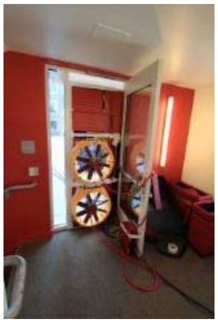
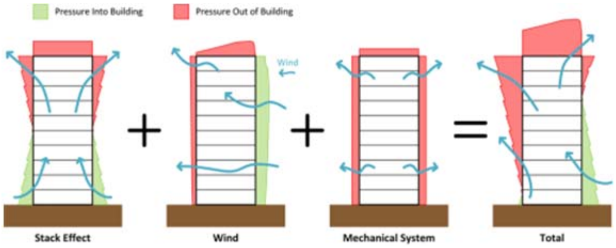
Air Leakage Control in Multi-Unit Residential Buildings

Development of Testing and Measurement Strategies to Quantify Air Leakage in MURBS





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EXECUTIVE SUMMARY

The uncontrolled flow or air in to, out of, and within multi-unit residential buildings (MURBs) can create performance problems with respect to energy consumption, moisture, and indoor air quality. Currently, there is no mandatory airtightness requirement for MURBs in Canada. This study provides a review of the current state of the industry with respect to airtightness in MURBs including testing requirements and techniques, performance targets, current MURB airtightness, and industry airtightness testing capacity.

Airflow in MURBs is driven by pressure differences that are primarily created as a result of wind, stack effect, and building mechanical ventilation systems. To help control the airflow as a result of these forces, air sealing is used both as part of the exterior building enclosure and as part of interior separators. The use of air sealing in interior separators such as floor slabs and walls is often referred to as compartmentalization.

Literature regarding airtightness testing, specifications and building case-studies with respect to MURBs was reviewed to gain an understanding of the current information available in industry. Based on this review it was found that airtightness testing of MURBs is not widespread in North America; however, the specialized airtightness testing equipment that is required to perform this type of testing is typically readily available. Additionally, while quantitative testing allows for the numerical comparison of airtightness performance, qualitative testing can be useful for identifying air leakage locations especially as part of forensic and quality control procedures.

Numerous test procedures and specifications exist in North America and world-wide. These include standards by CGSB (Canadian General Standards Board), ASTM (American Society for Testing and Material), ISO (International Organization for Standardization). Additionally, specific programs such as LEED (Leadership in Energy and Environmental Design) have requirements to achieve accreditation. One of the most consistently implemented testing procedures and performance standards in North America is governed by the United States Army Corps of Engineers (USACE) which mandates that all of its building be tested to ensure compliance with its requirement of 0.25 cfm/ft² (1.27 L/s·m²) of enclosure area at an indoor-to-outdoor pressure differential of 75 Pa. This performance target has been consistently met on hundreds of USACE buildings including barracks buildings which are similar in form to a typical MURB.

To determine the current airtightness performance of MURBs, a database of MURB airtightness testing results was created using data provided by project team members and well as other organizations in industry. Based on the data collected, MURBs currently being tested have an average airtightness of approximately 0.74 cfm/ft² (3.76 L/s·m²). This value includes all MURBs in the database that were appropriately tested except for those tested as part of the US ACE requirement. The airtightness of MURBs generally decreases with age which indicates that MURBs are being more designed and constructed more air-tightly now than they were previously. The buildings in the database were also analysed with respect to compartmentalization when data for balanced testing and 6-sided testing was available, and this analysis indicated that generally interior separators were more airtight than the exterior enclosure. However, this may be because 6-sided airtightness testing is required by LEED so most of this type of testing is done to meet the LEED requirement which may skew the results because buildings that are built to meet a specific performance requirement that will be verified through testing typically are more airtight than comparable buildings without this requirement. This is evident through the USACE building data which clearly indicates the value of an airtightness performance requirement and mandatory verification testing. In reality, it is likely that interior separators are less airtight than the exterior enclosure.

While a broad survey of industry was conducted to gauge industry perception and preparedness with respect to airtightness testing, respondents to the survey were more likely to be involved with airtightness of buildings than the average industry member, implying a bias in the survey responses. The responses indicate a general support for the implementation of airtightness testing and performance and regulatory requirement for MURBs, and many respondents felt that while industry capacity may not currently exist, it could be developed within approximately 2 years with the aid of training programs.

Airtightness was identified as important in MURBs for energy conservation, moisture control, indoor air quality, and acoustics, in order of importance.

Based on the review of test standards and procedures it was determined that an initial performance target, for the whole building, of 0.40 cfm/ft^2 (2.0 L/s·m^2) may provide a good value for use in Canadian codes and standards. However, testing procedures such as those by CGSB and ASTM need to be adapted to better accommodate the compartmentalized nature of MURBs, or a new testing standard could be created using the Pressure Neutralized Fan Depressurization/Pressurization technique. The implementation of any airtightness testing and performance requirement would require a grace period to allow for the development of industry capacity.

RÉSUMÉ

La circulation incontrôlée de l'air vers l'intérieur et l'extérieur des collectifs d'habitation, ou encore à l'intérieur même de ceux-ci, peuvent engendrer des problèmes de performance sur le plan de la consommation d'énergie, de l'humidité et de la qualité de l'air intérieur. Il n'existe actuellement, au Canada, aucune exigence obligatoire relative à l'étanchéité à l'air pour les collectifs d'habitation. Dans la présente étude, on se penche sur la situation actuelle de l'industrie en matière d'étanchéité à l'air dans les collectifs d'habitation, notamment les exigences et les techniques d'essai, les cibles de performance, l'étanchéité à l'air courante des collectifs d'habitation et la capacité de l'industrie à réaliser des essais d'étanchéité à l'air.

La circulation d'air dans les collectifs d'habitation est causée par les différences de pression qui sont principalement créées par le vent, l'effet de cheminée et les installations de ventilation mécanique des bâtiments. Afin d'aider à contrôler la circulation d'air engendrée par ces forces, on a recours à l'étanchéisation à l'air tant dans l'enveloppe extérieure du bâtiment que dans les séparateurs intérieurs. Le recours à l'étanchéisation à l'air dans les séparateurs intérieurs, comme les dalles de plancher et les murs, est souvent appelé la compartimentation.

Les documents portant sur les essais d'étanchéité à l'air, les spécifications et les études de cas d'immeubles visant des collectifs d'habitation ont été examinés afin de comprendre l'information dont dispose actuellement l'industrie. En se fondant sur cet examen, on a constaté que les essais d'étanchéité à l'air des collectifs d'habitation ne sont pas pratique courante en Amérique du Nord; cependant, l'équipement spécialisé nécessaire pour effectuer ces essais est habituellement facile à obtenir. De plus, bien que les essais quantitatifs permettent de réaliser une comparaison numérique de la performance sur le plan de l'étanchéité à l'air, les essais qualitatifs peuvent être utiles pour déterminer les endroits où il y a infiltration d'air, particulièrement dans le cadre des procédures en laboratoire et de contrôle de la qualité.

Il existe de nombreuses procédures et spécifications d'essai en Amérique du Nord et à l'échelle mondiale, notamment les normes de l'ONGC (Office des normes générales du Canada), de l'ASTM (American Society for Testing and Material) et de l'ISO (Organisation internationale de normalisation). En outre, des programmes spécifiques, comme LEED (Leadership in Energy and Environmental Design), établissent des exigences pour l'obtention d'une certification. L'une des procédures d'essai et normes de performance le plus souvent utilisée en Amérique du Nord est régie par le United States Army Corps of Engineers (USACE) qui exige que tous ses bâtiments soient mis à l'essai afin de s'assurer qu'ils ont une enveloppe offrant une performance de 0,25 pi^3/min par pi^2 (1,27 L/s par m²) à une pression différentielle de l'intérieur vers l'extérieur de 75 Pa. Cette cible de performance a toujours été atteinte dans des centaines de bâtiments de l'USACE, notamment les bâtiments de casernement dont la forme rappelle celle d'un collectif d'habitation typique.

Pour déterminer la performance actuelle des collectifs d'habitation sur le plan de l'étanchéité à l'air, on a créé une base de données sur les essais d'étanchéité à l'air des collectifs d'habitation à partir de données fournies par les membres d'équipes de projet ainsi que par d'autres organisations de l'industrie. En se fondant sur les données recueillies, les collectifs d'habitation qui sont mis à l'essai actuellement ont une étanchéité à l'air d'environ 0,74 pi^3/min par pi^2 (3,76 L/s par m²). Cette valeur vaut pour tous les collectifs d'habitation figurant dans la base de données qui ont été adéquatement mis à l'essai conformément à l'exigence de l'USACE. L'étanchéité à l'air des collectifs d'habitation diminue généralement au fur et à mesure qu'ils prennent de l'âge, ce qui signifie que les collectifs d'habitation sont maintenant conçus et construits pour être plus étanche à l'air qu'ils ne l'étaient auparavant. La compartimentation des immeubles figurant dans la base de données a été analysée lorsque les données sur les essais équilibrés et les essais sur six côtés ont été accessibles, et cette analyse a révélé que les séparateurs intérieurs étaient généralement plus étanches à l'air que l'enveloppe extérieure du bâtiment. Cependant, ce résultat peut être attribuable aux essais d'étanchéité à l'air sur six côtés qui sont exigés pour la certification LEED, ce qui pourrait fausser les résultats parce que les immeubles construits pour être conformes à une exigence de performance précise, qui sera vérifiée à l'aide d'essais, sont habituellement plus étanches à l'air que des immeubles comparables qui ne respectent pas cette exigence. On le constate par les données sur les bâtiments de l'USACE qui indiquent clairement la valeur d'une exigence relative à l'étanchéité à l'air et

des essais de vérification obligatoires. En réalité, il est probable que les séparateurs intérieurs sont moins étanches à l'air que l'enveloppe du bâtiment.

Alors, une enquête auprès des gens de l'industrie afin de juger de leur perception et de leur état de préparation relativement aux essais d'étanchéité à l'air les répondants à l'enquête étaient plus susceptibles d'être impliqués avec étanchéité à l'air des bâtiments que le membre moyen de l'industrie, ce qui implique un biais dans les réponses à l'enquête. Les réponses indiquent un appui général en faveur de la mise en œuvre des essais d'étanchéité à l'air et des exigences règlementaires relatives à la performance des collectifs d'habitation, et bon nombre de répondants pensaient que bien que la capacité de l'industrie existe actuellement, elle pourrait être développée d'ici deux ans en offrant des programmes de formation. L'étanchéité à l'air a été soulignée comme étant importante dans les collectifs d'habitation sur le plan de l'économie d'énergie, du contrôle de l'humidité, de la qualité de l'air et de l'acoustique (dans cet ordre de priorité).

En se fondant sur l'examen des normes et procédures d'essai, on a établi qu'une cible de performance initiale pour l'ensemble du bâtiment de 0,40 pi^3/min par pi^2 (2,0 L/s par m^2) pourrait présenter une bonne valeur pouvant être utilisée dans les codes et normes du Canada. Toutefois, les procédures d'essai, comme celles établies par l'ONGC et l'ASTM, doivent être adaptées afin de correspondre davantage à la nature compartimentée des collectifs d'habitation, ou l'on pourrait rédiger une nouvelle norme en se servant de la technique de dépressurisation/pressurisation avec un ventilateur à pression neutre. Pour mettre en œuvre tout essai d'étanchéité à l'air et une exigence de performance, il faudrait qu'il y ait un délai de grâce afin de permettre à l'industrie de développer sa capacité.

1. Project Overview

1.1. Background

Air leakage or inadequately controlled airflow into, out of, and within multi-unit residential buildings (MURBs) has historically been associated with performance issues including moisture damage as a result of interstitial condensation, comfort issues as a result of cold drafts, and indoor air quality concerns. Recently, in response to increasing societal concerns and rising energy costs, additional focus has been put on limiting air leakage as part of energy conservation targets. As Lovatt correctly identifies, an "airtightness testing requirement … represents one of the first 'as-built' requirements related to energy use in building codes." (Lovatt 2008)

Testing of air leakage characteristics in houses has been common practice in Canada for approximately 35 years with roughly 250,000 to 500,000 houses having been tested in that time. The technology associated with measurement is readily available and many practitioners are able to undertake the testing. As a result of this wide-scale testing, a large volume of data has been accumulated that provides a comprehensive profile of typical airtightness levels in houses. While some air leakage testing has been undertaken on larger buildings, due to the often more complex nature of testing procedures, lack of regulation, and the larger scale equipment that can be required, this type of testing is significantly less frequent and is particularly rare for MURBs. Because limited testing has been performed and the results from tests that have been performed are largely not compiled, it is difficult to determine typical air leakage characteristics for MURBs. As there are over 3 million residential dwellings in Canadian MURBs and combined these use more than 141 million gigajoules of energy each year, this represents a significant knowledge, testing, and regulation gap. (Natural Resources Canada 2007)

As part of controlling air leakage into and out of MURBs it is practical to set quantitative requirements in building regulations; however, to set these requirements, certain information is necessary: a qualitative understanding of airflow; an understanding of the required level of airtightness for performance; an understanding of current airtightness performance and the feasibility of achieving certain airtightness targets; and a practical and economical testing method to confirm that the airtightness targets are met. This report seeks to further the understanding of these areas by providing an update and expansion of the previous CMHC research report *Air Leakage Characteristics, Test Methods and Specifications for Large Buildings (2001)* by Proskiw and Phillips.

1.2. Scope

To develop the understanding of airtightness in MURBs, this study undertook a number of tasks. These tasks, as specified in the project proposal, are listed below.

- Literature review
- Study of large building airtightness regulatory requirements in international jurisdictions and industry capacity to ensure compliance with regulations
- Review of industry preparedness in Canada to address air leakage control in MURBs

To complete these tasks, a number of distinct techniques were used and these are provided below.

- Review of literature relevant to MURB airtightness
- Review of testing protocols and standards (Canadian and International)
- Survey of industry involvement and preparedness
- Compilation of a MURB airtightness database

This study deals specifically with airtightness characteristics of the exterior building enclosure of MURBs and also provides some discussion of internal airflows, in particular with respect to compartmentalization.

2. Airflow in Multi-Unit Residential Buildings

Airflow control in buildings is a key component of building performance for reasons of durability, air quality, comfort, and energy efficiency. Common modes of airflow in a typical MURB are shown in Fig.2.1.

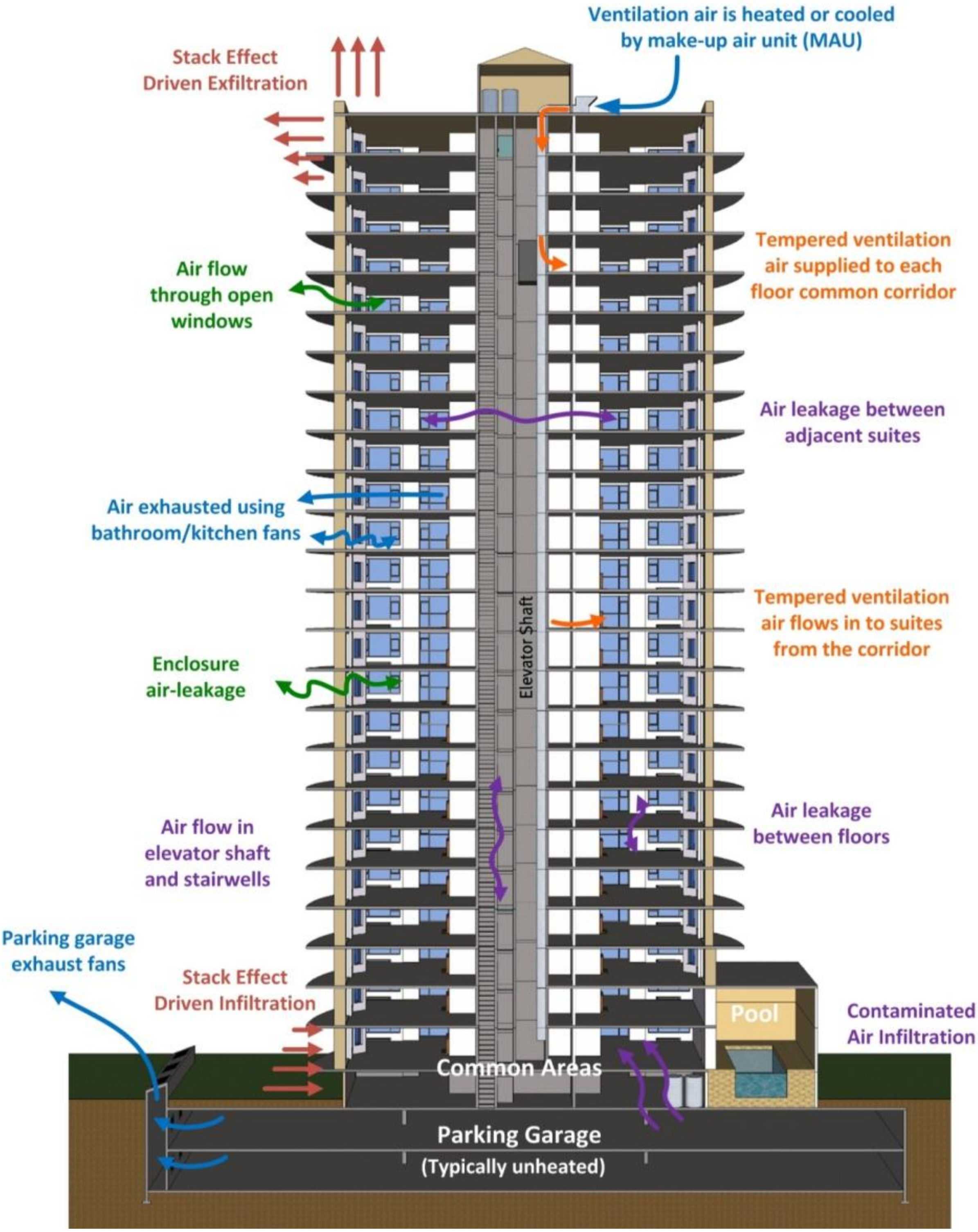


Fig.2.1 Modes of Airflow in a Typical High-rise MURB

The control of airflow can be separated into two fundamental components: driving forces and control methods. Before effective control of airflow can be established, the driving forces behind the airflow need to be understood. These components of airflow are discussed in the subsequent sections.

