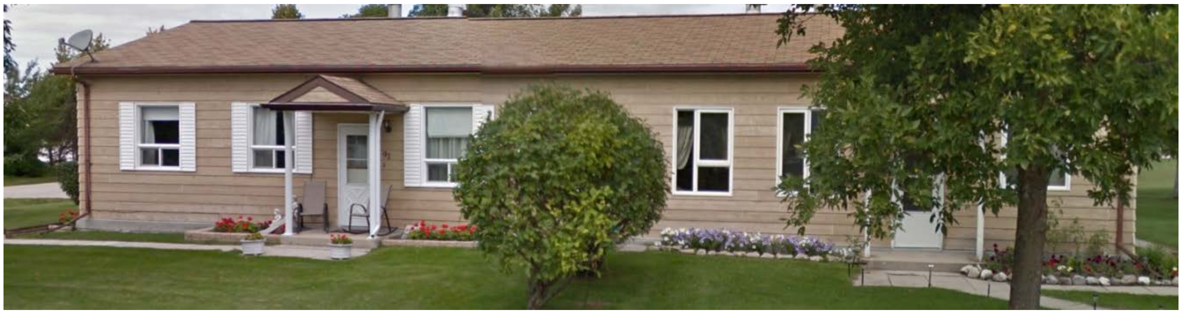
A two-story building with the apartments sharing a common corridor and, in some cases, have individual exterior entrances. The HVAC systems can be either fully centralized or a mix of centralized and suite-located

Motel Style

A single-story building with the apartments sharing a common corridor with individual exterior entrances. These buildings have a main entrance/vestibule serving the corridor and common area.

MURB'S Which Cannot Be Tested With the New Protocol

Duplex



Basically, this is a house divided into two apartments, each with separate entrances. Each unit typically has its own HVAC system.

Since there is no common corridor, this type of MURB cannot be tested with the new protocol.

Fourplex

Basically, this is a house divided into four apartments, each with separate entrances. Each unit typically has its own HVAC system.

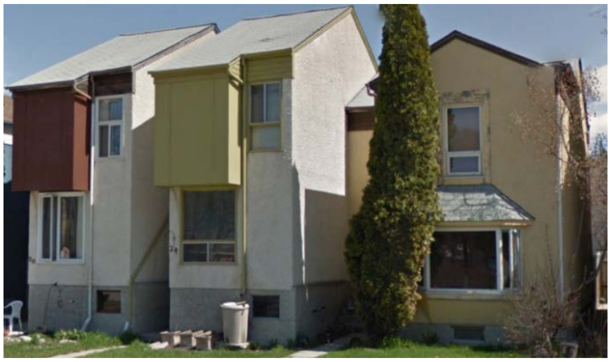
Stacked townhouse

A building with the majority of apartments accessed through a common corridor. The remaining apartments have separate entrances and do not have apartment access from the corridor.

Townhouse

A building with adjacent apartments with separate exterior entrances.

Triplex



A house divided into three apartments with separate entrances.