2.2. Driving Forces

Airflow between spaces (i.e. rooms, suites, storeys) in residential buildings is driven by pressure differences between these spaces. These pressure differences can exist between the exterior and the interior, or between internal building spaces. The pressure differences can be created by the wind, stack effect, and mechanical supply and exhaust fans. These forces are further discussed in the following sections.

2.2.1 Wind

Wind typically creates the peak pressure differences across the building enclosure. Positive pressure differentials occur on the windward side of the building, forcing air into the building through openings. At the same time, negative pressure differentials on the roof and leeward sides will draw air out of the building. These pressure differences tend to cause air to flow through the building horizontally from the windward side towards the leeward side of the building.

Wind pressures experienced by a building depend generally on the climate in which the building is located and the exposure of the building to wind which can be impacted by the shape, height, and orientation of the building as well as local geography, and sheltering provided by neighbouring objects.

Wind pressures up to 50 Pa for exposed buildings located in Canada are common and can range much higher for short periods. Average pressures in the range of 5 Pa to 10 Pa are common; however, this depends on the exposure of the building, microclimate, and building geometry including height above grade.

The pressures created on a building as a result of wind are typically measured as a proportion of stagnation pressure, which is the pressure caused by moving air when it comes to rest against a surface (also referred to as the velocity pressure.) To provide the pressure at a point on the building as a fraction of the stagnation pressure, a unitless local wind pressure coefficient is used (C_p). Full stagnation pressure ($C_p = 1$) is typically not achieved for a large area of a building enclosure. The local pressure coefficient distributions on the surface of a typical tall rectangular building (i.e. a high-rise MURB) are shown in Fig.2.2 for varying wind angles, and on a whole building at once in Fig.2.3 for the case of wind normal to the windward face of the building.

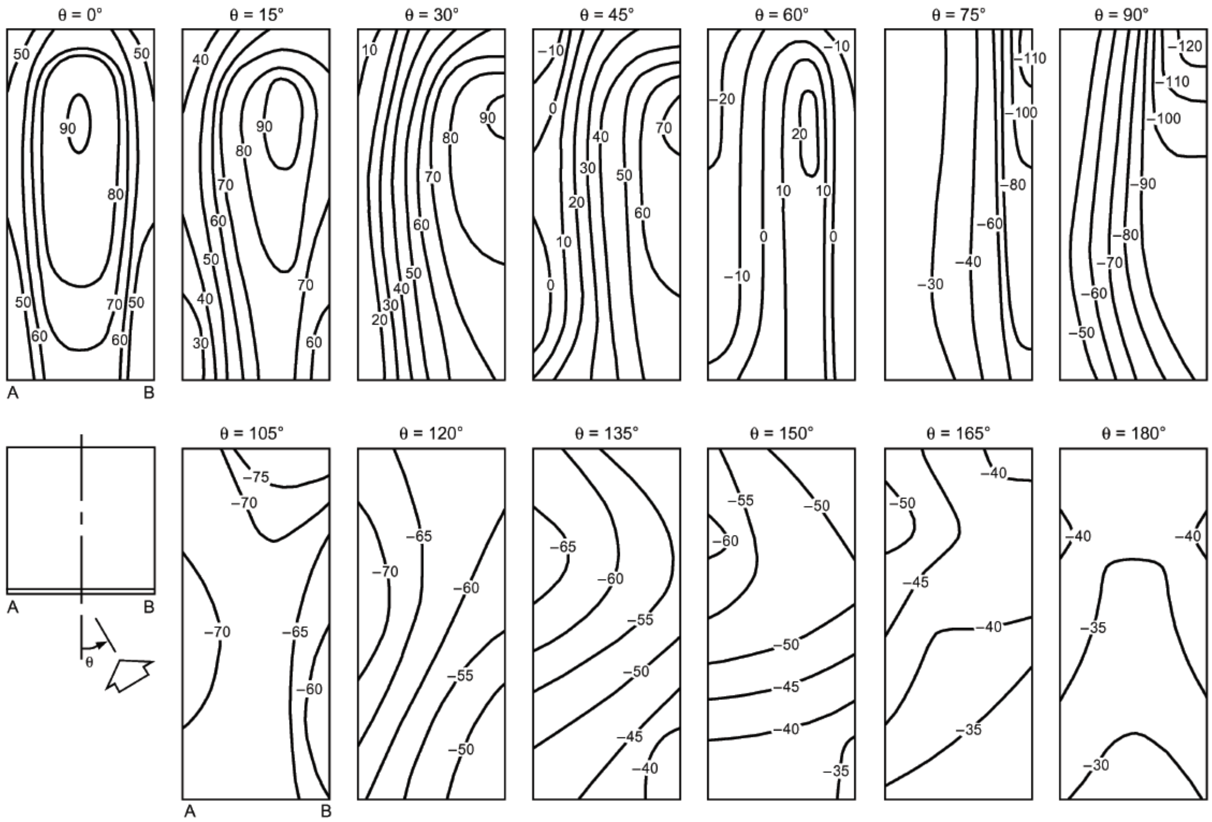


Fig.2.2 Local Pressure Coefficients (C_p x 100) for Tall Buildings (ASHRAE 2009)

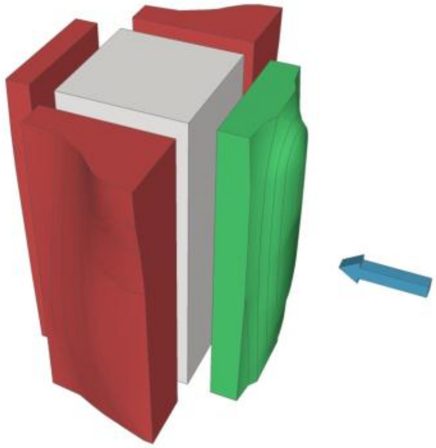


Fig.2.3 Pressure magnitude representation of positive (green) and negative (red) wind pressures acting on the vertical building enclosure as a result of wind direction.

The pressure caused by the wind at stagnation (assuming an air density of 1.2 kg/m^3) is shown in Fig.2.3. 75%, 50%, and 25% lines are also illustrated for reference as the full stagnation pressure of the wind is rarely achieved on the surface of a building, as shown by the local pressure coefficient discussed above. The coloured sections of the graph identify approximate ranges for low, average, high, and extreme average wind speeds in Canada to provide context.

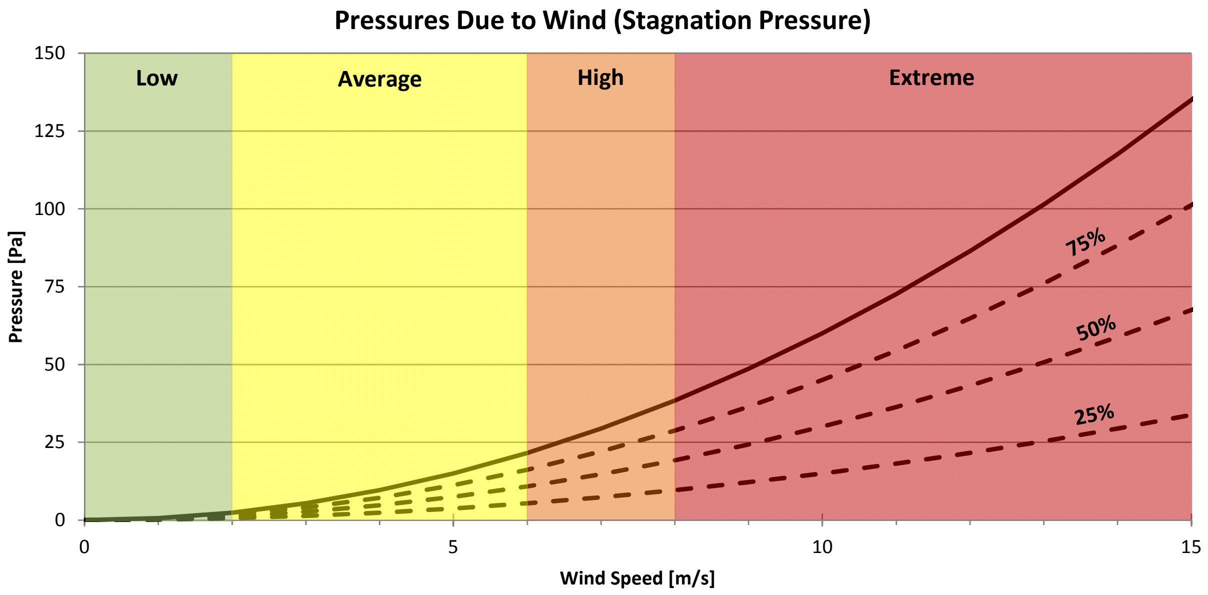


Fig.2.4 Pressures Due to Wind

An important characteristic of wind with respect to its impact on building airflow is that it is very dynamic both temporally and spatially. The magnitude and the direction of the wind are constantly fluctuating which makes it very difficult to predict the effect it will have on the building at any given moment in time. Because the direction of the wind varies, the pressures created by the wind on a building also change. While wind direction and magnitude fluctuate at high frequency, for the impact on buildings with respect to exfiltration, infiltration, longer term average wind speeds and directions are more relevant and these can be determined from historical weather data.

The distribution of the magnitude of hourly average wind speeds at a given location has often been found to approximately follow a Weibull probability distribution function with a *k* value (shape parameter) of approximately 2 (Yilmaz and Celik 2008). (A Weibull distribution with k equal to 2 is also known as a Rayleigh distribution.) Weibull distributions with a shape parameter of 2 are shown in Fig.2.5. The coloured areas again identify approximate ranges for average wind speeds to provide context.

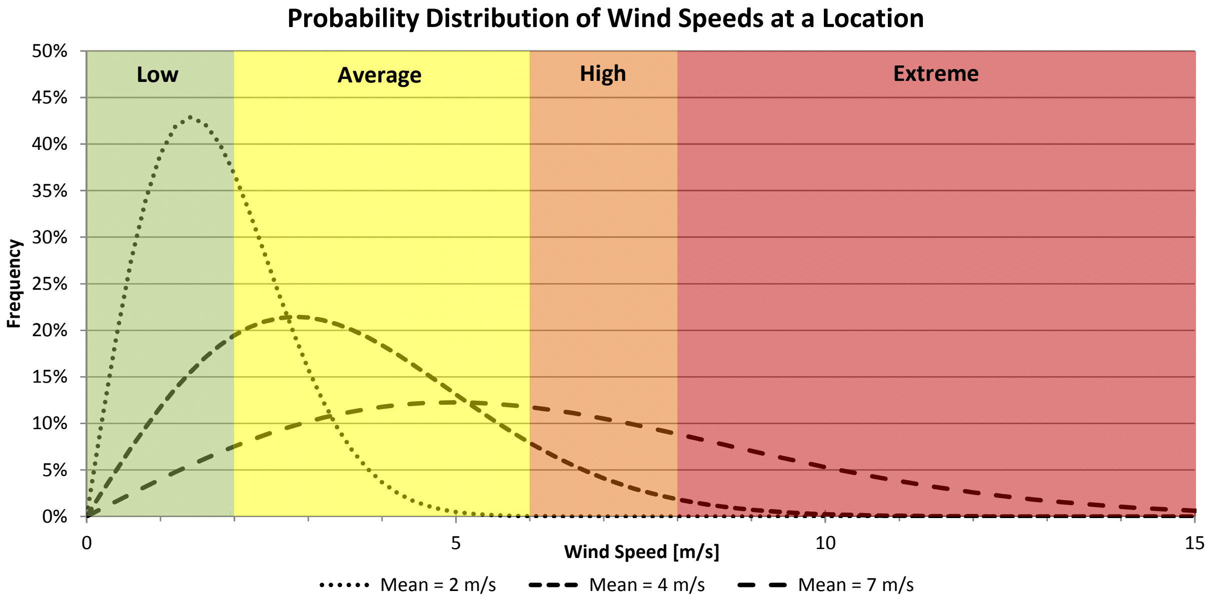


Fig.2.5 Probability Distribution of Wind Speeds at a Location (k = 2)

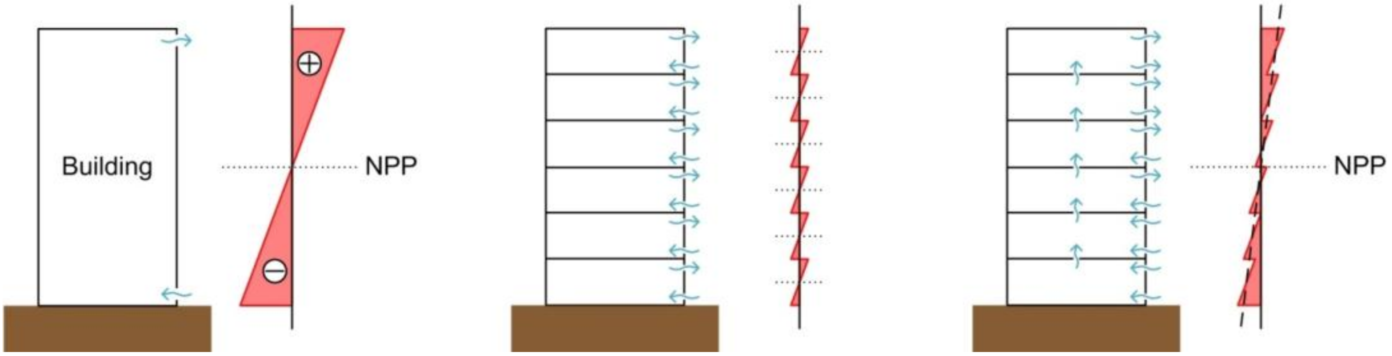
For a mean wind speed of 4 m/s, the mean stagnation pressure of the wind is 10 Pa. Additionally, for the distribution shown with mean wind speed of 4 m/s, the median (50th percentile) and the 90th percentile wind speeds are 3.3 m/s and 4.9 m/s and the associated stagnation pressures are 6.5 and 14.4 Pa respectively. While this distribution is only an approximation of wind speeds based on an average wind pressure, it does indicate that only rarely do large pressure differences develop across a building enclosure as a result of wind.

While wind pressures can be high relative to other driving forces, they occur for a relatively short period of time over the course of the year. Due to the typically relatively low pressures developed and the high variability of wind direction and magnitude, wind is not typically a significant long-term driving force of airflow in to, out of, and within buildings compared to stack effect. They do however need to be considered in evaluating in-service airflows and ventilation rates

2.2.2 Stack Effect

Stack effect (sometimes also referred to as “chimney effect”) is a driving force for air movement within a building due to the difference in air density caused primarily by the difference in temperature between the interior of the building and the surrounding exterior environment. Warm air is less dense than cool air, thus as one travels up or down in two neighbouring columns of air of different temperature, pressure differences develop across the boundary. During the winter months, this effect creates a positive pressure (forcing air out) on the building enclosure at the ceiling and at upper wall levels, and negative pressure (drawing air in) at the lower portions of the building. In the summer, this effect is reversed; however, temperature differences between interior and exterior during the summer are typically less extreme than during the winter so the magnitude of the effect is reduced.

Fig.2.6 shows three illustrations of the pressure differences developed across the building enclosure due to stack effect where the interior of the building is warmer than the exterior. The three scenarios vary based on the airtightness of the floors in the buildings.



a) No Separation
b) Separated Floors
c) Some Flow through Floors

Fig.2.6 Schematics Showing Stack Effect in a Building Depending on Compartmentalization of Floors

The first image (Fig.2.6a), shows the pressure difference developed across the exterior enclosure of a building due to stack effect if there are no internal separations. The neutral pressure plane (NPP) is defined as the plane at which there is no pressure difference between the interior and exterior of the building, and is horizontal in the absence of wind. The location of the NPP varies depending on the distribution and flow resistance of openings in the building enclosure. If there are more openings towards the top of the building, the NPP will be above the mid-height of the building, and if there are more openings towards the bottom of the building, it will be lower than the mid-height of the building. In this example, the warmer air inside the building is less dense than the exterior colder air. This will tend to cause a negative pressurization at the bottom of the building and a positive pressurization at the top of the building. These pressure differentials will then act to draw air into the building at the bottom and force it out at the top through any openings, intentional or unintentional. If the opposite were true, stack effect forces would be reversed thus forcing air into the building near the top and out of the building near the bottom. Typically, however, stack effect forces are more extreme in a heating climate because of the larger temperature differences that occur during cold weather.

The second image (Fig.2.6b) illustrates the pressure differences developed if the building is separated into floors that are perfectly airtight and separated completely from vertical shafts (i.e. elevators, stairwells etc.). By introducing these airtight separations, the building is essentially split into six sections that operate independently. Thus, a NPP is developed on each floor and air is pulled in at the bottom of each floor and pushed out at the top.

The third image (Fig.2.6c) shows a more realistic building in which there is some airflow through the floors, for example at vertical shafts and unsealed plumbing penetrations. The airflow through the floors provides a link between the previously separated storeys; however, more flow resistance still exists than the entirely open case. Thus, the pressures developed are essentially a combination of those developed in the first two cases.

Fig.2.7 provides an indication of the theoretical pressure differences developed across the enclosure depending on the distance from the neutral pressure plane and the temperature difference for a typical MURB (i.e. the maximum pressure difference across the building enclosure).

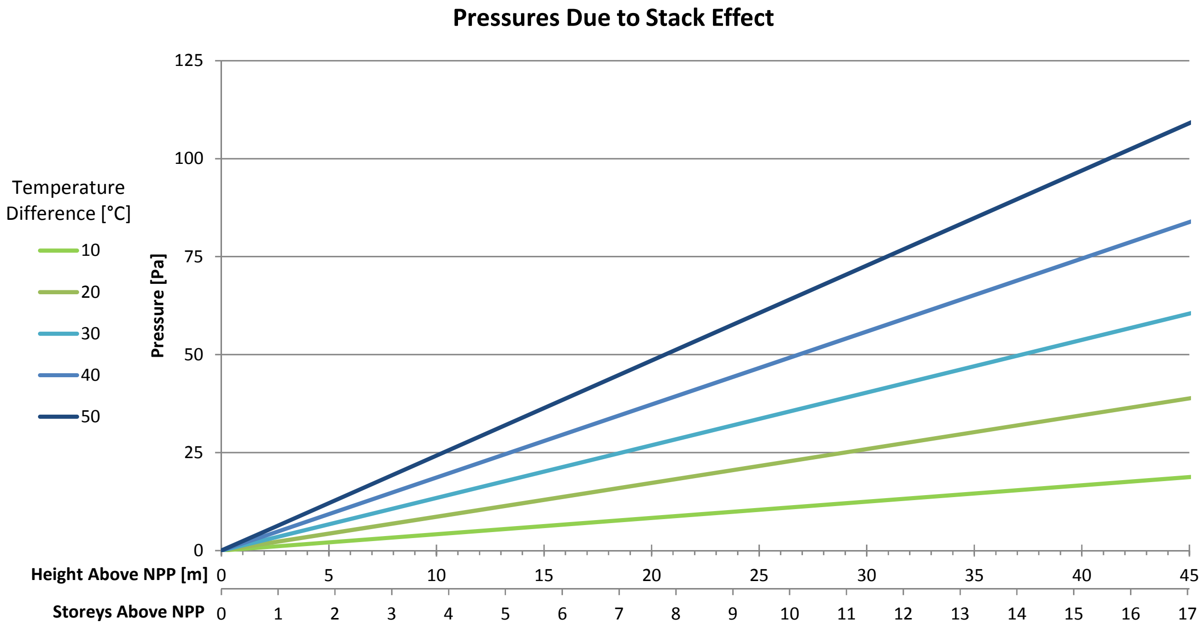


Fig.2.7 Pressure Differences Developed Due to Stack Effect in a High-rise Building (up to 90m, ~34 stories)

In a typical MURB, the interior separators (walls and floors) are not very airtight and elevator shafts and stairwells, even if weather-stripped, will leak to the corridors. Thus, as a result of stack effect pressures an overall interior air flow pattern is typically developed as shown in Fig.2.8.

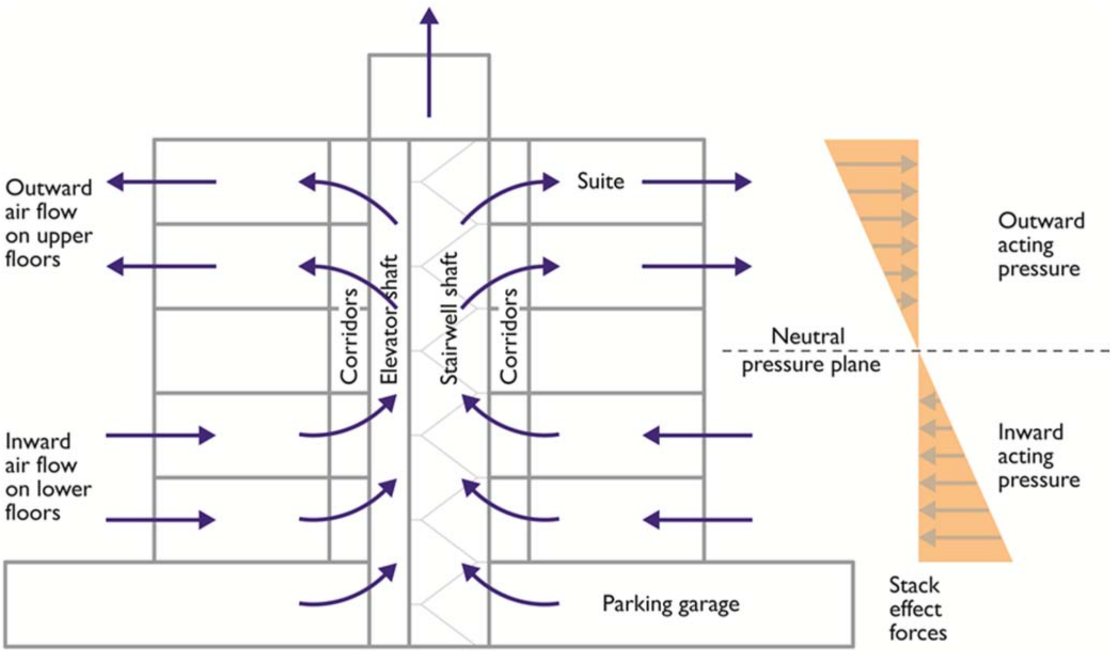


Fig.2.8 Stack Effect Forces and Airflow Within Multi-Unit Residential Building Where Exterior Temperature is Colder than Interior Temperature

Unlike wind which changes in direction and magnitude at high frequency, temperatures typically remains fairly stable and thus the direction of stack effect forces often remains constant for extended time periods. While the actual distribution and magnitude of the pressure differences developed due to stack effect in a real building will depend on the flow resistance and distribution of openings through both the building enclosure and interior separators such as floor slabs, and between vertical shafts and floors, the pressures created due to stack effect is a consistent driving force that is a significant factor in long-term airflow patterns for a building.

2.2.3 Mechanical Systems

Buildings typically have mechanical ventilation systems to ensure the provision of adequate fresh air for the maintenance of indoor air quality and occupant health. These systems frequently develop pressure differences across the building enclosure and interior separators when they draw air out of or force air into building spaces. In fact, some systems rely on the development of these pressure differences for the proper operation of the ventilation system. The pressure differences that are developed by the mechanical systems, whether intentional or unintentional, cause airflow within a building.

The magnitude of mechanical pressure differences vary widely based on building type, mechanical system, occupancy, and several other factors. Intentional pressure differences created between spaces by mechanical systems are usually in the order of 5 to 10 Pa in MURBs; however, much larger pressure differences can be developed in tight buildings or suites with powerful exhaust or supply fans. For example, operating a high capacity range hood in a relatively small and airtight space could significantly depressurize the space.

In multi-unit residential buildings the most common approach to ventilation is a pressurized corridor ventilation system. A corridor pressurization system uses a make-up air unit (MUA), also known as an air-handling unit (AHU), that is generally located on the rooftop. Outdoor air is provided defined schedule: in newer MURBs (the past 30 years) it generally operates continuously, while in older MURBs it may be shut-off at certain times of day or seasonally. As the air is drawn in, it is filtered and heated or sometimes cooled according to the temperature set point of the MUA. Once the air is blown into the building it is distributed to each floor through a large vertical duct often located next to the elevator shaft. A grille is provided at each floor to allow air to flow from the duct to the corridor. This flow of air in to the corridor pressurizes the corridor relative to the surrounding spaces, thus giving the system its name. The pressure differential between the corridor and adjacent suites forces air through door undercuts or specially-designed air transfer ducts into the suites. A door undercut is an intentional gap at the bottom of a suite entrance door that is created to allow the flow of ventilation air. In older corridor pressurization ventilation designs, no provisions were made for continuous exhaust systems in the suites; some newer designs do account for this. Instead, on-demand exhaust fans are usually located in bathrooms, at kitchen range hoods, and connected to clothes dryers to exhaust point source air contaminates (primarily humidity and odours). Fig.2.9 shows the components of a typical pressurized corridor ventilation approach and the schematic in Fig.2.10 shows the airflows in a MURB utilizing this approach.

Fig.2.9 Rooftop Make-up Air Unit, Corridor Supply Grille, and Door Undercuts Utilized as Part of the Pressurized Corridor Air Distribution System in Most MURBs

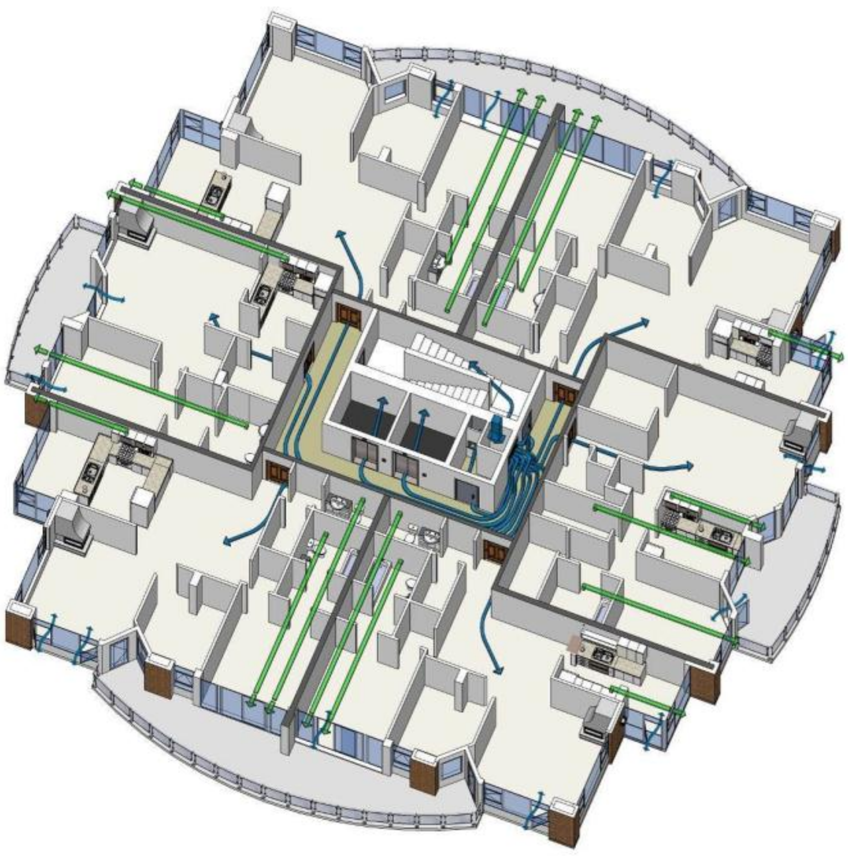


Fig.2.10 Schematic of Typical MURB floor showing a typical Pressurized Corridor Ventilation Approach. Blue arrows show supply airflows and green arrows show exhaust airflows.

A standard pressurized corridor ventilation system is an unbalanced mechanical ventilation system as it generally provides continuous supply, but only intermittent exhaust, in the form of occupant-controlled exhaust fans. Bathroom fans, dryer exhausts, and range hoods operate for relatively small fractions of each day. For the vast majority of hours, a suite has no mechanical exhaust operating. Since there is more supply than exhaust, the pressure tends to increase in interior spaces relative to the exterior which will cause exfiltration through the building enclosure. In a heating climate, the exfiltration of relatively warm and humid interior air through the building enclosure to the exterior creates a risk of condensation within the building enclosure.

The opposite unbalanced condition can also occur with this ventilation system. The system provides a constant amount of air to each suite regardless of the operation of exhaust devices. Thus, while a space can become positively pressurized as discussed above, when on-demand exhaust fans are used, the suite can be depressurized relative to the exterior and/or neighbouring suites. The magnitude of this pressure differential increases as the number of exhaust appliances are operated (e.g. if the dryer, range hood, and bathroom fans are operated simultaneously). This can cause infiltration of air from the exterior through the building enclosure, which in a cooling climate can cause similar condensation issues as discussed with regards to exfiltration in a heating climate. Additionally, airflow through interior separators can bring with it contaminants, of which the most common complaint is cooking odours.

An enclosure that is more resistant to airflow necessitates higher pressure differentials be developed to supply air to building spaces. This can cause unintended air leakage (through any weak points in compartmentalizing elements and/or the building enclosure) and create performance issues for mechanical supply and exhaust fans, which require more power to overcome higher pressures. Furthermore, as these higher pressure differentials are developed, air can be forced in to and out of adjacent spaces which can increase the cross-contamination of air within the building. In some cases, depressurization of a suite can cause dangerous back-drafting of combustion appliances, such as fireplace or in-suite domestic hot water tanks, which get their make-up air from the suite.

As the pressurized corridor system is an unbalanced system that operates based on a pressure difference between the corridor and the suites, if a suite entrance door is opened this will significantly alter the flow path resistance, and consequently the flow pattern for that floor. Similarly, opening windows and operating fans can change flow paths and thus change both ventilation rates and potentially the air source both within suites and for the rest of the building.

Gas fireplaces, whether decorative in function or for space-heating, also affect pressures differentials across the building enclosure and air leakage in MURBs. Atmospheric combustion fireplace units use indoor air for combustion resulting in significant air-exchanges while operating. The open chimney is also a source of air leakage throughout the year. Sealed combustion fireplace units use dedicated outdoor air for combustion; however, the fireplace inserts, duct work, and dampers are a source of potential air leakage.

2.3. Cumulative Effect of Driving Forces

Fig.2.11 qualitatively illustrates the cumulative effects of stack effect, wind, and mechanical systems on the total pressure regime acting on a building enclosure at a given instant in time. While the relative magnitudes of the forces for these conditions are represented accurately in the image (for an outdoor temperature of -5°C and a wind speed of 4 m/s), the image is primarily intended to illustrate the varying pressure regime for the building and the resulting airflow regime. These flows have profound effects on ventilation system operation, which is beyond the scope of this report.

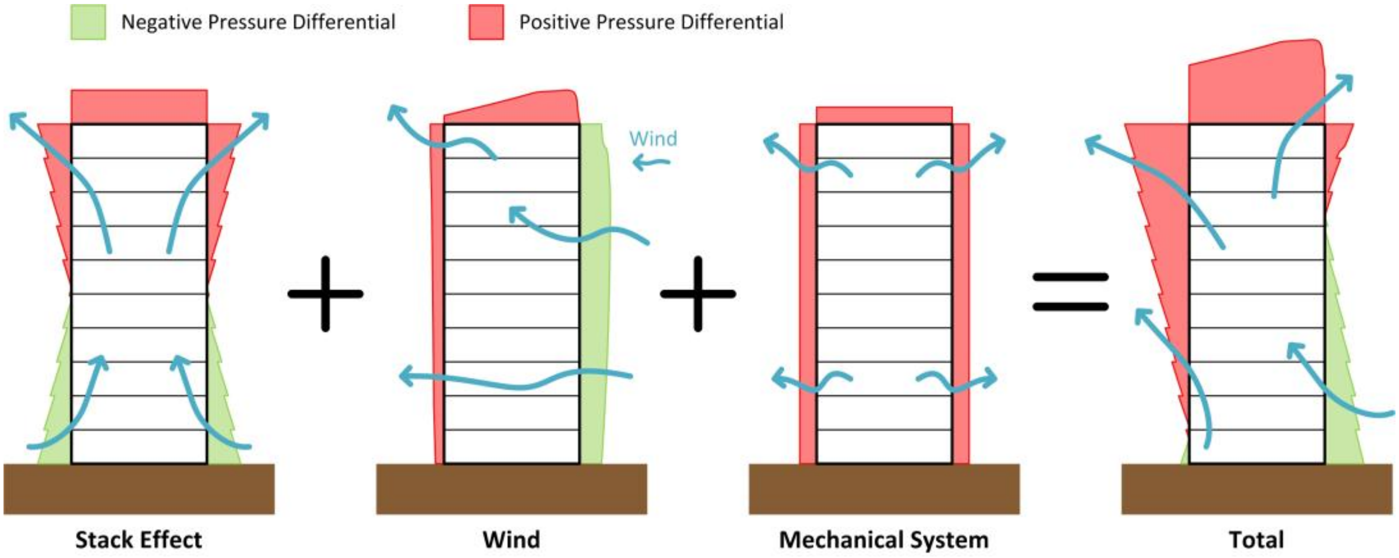


Fig.2.11 Cumulative Effect of Driving Forces of Air Movement on a tall MURB

While wind in the graphic above appears to have a significant effect on airflow in to, out of, and within the building, wind is not typically a significant long-term driving force of airflow compared to stack effect and mechanical system due to the high amount of variability in magnitude and direction.

The combination of wind, stack effect, and mechanical systems, together with varying airtightness levels of the building enclosure, floors, interior separators, stairwells, elevator shafts, and other building characteristics, creates a very complex pressure profiles and air movement patterns within building. This often results in poor indoor air-quality and ventilation rates within suites. While often proposed solutions to these problems rely on complex modeling and mechanical systems, airflow control strategies that simplify these variables are likely to provide more economical, effective, and efficient solutions for long-term implementation in the building industry.

2.4. Control of Airflow in MURBs

The quantity of airflow that can occur depends on the magnitude of the driving force (the pressure difference) and on the resistance to airflow (permeability) of the separator. Thus, to control airflow one can control either the pressure difference or the air permeability of the separator. Building enclosure air barriers and interior compartmentalization control the permeability of the separator to control airflow, while mechanical systems control the pressure difference.

2.4.1 Exterior Enclosure Air Barrier Systems

While mechanical systems and localised sheltering can be used to dampen the pressures experienced by the building enclosure, the primary control of air flow in MURBs is provided by the exterior enclosure air barrier. The air barrier system must comply with a number of design requirements in order to function adequately and remain airtight over the life of the building enclosure assembly. The following considerations have a direct impact on MURB airtightness.

- All the elements (materials) of the air barrier system must be adequately air-impermeable.
- The air barrier system must be continuous throughout the building enclosure. It must span across dissimilar materials and joints, and be sealed around penetrations such as ducts, pipes, and light fixtures.
- The air barrier system must be structurally adequate or be supported to resist air pressure forces caused by peak wind loads, sustained stack effect, or fans. It must transfer any structural loads as a result of air pressure (primarily wind) to the building structure. Furthermore, the air barrier system must be sufficiently rigid or be supported so that displacement under pressure does not compromise its performance or that of other elements of the assembly.
- The air barrier system should have a service life as long as that of the wall and roof assembly components or alternately should be easily accessible for repair or replacement.

An air barrier system is often provided by a combination of materials; however, there are usually one or two materials that play a dominant role within any particular air barrier strategy. For example, sheet polyethylene and butyl sealant are the dominant materials in a sealed polyethylene approach. General air barrier strategies for MURBs are discussed in this section; however, it is typically the continuity of the air barrier at interfaces and penetrations that is most critical to air barrier performance and these locations are the primary locations where building enclosure leak air. Regardless of which system or combination of systems is used, it is critically important to overall airtightness that continuity is maintained at all parts of the building enclosure including above grade walls, roofs, below grade walls, floor slabs, interfaces, transitions, fenestrations, and penetrations.

Air barrier systems for roofs rely on either the roofing membrane as the air barrier membrane, or supplemental air barrier membranes and/or monolithic materials to be airtight. Roof air barrier strategies share common attributes with wall strategies; however the number of potential air barrier strategies is limited. Critical roof air barrier details occur at roof to wall interfaces, parapets, penetrations, and expansion joints. Manufactured fenestration components including windows, window wall, curtain wall, doors and skylights are relatively airtight by use of frame joints/gaskets and sealants. The airtightness of fenestration products is regulated by building and energy codes and typically products are tested to meet the requirements outlined within referenced CSA A440, NFRC, or ASTM standards. These standards are further covered in Section 5 of this report.

Some of the strategies discussed may not be suitable for increased exposure conditions in some low-rise MURBs and in taller MURBs. For example, an air barrier system may not be adequately supported to resist the higher wind pressures common for taller buildings. It is important to note that membranes, gaskets, and sealants, used at transitions in the air barrier or penetrations, must also remain intact when wind pressures are applied to them. As an example, efforts to achieve a satisfactory barrier to air movement in low-rise residential construction in the early 1980s focused on the use of polyethylene sheet in Canada and the Northern US. The poly was structurally supported by the frame, insulation and interior sheathing, and also functioned as a primary vapour retarder material within the assembly. This approach is still commonly employed in low rise wood-frame MURBs though is not suitable for taller or more exposed MURBs where building pressure differentials are higher.

As a result, in taller MURBs it is common to use alternate approaches to seal rigid sheet materials used in construction by sealing the joints between them with gaskets or sealant, or cover with monolithic adhered or restrained sheathing membranes.

Prescriptive and general requirements for air barriers within MURBs are included within Canadian and US Building Codes, Energy Codes and Energy Standards. In Canada, air barrier performance criteria are generally specified for enclosure materials and components rather than for the entire building. This is primarily because it can be difficult and costly to determine entire building air leakage rates. Also, moisture related damage as a result of air leakage is typically due to excessive air leakage at specific components or joints rather than the entire building. However, in efforts to improve energy efficiency in the US, whole building airtightness testing is now required within the 2012 IECC for small and large buildings. Whole building airtightness targets of 3 to 5 ACH at 50 Pa for houses and small MURBs and less than 0.40 cfm/ft^2 (2.0 $L/s\cdot m^2$) of enclosure area at 75 Pa for larger MURBs are required in states adopting the 2012 IECC. (Further discussion of the different metrics used to describe airtightness is provided in Section 3.) These and other regulatory requirements across North America and in other global locations are covered further in Section 5.7.

The following common air barrier strategies for walls in low-rise to high-rise MURB construction in North America are discussed in the following sections.

- Sealed Polyethylene Approach
- Airtight Drywall Approach (ADA)
- Exterior Approaches
- Sealed Sheathing Approach
- Sealed Sheathing Membrane Approach
    - Unsupported Sheet Membranes
    - Supported Sheet Membranes with vertical strapping
    - Sandwiched Membranes behind exterior insulation
    - Self-Adhered and Liquid Membranes
- Sprayfoam
- Monolithic Material (Cast-in-place Concrete)
- Window Wall and Curtain Wall
- Other

Sealed Polyethylene Approach

The polyethylene sheet (typically, a minimum thickness of 6mm) is sealed at the top and bottom plates (wood or steel stud) to form the wall air barrier. All joints in the polyethylene are sealed and clamped between the framing and gypsum board. The wind load is transferred to the gypsum board in the inward direction and the framing in the outward direction. The polyethylene must be supported by both the outboard insulation and the drywall on the interior. Locations where interior finishes are not normally provided, such as at drop ceiling spaces and below the rim of bathtubs, require specific measures, such as the installation of sheathing, to ensure support of the polyethylene.

In wood-frame construction, the continuity of the air barrier at the floor header is maintained by sealing the polyethylene to the wood framing and by sealing layers of wood framing together with sealant or gaskets, by carrying a vapour permeable membrane to the outside of the header, or through the use of foam in the floor joist space. In non-combustible construction, transitions are made through floor slabs by sealing the polyethylene to the floor and ceiling.

Special attention must be paid to sealing penetrations of the gypsum board at electrical fixtures or other services. Flanged electrical boxes and other proprietary products have been adapted for these purposes. It is also necessary to ensure continuity of the air barrier at intersections with partition walls (at exterior wall and ceiling).

Non-curing sealants are appropriate for placement between sheets of polyethylene where drying of the sealant is not possible. However, other types of sealants and gaskets are required when sealing polyethylene to wood framing or between layers of wood.

This strategy is not typically suitable for more exposed and taller MURBs due to higher wind loads. Industry experience has found that it is also difficult and labour intensive to make this strategy sufficiently airtight to meet some testing requirements. A summary of the benefits and limitations of this approach is summarized in Table 2.4.1.

Fig.2.12 Sealed Polyethylene Approach. *Utilizes acoustic sealant and construction tape for joints, details, and transitions. This approach often relies on other elements such as the rigid insulation and sprayfoam between floor joists to transition between floors. Industry familiarity with this approach and combined vapour barrier function means that many designers will elect to use this approach in designs even while not appropriate, such as when required to accommodate loadings in taller and more exposed MURBs.*

Table 2.4.1 Summary of Benefits and Limitations for Sealed Polyethylene Approach

Air barrier Strategy	Benefits	Limitations
Sealed Polyethylene Approach	• Common, therefore trades are familiar with this approach in most climate zones • Also functions as vapour barrier (in climates where needed) • Relatively inexpensive	• Unable to accommodate high pressures and therefore limited to low-rise buildings • Easily damaged during construction • Difficult to transition between floors levels and past interior details. • Also functions as a vapour barrier (unintended in some climate zones where not needed)

Airtight Drywall Approach (ADA)

The interior gypsum board and framing members provide the air barrier in this strategy. Continuity between different materials is created with sealant or gaskets. Special attention must be paid to seal penetrations of the gypsum board at electrical fixtures and other services, as well as the intersection of partition walls with exterior walls and the ceiling. An advantage of this system is that the gypsum board is exposed for inspection and maintenance at all times. Nail pops, cracks and other damage are therefore accessible for repair over the life of the building. This approach is suitable for taller MURBs because of the rigidity of the drywall and ability to accommodate higher pressures. A summary of the benefits and limitations for this approach is provided in Table 2.4.2.

Table 2.4.2 Summary of Benefits and Limitations for Airtight Drywall Approach (ADA)

Air barrier Strategy	Benefits	Limitations
Airtight Drywall Approach (ADA)	• Trades are familiar with this approach in many climate zones • Relatively cost effective, not requiring additional materials (other than some sealants and gaskets) • Rigid support able to accommodate higher pressures • Visible and easy to repair	• Some difficultly in penetration detailing • Transition details where drywall not used (i.e. partition walls, drop ceilings etc.), can be difficult to make airtight unless properly pre-planned • Need for additional vapour barrier (paint or membrane) in some climate zones

Exterior Approaches

There are several possible exterior approaches for achieving airtightness in MURB wall assemblies, some of which are shown in Fig.2.13. Exterior approaches are divided into two primary categories depending on whether the exterior sheathing (i.e. gypsum, plywood, oriented strand board (OSB) etc.) is sealed or whether the water resistive barrier (WRB) outside of the sheathing is sealed (i.e. self-adhered membranes (SAM), spun bonded polyolefin (SBPO), self-adhered vapour permeable membrane, liquid membrane, etc.):

- Sealed Sheathing Approach
- Sealed Sheathing Membrane Approach, including:
    - Unsupported Sheet Membranes
    - Supported Sheet Membranes with vertical strapping/girts
    - Sandwiched Membranes behind exterior insulation
    - Self-Adhered and Liquid Membranes

Fig.2.13 An exterior air barrier approach can be utilized to either seal the joints in the exterior sheathing or seal the exterior sheathing membrane. Selection of which component to seal will depend on cladding type, MURB height and contractor familiarity with the approach.

A significant advantage of exterior approaches is that penetrations of the interior wall finish for electrical outlets and disruptions such as stairs, plumbing fixtures and partitions, do not affect the continuity of the air barrier.

One exterior approach, the Sealed Sheathing Approach, utilizes the sheathing with sealed joints as the primary air barrier element. A variation of this approach utilizes the exterior sheathing together with sealant joints or strips of membrane to create a continuous air barrier (Fig.2.14). This approach has been quite successful in demonstrating low air leakage rates for

MURBs and is becoming more common. Where this approach has been used, overall airtightness levels well below 0.4 cfm/ft^2 (2.0 L/s·m²) at 75Pa have been achieved consistently. Experience and testing results have shown that it is often much more difficult to achieve the same level of airtightness using unsupported membranes.

The Sealed Sheathing Membrane Approach utilizes a vapour permeable sheathing membrane (often also functioning as the WRB) as the primary air barrier element, as shown in Fig.2.15. The exterior sheathing membrane is made airtight utilizing sealant and tape. This approach can be used successfully in mid-rise MURBs if the membrane is properly supported and protected from tearing at sharp penetrations, such as at brick ties, as demonstrated in Fig.2.16. Vertical wood strapping or metal girts can be used to improve the support for the air barrier membrane in a Supported Sheet Membrane Approach (Fig.2.17). A variation on this approach utilizes the vapour permeable sheathing membrane as the primary element with additional insulation placed to the exterior side of the membrane, therefore sandwiching the membrane between two rigid elements which provides better support for the membrane.

Adhered or liquid-applied air barrier membranes are common materials for an exterior air barrier strategy and are suggested in many applications because of their improved robustness, some self-sealing characteristics, and rigidity. Vapour permeable (i.e. self-adhered house-wraps type products) and vapour impermeable (i.e. bitumen modified and butyl based SAMs) are available, and use of either class of products will depend on insulation placement and required vapour control function. Examples of these systems are shown in Fig.2.18 and Fig.2.19. Since these materials are adhered to the substrate they are better able to resist suction loads with minimal risk of tearing. These types of systems utilizing membranes adhered to rigid sheathing are therefore more suitable for taller MURBs. The use of self-adhered membranes applied to the exterior of gypsum sheathing and steel studs is a common and successful air barrier approach in high-rise buildings and common retrofit strategy in high-rise MURB rehabilitations. Table 2.4.3 summarizes the benefits and limitations of each exterior air barrier approach.

Fig.2.14 Sealed Sheathing Approach. *This approach utilizes the rigid exterior sheathing sealed with sealants, membranes or tapes. The system provides good performance for all MURB heights due to rigidity, ease of inspection and detailing.*

Fig.2.15 Sealed Sheathing Membrane Air Barrier Approach. *When property detailed and supported, the sealed exterior sheathing membrane air barrier approach can be successful strategy for airflow control in a MURB. Notice the use of tapes to seal the sheathing membrane for this 4-storey wood-frame MURB. Rigidity and support of the membrane will be added in form of vertical wood strapping used to create the cavity for a rainscreen wall assembly.*

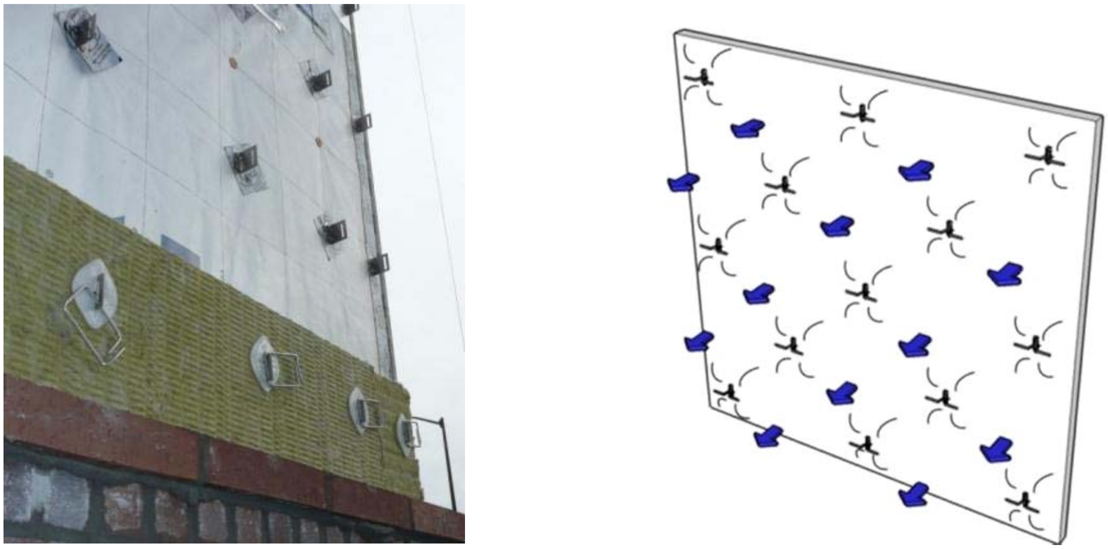


Fig.2.16 Sealed Sheathing Membrane Air Barrier Approach with Brick Ties. *A limitation of the sealed sheathing membrane approach is the potential for the air barrier membrane (and WRB) to tear or become damaged around brick-tie penetrations. Solutions include SAM reinforcement over the sheathing membrane at the fastener locations or use of self-adhered and liquid membranes.*

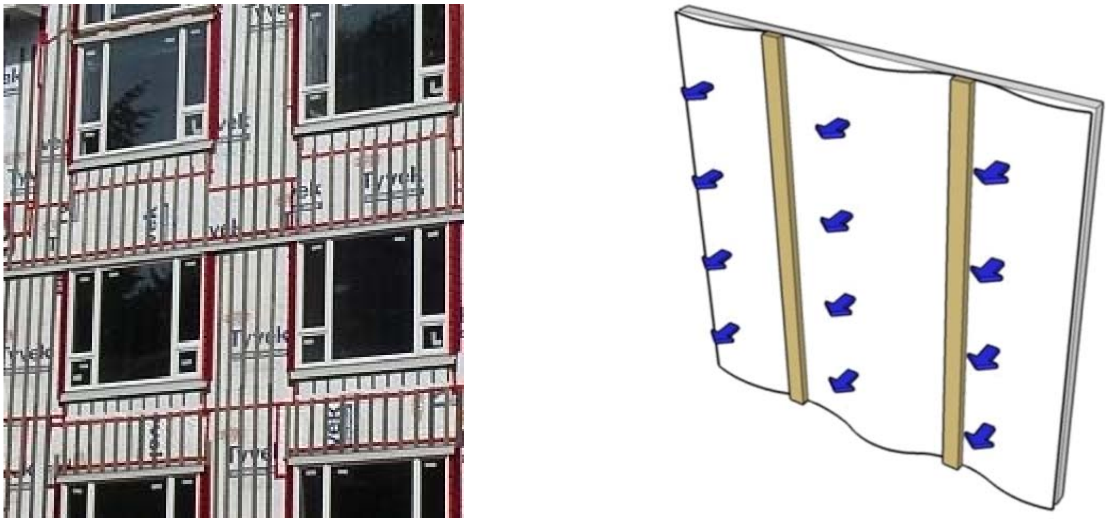


Fig.2.17 Supported Sheathing Membrane Approach with Vertical Strapping/Girts. *Exterior sheet air barrier membrane with vertical wood strapping or metal girts more evenly distributed loads and deflection of the membrane. There is very little test data available to allow for a more analytical or even empirical approach to the determination of structural adequacy for sheet membrane barrier systems. Precautionary measures could include tightly spaced strapping to secure the membrane and selection of more robust membrane, with respect to both strength and tear-resistance. The use of self-adhered and liquid membranes basically makes the sheathing and membrane an integral, rigid air barrier material.*

Fig.2.18 Self-Adhered Vapour Permeable Air Barrier Membrane on Plywood. *The membrane performs the function of the WRB/sheathing membrane and when adhered to the plywood provides a rigid air barrier system suitable for taller wood-frame MURBs regardless of cladding strategy.*

Fig.2.19 Self-Adhered Membrane (SAM) Air Barrier Membrane Applied to Fiberglass Faced Gypsum Sheathing. *The simplicity of this system and use of exterior insulation makes this air barrier system common for non-combustible high-rise MURB construction and in particularly for exterior enclosure rehabilitations.*

Table 2.4.3 Summary of Benefits and Limitations for Common Exterior Air Barrier Strategies

Air barrier Strategy	Benefits	Limitations
Sealed Exterior Sheathing Approach	• Visible and easy to install on exterior of building • Minimal detailing (sealants or tapes at all joints) • Rigid support	• Transition detailing between exterior and interior air barrier approaches (i.e. at ceilings) can be difficult without pre-planning • Weather can delay application of sealants and tapes on exterior sheathing • Must accommodate shrinkage and movement of wood-framing • WRB still required to exterior
Sealed Exterior Membrane Approaches		
Unsupported Sealed Sheet Membrane	• Visible and easy to install on exterior • Minimal detailing • Cost effective as also performs WRB function	• Unable to accommodate high pressures (limited to low-rise MURBs) • Can be easily damaged during construction from wind (blow off, tear) • Easily torn around sharp penetrations (i.e. brick ties) and flashings • Most difficult of sealed membrane approaches to make airtight
Sealed Sheet Membrane Supported by Strapping/Girts	• Visible and easy to install on exterior of building • Minimal detailing (sealants or tapes at all sheet laps and interfaces) • Improved rigidity over unsupported • Cost effective as also performs WRB function	• Requires strapping or girts for support • Can accommodate higher wind pressures, but not recommended for high-rise applications
Sealed Sheet and Adhered Membranes Sandwiched between sheathing and exterior insulation	• Visible and easy to install on exterior of building • Minimal detailing • Rigid support between sheathing and exterior insulation • Cost effective as also performs WRB function	• Air barrier detailing must be largely complete prior to installation of exterior insulation • Screws through insulation may damage some loose membranes decreasing airtightness (suggest adhered membranes to counter this)
Sealed Membranes Adhered to Sheathing (Self-adhered, cementitious, and liquids)	• Visible and easy to install on exterior of building • Minimal detailing • Single material • Rigid support (integral support of membrane and exterior sheathing)	• Membranes/liquids may be more expensive than some other options • Some membranes are weather sensitive

Sprayfoam

Closed cell polyurethane sprayfoam can be applied to the exterior of sheathing to form the primary air barrier element and includes the added benefit of providing thermal insulation. Proper application of the sprayfoam and additional membrane detailing to accommodate building movement and foam shrinkage, particularly at interfaces and framing elements such as girts, are necessary to achieve high degrees of airtightness. Fig.2.20 shows sprayfoam applied to the exterior of a wall, providing the thermal insulation and continuous airtight element for the majority of the area.

Within wall assemblies, the use of either ½ pcf (pounds per cubic foot) open cell or 2 pcf closed cell sprayfoam applied within the wood-frame wall and roof joist spaces can also form part of an air barrier strategy. Joints, cracks and gaps that are too small to be effectively sealed with sprayfoam (such as between the bottom plate and floor, or between top plates or at other small gaps) need to be air-sealed with other sealants and adhesives as part of this approach.

Closed cell sprayfoam is also often utilized as a supplement to other air barrier strategies to air-seal transition areas, such as between floor and roof joists, as illustrated in Fig.2.21. Table 2.4.4 summarizes the benefits and limitations of this air barrier system.

Fig.2.20 Closed Cell Sprayfoam Applied on the Exterior of the Exterior Sheathing/Back-up Wall as the air barrier strategy for these walls. Appropriate self-adhered membranes are used to transition between the foam and penetrations including windows.

Fig.2.21 Sprayfoam used as transition material as part of other air barrier strategies. *Sprayfoam is often used between floor and roof joists for continuity between wall and roof elements. In some cases, where the sprayfoam is poorly applied, touch-ups are needed to seal cracks and gaps missed during the first pass.*

Table 2.4.4 Summary of Benefits and Limitations for Sprayfoam Air Barrier Strategies

Air barrier Strategy	Benefits	Limitations
Sprayfoam	• Seals center of wall well • Able to fill voids/holes and transition interfaces well • Performs insulation and air barrier functions • Cost effective as also performs thermal insulation function	• Does not address details and small cracks, gaps and transitions requiring additional materials (sealants, tapes etc.) • Expensive as air barrier only • Long term stability and shrinkage may be an issue with some applications and situations • Combustible

Monolithic Material – Cast-in-place Concrete

Monolithic cast-in-place or precast concrete walls can form part of an air barrier strategy, as shown in Fig.2.22. This strategy is often used where the concrete wall or slab is already being used for structural reasons (i.e. as a slab, shear wall, below grade, or as part of an exposed concrete wall assembly). This type of air barrier can be effective and is extremely durable if properly detailed. The primary concerns with the system are with regard to proper concrete consolidation, cracking, and continuity of airtightness across the concrete joints (control, cold, panel, and interfaces) at formwork tie holes and at interfaces to other assemblies.

Concrete placed within insulating concrete forms (ICFs) also forms the air barrier within this system and is sometimes used in MURB construction. Correct concrete mix design and specific placement practices are necessary to ensure properly consolidated concrete within the insulating forms.

Concrete block walls are also used in MURBs, sometimes as exterior infill walls. However, because of the porosity of the blocks and joints, the block walls must be coated with an air barrier parging or membrane; liquid or self-adhered sheet applied products are common. Table 2.4.5 summarizes some of the benefits and limitations of this system.

Fig.2.22 Mass Concrete Walls. Concrete and joint sealants perform the air barrier function. *The proper control of cracks and joints also required for water penetration control will lead to airtight assemblies.*

Table 2.4.5 Summary of Benefits and Limitations for Monolithic Concrete Air Barriers

Air barrier Strategy	Benefits	Limitations
Monolithic Concrete	• Structural material is naturally airtight and very durable • Single material performs air barrier function	• Detailing of joints and interfaces and cracks • Cracking will reduce airtightness • Some wall assemblies may require an additional air barrier for convection control (i.e. exposed concrete with interior insulation)

Window Wall and Curtain Wall

The use of window wall and curtain wall assemblies is common in modern MURBs across North America, as in the buildings shown in Fig.2.23. It is also very common for the building enclosure to be entirely made up of window or curtain wall assemblies. The air barrier system within window wall and curtain wall systems consists of the glass, frames, and gaskets and sealants that connect and join components together and at interfaces to other assemblies.

Manufactured window wall and curtain wall assemblies are regulated by building and energy codes, and products are tested to meet the requirements outlined within CSA A440, NFRC, or ASTM standards. As a result, these components tend to be very airtight. Issues with airtightness typically only arise at interfaces, and sometimes over time as operable window and door hardware and weather seal gaskets age.

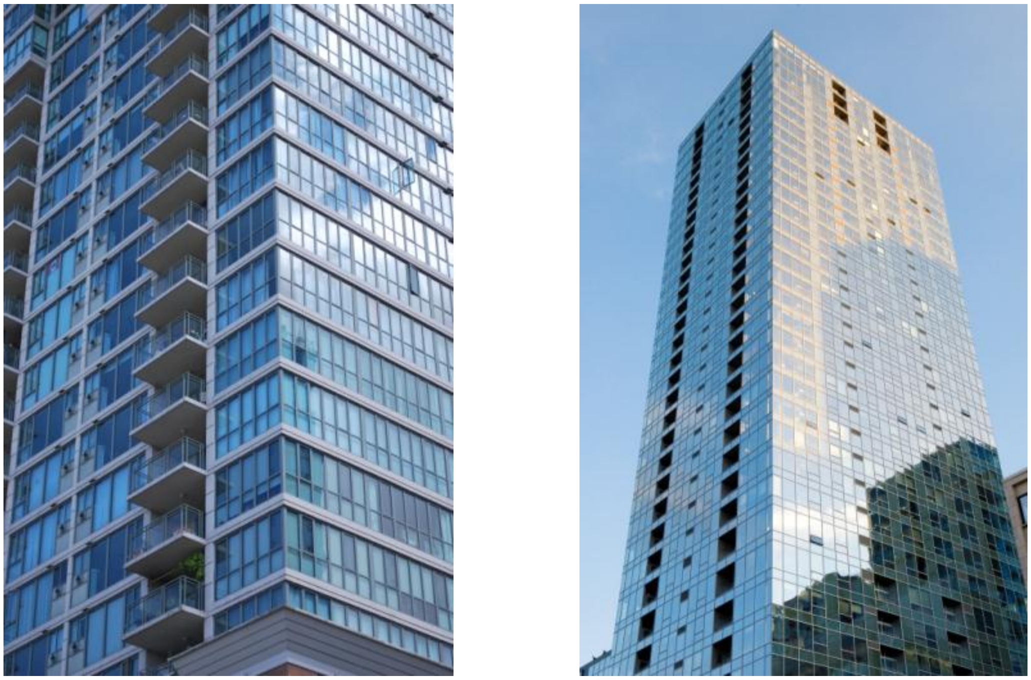


Fig.2.23 Window wall (Left) and Curtain wall (Right) assemblies occupying the majority of the vertical enclosure area of these MURBs. *The air barrier system of these wall assemblies is achieved by the gaskets and sealants between the joints and interfaces of these manufactured window assemblies and interfaces to other components including slab edges.*

Other Approaches

An additional air barrier approach used in wood-frame construction in Europe and commonly in Passivhaus construction is the use of thick insulated wood-frame walls with taped and sealed plywood or OSB sheathing at the interior surface as the air barrier. Special pressure adhesive tapes are used to tape the joints in the plywood and between elements to create a continuous air barrier when properly applied, as shown in Fig.2.24. Care must be taken at transitions between floors and to roofs, but the rigidity and visibility of this approach generally results in very airtight buildings and is a potential solution for mass-timber and other prefabricated walls.

Fig.2.24 Taped Plywood Sheathing as the Interior Air barrier System of Pre-fabricated Wood-panels. *Durable and long-lasting tapes must be used to maintain airtightness over the life of the building.*

2.4.2 Occupant Behaviour

Occupant behaviour in MURBs has an impact on both the airtightness of the building enclosure, and the pressures experienced across the building enclosure. Both intentional and unintentional occupant behaviour performed individually or as a group can have negative and often unintended consequences on the in-service building airtightness, the degree of compartmentalization, and the pressures experienced by the building.

Most commonly, occupant changes to the air barrier are in the form of opening windows and doors, as MURBs typically have operable windows and in many cases patio doors. Operable windows are a considerable source of air leakage in a multi-unit residential buildings, and while an obvious and intentional opening in the enclosure, windows are often left open depending on occupant preference for thermal comfort, air quality, or ambiance. In many older MURBs, opening windows is actually the intentionally designed method for meeting ventilation requirements (Fig.2.25).

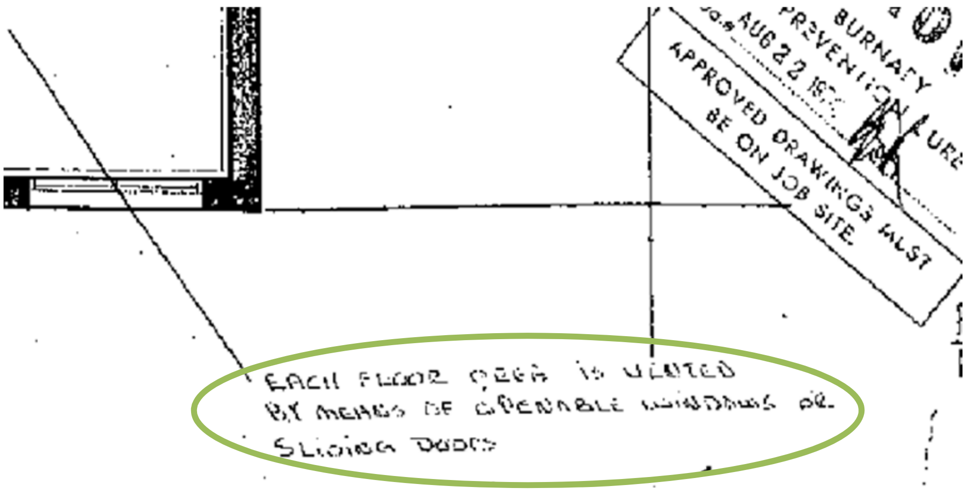


Fig.2.25 Original Mechanical Design Drawing Note for 1970s vintage MURB in Burnaby, BC

As an example, if you were to take all of the leakage area through the building enclosure in a relatively airtight 20 storey MURB, it would add up to the equivalent leakage area occupied by a only few open windows in that same building. It therefore takes only a few windows to be open at any one time to essentially decrease the actual airtightness of a MURB by an order of magnitude, thereby profoundly changing pressure regimes and airflows. This has significant effects on airflow distribution through and within taller MURBs, which in turn affects space conditioning and indoor air quality.

Anecdotal observations of MURBs across North America indicates that the number of windows left open, even during wintertime at very cold temperatures, is often surprisingly high. As an example, Fig.2.27 produced by Proskiw and Philips (2006) shows the operable windows left open, by floor, in an 18-storey MURB in Winnipeg at -25°C. The same study also looked at building airflow and movement of the neutral pressure plane as a result of this phenomenon and concluded that the effective airtightness of MURBs likely has little to do with the design and construction of the buildings, but with the occupants and their use of the windows.

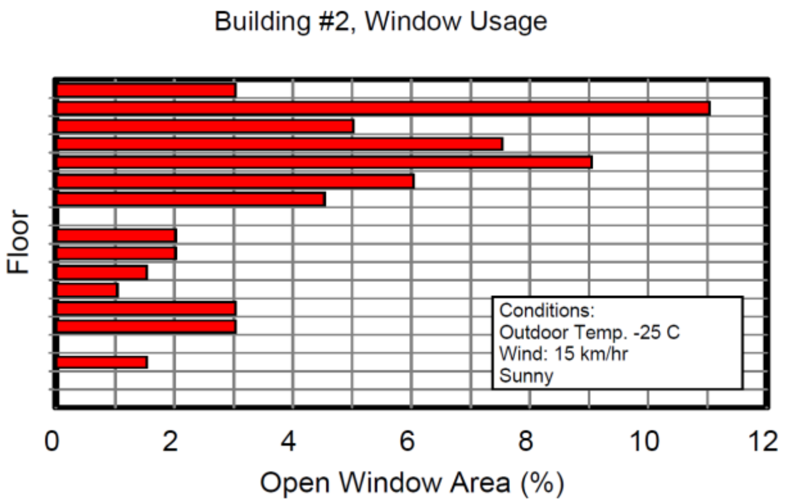


Fig.2.26 Window Usage in a 18-storey MURB in Winnipeg during -25°C Wintertime Conditions (Proskiw and Phillips, An Examination of Air Pressure and Air Movement Patterns in Multi-Unit Residential Buildings 2006)

There are countless stories and observations within tall MURBs in cold climates where occupants at upper floors leave their windows open during the winter to cool their suites down from overheating, since they are being heated by all of the air rising from the suites below. Perpetuating the problem, people on lower floors then turn up their heat even more to counter drafts from cold air entering their suites by leakage through the enclosure, which is very often then exacerbated by increased stack effect due to the increased heating. This scenario is likely driving the behaviour shown in Fig.2.26 above.

Aside from operable windows, occupants can influence building airtightness and building pressures within MURBs in other ways. Some examples include:

- Blocking suite entry door undercuts which are meant to provide fresh air to the suite via the pressurized corridor approach. This affects the distribution of airflow from the corridors into each suite and suite pressures resulting in unintended airflows within MURBs. Many occupants block door undercuts or install weatherstripping, often unaware of the purpose of this gap, in attempts to reduce drafts, odours and noise.
- Operating bathroom and kitchen exhaust fans, which can slightly or significantly depressurize the suite they are operating in, depending on the airtightness of the suite. This acts to pull air into the suite from adjacent spaces including neighbouring suites and common areas affecting indoor air quality (through odours) and operating pressures.
- Damaging air barrier materials such as poly and drywall during interior renovations and modifications.

2.4.3 Compartmentalization

Air barrier systems are also used as part of internal building separations. In the past these air barrier systems have mostly been implemented for fire and smoke control as well as acoustics; however, they also provide an effective way of controlling in-service airflows within the building. These internal air barriers compartmentalize spaces within the building and make airflows into and out of each space more predictable and easier to control.

One airflow control strategy involves compartmentalizing spaces within the building. This can be done by creating an airtight perimeter between the dwelling unit, the common corridor (if present), and the adjacent dwelling units (to the sides, above and below). In practice, this is not a difficult task because a separation is intended between dwelling units, as well as between dwelling units and corridors or other public spaces. The two primary focal points are sealing wall and ceiling penetrations, and creating a relatively airtight entry door (this assumes that the ventilation strategy does not utilize the door undercut approach) as well as sealing the doors and openings of vertical shafts including the elevator and stairwells. Proper detailing for fire, smoke and sound control will tend to be airtight.

Compartmentalizing the interior spaces of the building also changes the impact of stack effect forces. The lack of internal airflow means that these forces now act over each floor rather than the entire height of the building. As a result the driving forces for air movement through the building enclosure are much smaller. This strategy also allows for the use of more effective and energy efficient in-suite ventilation systems such as individual in-suite HRVs to be used in MURBs. Compartmentalization also limits airflow due to other driving forces such as pressure differences between suites caused by exhaust fan operation and opening or closing windows. Fig.2.27 shows the theoretical resulting stack effect forces from perfectly compartmentalizing the floors of a MURB.

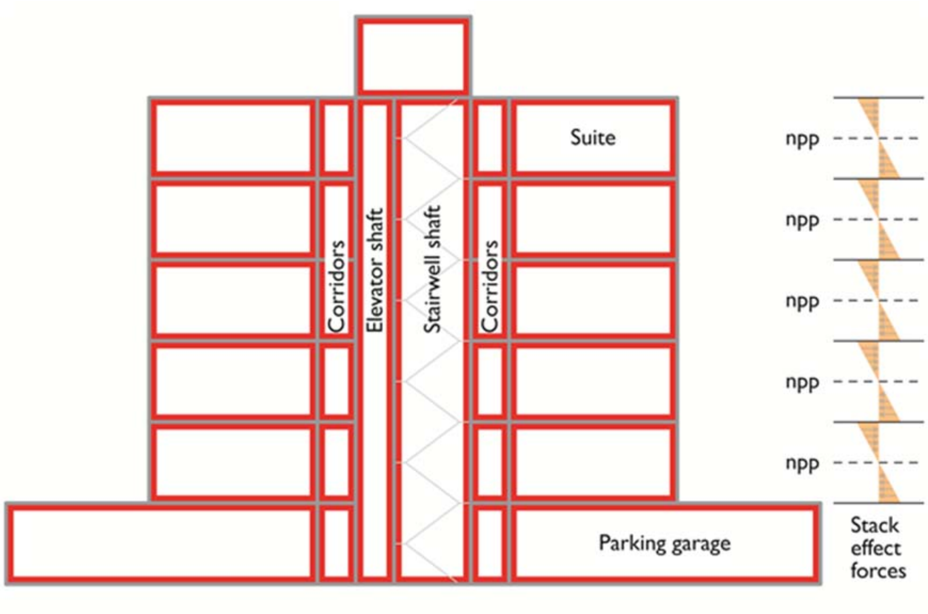


Fig.2.27 Compartmentalization of the Interior Spaces of a Multi-Unit Residential Building and Impact on Stack Effect Forces

2.4.4 Mechanical Systems

While mechanical systems create pressure differences that act as a driving force for airflow into, out of, and within MURBs, these pressure differences can also be used to intentionally control airflows. A common application of this is corridor pressurization ventilation systems. These systems intentionally raise the pressure of the interior common corridor to force the flow of air from the corridor into adjacent suites. This is intended to provide both a means of ventilation as well as smoke and odour control. Another application is in laboratories that deal with dangerous contaminates that could potentially be transferred through the air. In these situations the laboratory room is often depressurized relative to surrounding spaces using mechanical systems. This ensures that no contaminates can leave the lab.

Commonly, however, mechanical systems are not designed or implemented such that they can effectively control the pressure regime within a building and are unable to overcome the significant driving forces. This can create situations of cross-contamination of air within the building, under-ventilation, and over-ventilation. Thus, while mechanical systems provide the potential for airflow control, implementation of these systems is often unreliable and can be energy intensive.

3. Airtightness Reporting and Calculations

Due to the wide range of test methods and standards available for air leakage testing, a number of different reporting techniques for air leakage values are commonly used. This section of the report provides the relevant calculations and conversions for comparing these values.

Based on the results of air leakage tests, an empirical formula has been developed to relate the pressure difference across the air barrier with the airflow rate as shown in Eq. 1.

$$Q = C\,(\Delta P)^n \qquad \text{Eq. 1}$$

Where: Q = Airflow Rate per Unit Area [m^3/s]

C = Flow Coefficient [$m^3/s{\cdot}Pa^n$]

ΔP = Pressure Difference [Pa]

n = Flow Exponent [dimensionless]

Eq. 1 is essentially a combination of the fundamental relationships for laminar flow through a porous medium (n = 1) and turbulent flow through a sharp edged orifice (n = 0.5). Consequently, the values for n are bounded by the values for laminar and turbulent flow (i.e. $0.5 \leq n \leq 1$). The value for n is either determined experimentally using a multi-point test (measuring air leakage at a range of different pressure differences) or, more frequently, assumed as a standard value of 0.60 based on typical results for large buildings including MURBs, which is also supported by test data from the literature review. *C* and *n* are both characteristics of the building enclosure, thus they are constant for all flow rates and pressure differences.

The flow exponent, *n*, will also provide some insight as to the validity of the test and relative tightness of the building enclosure. A lower *n* value indicates a very tight building with tortuous leakage paths, whereas a higher *n* value indicates a very leaky building with large open holes. Exponent values less than 0.50 or greater than 1.0 in theory indicate a bad multipoint test. Since this range is dictated by the physics of fluid dynamics and the characteristics of developing airflow through leaks, if the *n* value is outside of these boundaries, testing data is likely innaccurate. Except for very rare circumstances, *n* values should not take on values less than 0.45 or greater than 0.80 (U.S. Army Corps of Engineers 2010). The allowance for the *n* value to be below 0.5 is because the 0.5 limit is only valid under the assumption that the leakage holes are rigid and do not change in shape or size as a reaction to a change in the pressure difference. If the leakage holes do change in shape or size as a result of a change in the pressure difference, an *n* value slightly below 0.5 may be determined. This is not actually the physical case but occurs because different systems are actually being tested at each of the pressure differences.

Eq. 1 also provides the basis for converting results to different standard pressures for comparison. If *C* and *n* are known, then a flow rate at any given pressure difference can be calculated. Additionally, it is sometimes useful to calculate a conversion factor in the form of Eq. 2.

$$Q_i = C\,(\Delta P_i)^n$$

Therefore:

$$Q_2 = Q_1\left(\frac{\Delta P_2}{\Delta P_1}\right)^n$$

$$Conversion\ Factor = \left(\frac{\Delta P_2}{\Delta P_1}\right)^n \qquad \text{Eq. 2}$$

3.1. Reporting Techniques

The most common reporting methods for quantifying air leakage rates are provided in the following sections.

3.1.1 Airflow Rate

In some cases, the total measured airflow rate is used to indicate the air leakage characteristics of a building enclosure. This number can be useful for ventilation and energy calculations, and it is known since it equals the airflow rate of the fan. The airflow rate must be given at a specified pressure differential for it to have meaning. Typically airflow rates are reported at pressure differentials of 50 or 75 Pa. In some cases they are provided at lower pressures to represent in-service conditions.

$$Air\ Flow\ Rate\ @\ x\ Pa\ Pressure\ Difference = Q_x [m^3/s] \qquad \text{Eq. 3}$$

3.1.2 Normalized Airflow Rate

The normalized airflow rate, also known as the Normalized Leakage Rate, is the airflow rate divided by a specific area. Typically the area used is the total enclosure area of the space tested, which in many cases is the total enclosure area of the whole building. In some cases, such as some European standards, only the above-grade area of the building enclosure is used; however, this is not generally recommended.

$$Normalized\ Air\ Flow\ Rate\ at\ x\ Pressure\ Difference = \frac{Q_x}{A} [m^3/s \cdot m^2] \qquad \text{Eq. 4}$$

3.1.3 Air Change Rate

Air change rate, typically measured in air changes per hour (ACH), is a measure of how frequently the air volume in a space is replaced with outdoor air. This value is found by dividing the flow rate into a space by the volume of that space as shown in Eq. 5. The volume of the space used for this calculation should be the entire volume enclosed by the air barrier elements being tested.

$$ACH\ @\ x\ Pressure\ Difference = ACH_x\ or\ N_x = \frac{Q_x}{V} [h^{-1}] \qquad \text{Eq. 5}$$

3.1.4 Equivalent Leakage Area

Equivalent leakage area (ELA or EqLA) represents the size of a sharp-edged orifice which would produce the same net air flow at a given pressure differentials as would occur cumulatively through all leakage paths in the building enclosure. Flow through a sharp-edged orifice is described by Eq. 6.

$$Q = A \cdot C_d \cdot \sqrt{\frac{2 \cdot \Delta P}{\rho}} \qquad \text{Eq. 6}$$

Where: Q = Airflow Rate per Unit Area [m³/s]
A = Orifice Area [m²]
C_d = Discharge Coefficient [dimensionless]
ΔP = Pressure Difference [Pa]
ρ = Density [kg/m³]

For the calculation of EqLA in accordance with CGSB 149.10, a Discharge Coefficient of 0.61 is assumed and a reference pressure difference of 10 Pa is used; however, it can also be calculated at other pressure differences and specified by a subscript. Calculation of air density is possible, and correction calculations are provided in the standard; however, it is often adequate to assume a value of 1.2 kg/m³. Additionally, the flow rate can be expressed in terms of *C* and *n* using Eq. 1. Thus, Eq. 6 can be rearranged to the general form shown in Eq. 7 and the specific form shown in Eq. 8.

$$EqLA_{\Delta P} = \frac{Q_{\Delta P}}{0.61} \cdot \sqrt{\frac{\rho}{2 \cdot \Delta P}} \qquad \text{Eq. 7}$$

$$EqLA_{10} = \frac{Q_{10}}{0.61} \cdot \sqrt{\frac{1.2}{2 \cdot 10}} = C\ (10)^n \cdot 0.4016 \qquad \text{Eq. 8}$$

3.1.5 Effective Leakage Area

The effective leakage area (EfLA) is a term commonly confused with the EqLA. The EfLA is the measure used by the American Society for Testing and Materials (ASTM E 779) and is calculated in the same manner as EqLA except that a discharge coefficient (C_d) of 1.0 and a pressure difference of 4 Pa are used. (Sometimes pressure differences other than 4 Pa are used and specified by a subscript.) EfLA is calculated using Eq. 9.

$$EfLA = \frac{Q_4}{1.0} \cdot \sqrt{\frac{1.2}{2 \cdot 4}} = C\ (4)^n \cdot 0.3873 \qquad \text{Eq. 9}$$

ASTM E 779 also provides a variety of correction factors for temperature and density that should be applied; however, frequently the required information is not available and usually the impact of these corrections on the results is limited. Consult ASTM E 779 for details.

3.1.6 Specific Leakage Area (Normalized Equivalent/Effective Leakage Area)

Specific leakage area (SLA) is either the equivalent or effective leakage area normalized by dividing by the relevant enclosure area (similar to normalized airflow rate).

$$SLA = \frac{EfLA\ or\ EqLA}{A} \qquad \text{Eq. 10}$$

Just as it is important to distinguish between EfLA and EqLA, it is also important to distinguish which of these quantities was used to calculate the SLA. For clarity, it is often convenient to refer to SLA as the Normalized Equivalent or Effective Leakage Area (as is appropriate) so that the distinction can be clearly made.

3.1.7 Leakage per Unit Length

The leakage per unit length is similar to the normalized airflow rate except that instead of dividing by the relevant area, a length is used. This measure is typically used in cases where a crack length is clearly identifiable such as the perimeter of a window or door and thus the leakage per unit length of the frame is a relevant quantity.

$$Leakage\ Per\ Unit\ Legth\ at\ x\ Pressure\ Difference = \frac{Q_x}{L}\,[m^3/s \cdot m] \qquad \text{Eq. 11}$$

3.1.8 Conversions

This report will use the units typical in industry which are a conglomeration of the SI and IP system, thus this section provides a number of equivalencies to be used for conversion between the two.

Table 3.1 Convenient SI to IP Unit Conversions

Quantity	SI	IP
Area	1 m^2	10.764 ft^2
Volume	1 m^3	35.315 ft^3
Flow Rate	1 L/s	2.1 cfm
Flow Rate	1 m^3/s	2119 cfm
Pressure	1 Pa	0.00402 inches water
Air Permeance	1 L/s·m^2	0.1969 cfm/ft^2

4. Literature Review Summary

There are many good sources of North American and international information on air leakage test methods, specifications, and case-studies of large buildings including MURBs. Using the original CMHC research report *Air Leakage Characteristics, Test Methods and Specifications for Large Buildings (2001)* as a starting point, the literature review was expanded and updated to include past references and many other references from the last decade that were not captured by the earlier report. Over the past decade, a number of large buildings have been tested by many organizations, including our project team members. A list of references and a bibliography are provided at the end of this report.

While information collected through the literature review process is presented throughout this report, overall, the literature review identified the following key points with respect to airtightness in MURBs.

Equipment

- Quantitative testing requires specialized equipment; however, the equipment required to effectively test MURB airtightness exists and is readily available throughout Canada, the United States, and most of the developed world.
- Airtightness testing equipment has not changed significantly in the last 10 years (time of previous report), other than improvements in technology and the ability to control fans and collect data more easily using computer software. Wireless technology is also starting to be used to transmit data when using multiple fan-door setups.
- A variety of equipment can be used for qualitative testing including smoke generators, smoke pencils, and infrared cameras. Further discussion of these and other types of equipment is provided in Section 5.6.

Testing

- Numerous whole building test procedures exist; however, no standard development agency has created a standard method for balanced fan pressurization/depressurization testing of a single space within a larger building, which is one of the most relevant test methods for MURBs and described by a number of sources.
- The air barriers of large buildings in Canada and the United States are not commonly tested, and even less frequently for MURBs. The exceptions are the US Army Corps of Engineers, which requires testing of all of its new buildings, and the State of Washington, which has also implemented mandatory testing.
- Testing can be performed to determine if a building meets a specified performance criteria, as a quality control measure during construction, to locate source of air leakage, to enable quantitative comparisons of building performance, to determine if other forms of airflow control such as mechanical system could potentially be used, and to develop calibrated airflow models of existing buildings.
- Additional information regarding testing procedures is provided in Section 5.

Performance

- Air leakage performance ranges widely between buildings. More information is provided in Section 5.7 where airtightness standards are reviewed and Section 7 which includes analysis of the MURB airtightness database.
- If attention is paid to the air barrier design and installation, airtightness can be improved significantly compared to standard practice. Highly airtight buildings are possible.
- Preventing air infiltration by means of mechanical pressurization can significantly increase energy consumption.
- MURBs are significantly different from comparably-sized commercial buildings because they usually have operable windows, which can significantly impact the airflow and pressure regimes in to, out of, and within the building.
- A wide variety of metrics are used to specify airtightness of building. Further discussion of this was provided in Section 3 of this report.

As part of the literature review, a database was created of air leakage characteristics for MURBs including enclosure airtightness and other relevant building characteristics. The database is populated from available published data, as well as unpublished datasets maintained by several of the study partners. Data for air leakage measurements is reported in a variety of units and measures including air exchange rates, flow rates normalized per enclosure area, and equivalent leakage areas. The data is provided in standard units where sufficient test information is available to convert the data. It is intended that this database be continually updated so that relevant and accurate MURB airtightness testing data is available for both practitioners and policy makers. To facilitate this, a data entry form has been created that can be filled out by airtightness testers and then input into the database, a copy of which is included in Appendix C. A summary of the database is included in Appendix A, and an analysis of the data is provided in a later section of this report.

5. Test Procedures and Equipment

Airtightness testing is an important tool for evaluating the effectiveness of air barrier assemblies. It can be used as part of the quality control measures during construction, commissioning practices near the end of construction, energy auditing, and forensic investigations. Quantitative airtightness testing provides values for comparison with specified targets, standards, and industry averages, while qualitative testing provides a useful forensic tool for visually determining the location, direction, and magnitude of airflows.

5.1. System Quantitative Tests

The most common quantitative test method used to measure the air leakage of the building enclosure is by using a single fan-door (a.k.a. blower door) inserted into a doorway of the building to pressurize or depressurize the whole building. The pressure differential created is of sufficient magnitude to make naturally occurring pressure differentials insignificant to the test result. The airflow rate through the blower door is measured at various indoor to outdoor pressure differentials. This information is then used to characterize the building's airtightness. This test works well for smaller, single-zone, single level buildings; however, for large multi-storey buildings, air-leaky buildings, and compartmentalized multi-unit buildings, it may not be possible to equally pressurize (or even adequately pressurize) the entire building enclosure.

To overcome some of these issues, test methods have been adapted for complicated buildings such that they can be tested in smaller sections (i.e. by floor or by suite) using areas that are more manageable. When testing only a portion of a building, the air leakage through interior surfaces adjacent to the test area (i.e. suite demising walls, corridor walls, floors, and ceilings.) is very significant but can be eliminated by pressure neutralizing interior surfaces using additional fan-doors. Pressure neutralized air leakage testing can be more time consuming, but also produces more useful results as it provides data on air leakage through the exterior enclosure, and also through interior walls and floors.

Fig.5.1 presents a representative schematic showing the airflows and testing for a tall MURB at once versus the testing of a compartmentalized section of a MURB using pressure neutralizing techniques (i.e. by floor or by suite).

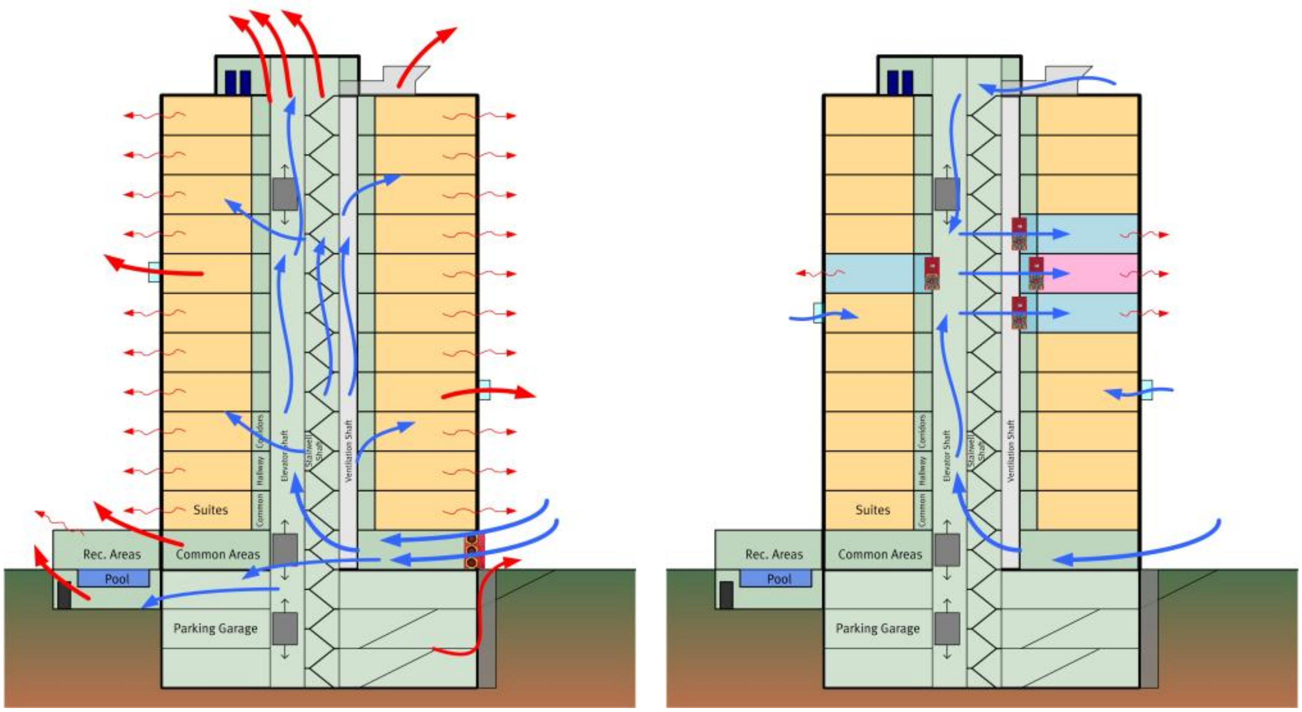


Fig.5.1 Methods for Airtightness Testing of Large MURBs – Whole building (left) and Compartmentalized Spaces (right).

A number of the available quantitative testing standards and techniques including whole building and neutralized testing methods are described in the following sections.

5.1.2 CGSB 149.10 – M86

CGSB 149.10-M86 Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method is one of the most common test procedures used in Canada, though it has not been updated since 1986. The test procedure was originally intended for smaller buildings, but can be adapted for larger buildings. The test consists of using either a single large blower or multiple smaller blowers to depressurize the building in increments of 5 Pa, starting at a 50 Pa pressure difference and working down to a 15 Pa pressure difference. The use of a single blower is preferable as it can provide more accurate results; however, it can be difficult to achieve even pressure distribution and often accommodations must be made to provide sufficient power to the larger blower unit. The testing standard also provides guidance regarding sealing intentional openings to achieve representative results, and how to measure the reference exterior pressure using multiple pressure taps. It recommends that the test not be conducted when the wind is greater than 20 km/hr (5.6 m/s).

The multiple points recorded in this test (both flow rate and pressure difference) allow for a correlation of Q (flow rate) and ΔP (pressure difference) using Eq. 1 to determine values for C (flow coefficient) and n (flow exponent).

5.1.3 CGSB 149.15 – 96

CGSB 149.15 Determination of the Overall Envelope Airtightness of Buildings by the Fan Pressurization Method Using the Building's Air Handling Systems is much the same as CGSB 149.10 except that, as the name suggests, it uses the building's existing mechanical ventilation system to pressurize the building. This technique is particularly relevant for larger buildings where achieving the necessary pressures with portable fan units can be difficult or impossible; however, its use is much less common than CGSB 149.10.

An important component of this test is the ability to measure the airflow rate through the building ventilation system with reasonable accuracy. In CGSB 149.10 calibrated fans are used, which allow for relatively easy measurement of flow rates;

however, when using a building's mechanical system under CGSB 149.15 the measurement becomes somewhat more difficult. Since most buildings do not have flow measuring devise of sufficient accuracy installed, pitot tube traverses of the main air supply duct or other methods must be used.

Other differences between this test procedure and CGSB 149.10 is that this test allows for pressurization or depressurization to be used, the exterior pressure is measured at the top and bottom of the building instead of at one level, and that only four measurement points (flow rate and pressure difference) are required instead of eight. While four points provide less accuracy than eight points, they still provide enough information to determine C and n.

This standard also provides guidance as to the weather conditions during which this test can be performed. The maximum permitted wind speed for this test is 20 km/hr (5.6 m/s). The minimum permitted outdoor temperature depends on the height of the building, with higher temperature limits for taller buildings since increased height can cause larger pressures due to stack effect. These limits are provided below in Table 5.1.

Table 5.1 Outdoor Air Temperature Limits from CGSB 149.15

Building Height [Storeys]	Minimum Outdoor Air Temperature [°C]
≤ 10	5
11 to 20	8
21 to 30	10
31 to 40	15

These conditions limit the effect of wind and stack effect on the pressure differentials across the building enclosure during the test, and thus enable more accurate results.

It is important to note that not all buildings have mechanical systems that are appropriate for the use of this method. For example, the systems may not be able to adequately pressurize the building. Also, this method requires more testing personnel, equipment, and time than CGSB 149.10, so is often more expensive (Proskiw and Phillips, Air Leakage Characteristics, Test Methods, and Specifications for Large Buildings 2001).

5.1.4 ASTM E 779 - 10

ASTM E 779 Standard test method for Determining Air Leakage Rate by Fan Pressurization describes an airtightness test method similar to that of CGSB 149.10. The primary differences between this standard and the CGSB standard are the range of pressures used for measurement and the method for calculating leakage area. ASTM E 779 specifies a range of test pressures from 10 Pa to 60 Pa in increments of 5 Pa to 10 Pa. The leakage area calculation calculates the Effective Leakage Area (EfLA) with a discharge coefficient of 1.0 and a reference pressure differential of 4 Pa, as described in Section 3.1.5.

This standard also provides limits regarding the weather conditions under which the test can be performed. "If the product of the absolute value of the indoor/outdoor air temperature difference multiplied by the building height, gives a result greater than 200 m °C, the test shall not be performed, because the pressure difference induced by the stack effect is too large to allow accurate interpretation of the results." (ASTM 2010)

This standard is currently being updated to better facilitate the testing of large buildings such as MURBs.

5.1.5 ASTM E 1827 - 96

ASTM E 1827 Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door is very similar to ASTM E 779, but is specifically for testing using an orifice blower door. The standard describes two methods of air leakage testing. The first is a single point method using a pressure difference of 50 Pa and a flow exponent, n, of 0.65 for calculation purposes. The second is a two-point method with one measurement at 50 Pa and the other at approximately 12.5 Pa to allow for the determination of the flow coefficient and the flow exponent. This standard provides more detailed recommendations than ASTM E 779 and includes a detailed description of intentional openings which must be sealed during the test..

5.1.6 ASTM E 2357 - 05

ASTM E 2357 Standard Test Method for Determining Air Leakage of Air Barrier Assemblies is a laboratory test method for measuring the airtightness of air barrier assemblies, but has also been applied in the field. This test method requires that the air barrier assembly specimen, or small mock-up on site, be tested at 25 Pa, 50 Pa, 75 Pa, 100 Pa, 150 Pa, 250 Pa, and 300 Pa. Because of the high pressure differences required for this test, it is better suited for small areas and would be much easier to perform in a laboratory setting. The test also requires that the air barrier specimen be loaded with air pressure to simulate sustained, cyclic, wind loading and then tested again. This loading is applied to the specimen according to a schedule provided in the standard and is not intended as a test of airtightness, but rather is intended to test the durability of the air barrier under high wind loads and then its retained airtightness. This method is most suitable for determining viable air barrier systems; however, it has limited potential for field airtightness measurements.

5.1.7 ASTM E 741

This test standard describes methods for using tracer gasses to determine naturally occurring air change rates (as opposed to those created by test equipment) in a space. The basis of these methods is that the measured concentration of a tracer gas can be used to determine the airflow rate into or out of a space. It can also be used to identify and quantify the source of airflow into a space. There are three primary techniques that are discussed in this standard: concentration decay, constant injection, and constant concentration.

Constant Decay

The constant decay method releases an arbitrary quantity of tracer gas into a space (but an appropriate quantity such that the concentrations are within the measurable range) and then measures the concentration of the gas over time. As air enters and leaves the space the tracer gas concentration reduces, typically following an exponential decay curve. Using the curve generated from this test, the air change rate in the space can be calculated. This technique is appropriate for determining the average air change rate over a period of time.

Constant Injection

The constant injection method releases a steady amount of tracer gas into a space and measures the equilibrium concentration that is reached. Since the rate of release of the tracer gas into the space and the equilibrium concentration are known factors, the air change rate can be calculated.

Constant Concentration

The constant concentration technique is similar to the constant injection technique except that instead of releasing the gas into the space, the concentration in the space is specified and the rate of gas release is dynamically adjusted to maintain the concentration. This technique is more complicated to perform than the previous two as it requires an automated real time monitoring of tracer gas concentration and the subsequent adjustment of release rate.

For all of these methods it is important that the tracer gas be evenly distributed throughout the space, often by use of small fans or by using multiple release points for the gas. An advantage of tracer gas measurement techniques is that they can be performed at in-service conditions which allow the results to provide a more clear indication of air flow for the building under realistic operating conditions.

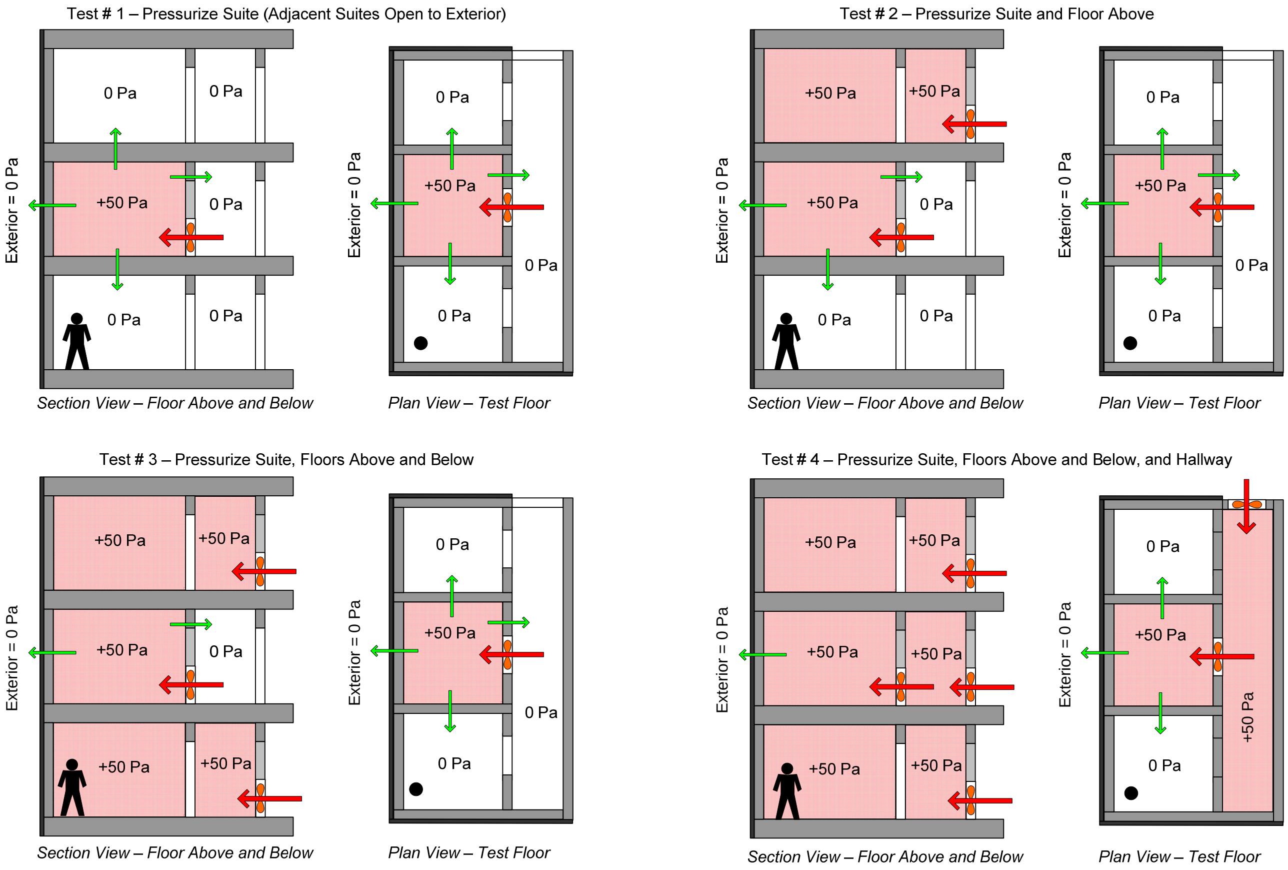
5.1.8 ISO 9972

International Standards Organization (ISO) Standard 9972 Thermal Insulation – Determination of Building Airtightness – Fan Pressurization Method is similar to CGSB 149.10 except that it permits for either pressurization or depressurization of the building and also permits use of the building's mechanical system to achieve these pressure differences as in CGSB 149.15. The pressure difference is specified as increments of no more than 10 Pa from 10 Pa up to 60 Pa.

5.1.9 Pressure Neutralized Fan Depressurization/Pressurization Technique

In larger, more complicated buildings with many separate spaces (such as MURBs), it is often impractical or impossible to pressurize or depressurize the entire building for the purposes of airtightness testing. Blower capacity may not be available, funding may be limited, and achieving a uniform pressure distribution may be difficult. To overcome these issues, the Balanced Fan Depressurization/Pressurization method has been developed to allow for the airtightness testing of discrete spaces within a building, such as an individual suite in a MURB. This method also permits for the isolation of each side of the enclosure for a space (for example, each of the six sides of a rectangular suite) so that the airtightness properties can be determined. This can be of particular value when considering internal airflows.

This type of test is conducted by first setting up a fan to depressurize the test suite. Then, adjacent spaces (neighbouring suites on the same level, above, and below and the corridor) are then depressurized to the same level as the test suite one-by-one, to allow the component of air leakage from the test suite to each of the adjacent spaces to be isolated. Once all of the adjacent spaces have been balanced with the test suite, any remaining air leakage must be through the exterior enclosure. Fig.5.2 shows a schematic representation of this process (Finch 2007).



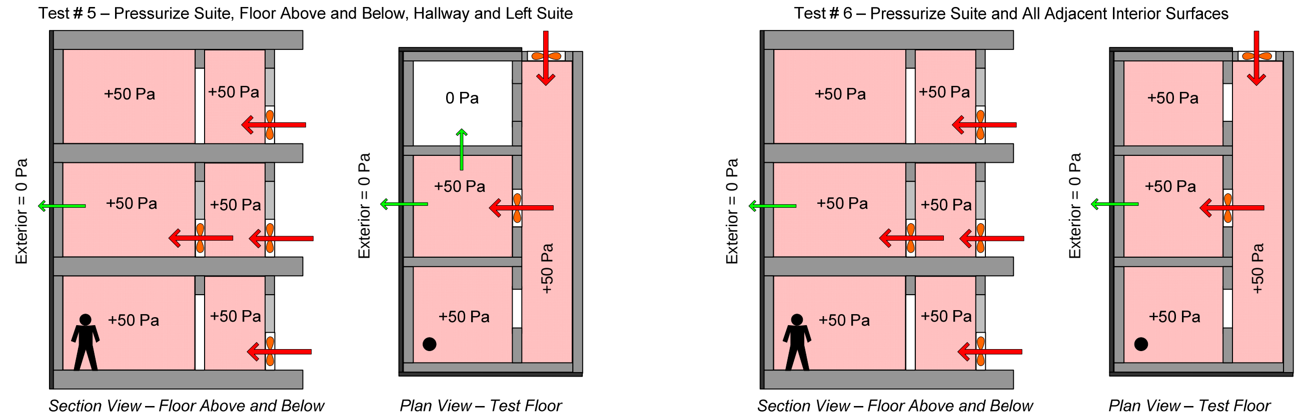


Fig.5.2 Balanced Fan Pressurization/Depressurization Method Schematic (Finch 2007)

Balanced fan techniques encounter inaccuracies from practical issues associated with getting multiple fans to operate in equilibrium. That is, the flow rate and pressure caused by one fan can affect the flow rates of the other fans. Further complicating this problem is that baseline pressure readings vary with wind. If, during the test, a building occupant were to open a balcony door or the elevator were to open on the test floor, this could significantly impact the flow rates and likely the test would need to be re-started. The method described in this section, however, helps to eliminate some of the difficulties with coming to equilibrium by allowing each fan to operate independently (Finch 2007).

Another potential challenge with this test procedure is that it requires the blocking of multiple doors within a building. This means that access to suites, stairwells, and corridors is limited during the test. Consequently, cooperation of building occupants is essential to the success of this test if performed in-service. Testing prior to occupancy can also be challenging as it requires balancing a tight construction schedule, coordination with the owner, turn-over and full completion of the building (without deficiencies in any air barrier component including broken windows, doors and other enclosure elements) for the test. Experience has shown this to be difficult in larger MURBs.

This test method provides the unique ability to isolate the air leakage contribution of different parts of a suite enclosure, which can provide valuable information regarding airflows in to, out of, and within the building that other test methods do not provide. Furthermore, because the test focuses on a small section of the building, the impact of stack effect and wind on the pressure difference is significantly reduced and makes for more even, consistent, and reliable pressure differences.

Despite some of the complications that arise as a result of the multiple fans required to perform this type of test, the advantages of this technique usually significantly outweigh the disadvantages and often this test method is the only feasible method for highly compartmentalized buildings such as MURBs. Additionally, many of the uncertainties and causes of errors can be adequately addressed when identified.

5.1.10 Multi-Zone Test Procedure

This procedure has been developed by Proskiw and Parekh (2001) as an alternative method of isolating zones within a building. It follows a similar procedure to that of the Pressure Neutralized Fan Depressurization/Pressurization test procedure, except that it does not require that adjacent zone be completely pressure equalized with the test area. Instead this procedure requires that the pressure difference to adjacent suites be modified (thus, the adjacent areas are pressurized/depressurize but not necessarily to the same level as the test zone) such that the air leakage at different magnitude pressure differences with the adjacent suites can be determined. The relationships between pressure difference and flow rate can then theoretically be used to determine the air leakage characteristics of the suite. This method is most advantageous if the space adjacent to the test area is large or relatively air leaky and thus difficult to pressurize (or depressurize) to the same level as the test area.

5.1.11 ATTMA Technical Standard L1 - 2010

British Airtightness Testing and Measurement Association (ATTMA) *Technical Standard L1: Measuring Air Permeability of Building Enclosures (Dwellings)* is a standard developed primarily for use with detached residential buildings and is similar in principle to CGSB 149.10. It requires a minimum of 7 flow rate measurements, taken at sequential pressure differences in no more than 10 Pa increments, starting at a minimum pressure difference of at least 25 Pa. The standard allows for either pressurization or depressurization of the building.

5.1.12 US Army Corps of Engineers

The US Army Corps of Engineers (USACE) has developed an airtightness testing protocol in conjunction with the Air Barrier Association of America (ABAA) as part of their program to meet energy saving targets. It is based on ASTM E 779 but provides some modifications, in particular to accommodate the increased pressure biases that can occur in high-rise buildings as a result of increased wind exposure and stack effect. The primary change made to this standard is that it specifies testing at a higher pressure difference of 25 Pa to 75 Pa (with an allowance for 85 Pa) with at least 10 points in this range. Also, testing according to this procedure must be performed in both pressurized and depressurized states to better account for any bias that may exist. This standard provides an exception for the testing of larger buildings that require greater 200,000 cfm (94,000 L/s) of airflow to create the required 75 Pa pressure difference. It permits these buildings to be tested in either the pressurized or depressurized state only (rather than both) as the equipment required to achieve this flow may not be capable of both pressurizing and depressurizing.

5.1.13 Other Procedures

Other testing procedures exist but are not in wide scale use. In many cases, these alternative procedures are modifications of the procedures discussed above, are intended primarily for research grade airtightness testing, and may not be suitable for widespread industry adoption without further development. For informational purposes, some of the other techniques are listed below.

- Nylund Technique

  This test method is based on the idea that internal airflows between spaces can be determined by measuring the pressured field within the zones adjacent to the test zone that is being pressurized/depressurized. This method, however, assumes that the airtightness of every zone is the same and that the interior air leakage between spaces is much less than the leakage to the exterior, that is, the exterior enclosure air barrier is much leakier than interior separators within the building.

- DePani & Fazio Technique

  This method is designed such that airtightness characteristics of a single suite can be determined with only one fan by first pressurizing the test suite, and then each of the neighbouring suites one at a time. Using linear algebra, the flow coefficients and flow exponents for each component of the building can be determined. This technique was developed for a three unit building; therefore, it may have some limitations for applications in buildings with more units. (DePani and Fazio 2001)

- AC Pressurization

  All of the other techniques to this point are considered DC pressurization, which rely on creating steady-state pressure differences to determine airflow rates and thus building airtightness characteristics. AC pressurization instead creates periodic pressure differences across the building enclosure and then uses the magnitude of the pressure difference and the time over which it changes to determine air leakage properties. (Colliver and Murphy 1992) This technique is somewhat similar in concept to the Lstiburek Technique discussed below.

- Lstiburek Technique

This technique operates on the basis of pressure perturbation. By increasing or decreasing the pressure at a location in a building and then monitoring how the pressure field within the building reacts, conclusions can be drawn with regard to building airtightness characteristics. (Lstiburek 2000)

5.2. Summary of System Quantitative Testing Procedures

For convenience, a summary of the various system quantitative tests, including some in addition to those discussed above, is provided here for reference, adapted with permission from a table in the Residential Pressure and Air Leakage Testing Manual produced by Retrotec. (Retrotec 2012)

Table 5.2 Summary of Airtightness Testing Procedures (Retrotec 2012)

Standard	CGSB 149.10	ASTM E 779	ATTMA Tech. Std. L1	USACE	Washington State
Applies to	Residences (adapted for all)	All Buildings (single zone)	Residences	Large Buildings	Large Buildings
Origin	Canada	USA	UK	USA	State of WA
Acceptable conditions	<20km/h wind	height x ΔT<200m°C	<6m/s wind Average ΔP < 5 Pa without pressurizing	Bias<10% of avg. and Baseline <30% of minimum pressure	95% confidence interval
Induced pressure point range	15 to 50 Pa	10 to 60 Pa	10 to 100 Pa	25 to 85 Pa	25 to 80 Pa
Number of points	8	> 5 each	7 each	≥ 10 each	12 each
Test Direction Preferred	Depressurize	Both	Both	Both	Both
Test Direction acceptable	Depressurize	Either but usually depressurize	Usually pressurize	Both unless building requires over 200,000 cfm	Both
Results	EqLA	EfLA CFM_{50}	$m^3/h{\cdot}m^2$ @ 50 Pa	CFM_{75}/ft^2	CFM_{75}/ft^2
Required Results	none	none	1 to 7 $m^3/h{\cdot}m^2$ (0.05 to 0.38 cfm/ft²) @ 50 Pa	0.25 CFM_{75}/ft^2	0.40 CFM_{75}/ft^2

5.3. Component Quantitative Tests

In some cases, it is useful to quantify the air leakage through a discreet building component such as a door or window. Two tests for this purpose are described below.

5.3.1 ASTM E 283 - 04

First published in 1965, *ASTM E 283 Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen* describes a laboratory test procedure for determining air leakage rates of building components. This procedure uses an airtight test chamber with the test specimen mounted and sealed in one side of the unit. The test chamber is then pressurized or depressurized using a fan system to apply a pressure difference across the specimen. The fan equipment should be such that a flow rate, and thus an air leakage rate, can be determined. To achieve accurate results with this standard, it is important that the specimen is well sealed into the test chamber and that the test chamber itself is entirely airtight. As this is a laboratory test, it indicates the airtightness of the specimen only, and does provide any information with regard to potential air leakage due to installation practices in as-built conditions.

5.3.2 ASTM E 783 -02

ASTM E 783 Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors is essentially the field test version of ASTM E 283. "The experimental set-up is basically the same as E 283 with the major difference being that a special test chamber has to be constructed and attached over the test specimen. Under normal field conditions, a single test chamber can generally be re-used two or three times, after which it normally has to be replaced. Generally, the biggest challenges encountered using E 783 are affixing the chamber over the specimen so as to adequately limit extraneous leakage and then accurately quantifying the extraneous leakage that remains. The test procedure, analysis method and methods of reporting results are the same as E 283. It can also be adapted to permit calculation of C and n, and used to test other types of building components." (Proskiw and Phillips, Air Leakage Characteristics, Test Methods, and Specifications for Large Buildings 2001) This test provides a measurement more indicative of in-service performance than does ASTM E 283 as it accounts for as-built conditions.

5.4. Qualitative Tests

While quantitative testing is preferable to obtain results for comparison, benchmarking, and the achievement of set targets, qualitative tests can also be a very useful tool. Qualitative tests are typically used in forensic investigations of air leakage to locate high leakage areas and gain an understanding of flow directions and magnitudes.

5.4.1 ASTM E 1186 – 03

ASTM E 1186-03 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems describes a variety of qualitative testing techniques for locating areas of air leakage, outlined in the following sections.

Infrared Photography

Using either fan equipment or the building's ventilation equipment, the building can be pressurized or depressurized relative to the exterior under conditions where there is at least a 5°C temperature difference between the interior and exterior. Once the building is pressurized (or depressurized), an infrared camera is used to illustrate the temperature of enclosure components. If the building is pressurized, the building should be viewed from the exterior, and if it is depressurized it should be viewed from the interior, so that the air leakage locations are visible. The surface temperature of enclosure components will change due to airflow over it, and this temperature difference will be visible using the infrared camera. Typically, temperature differences due to air leakage appear as streak or plume like patterns.

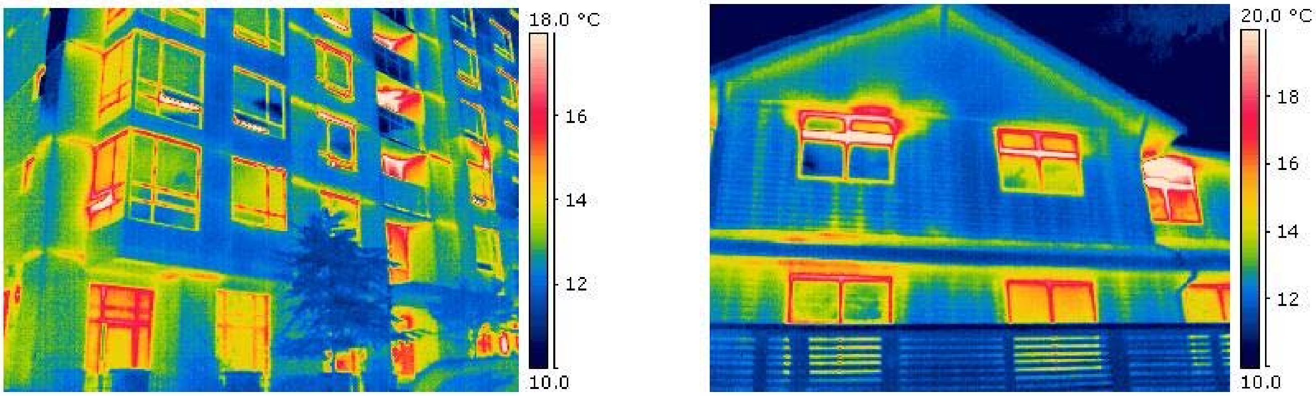


Fig.5.3 Infrared Images of MURBs from Exterior Showing Air Leakage at Operable Windows and Defects in Air Barrier Continuity

It is important to distinguish air leakage thermal patterns from those caused by other effects such as thermal bridging. Differentiation can be achieved by taking infrared photos of the exterior of the building while pressurized and while depressurized. Comparing these two images allows for the identification of temperature changes due to air leakage, and thus of air leakage locations. Figure 5.4 shows examples of air leakage locations detected through the use of infrared thermography.

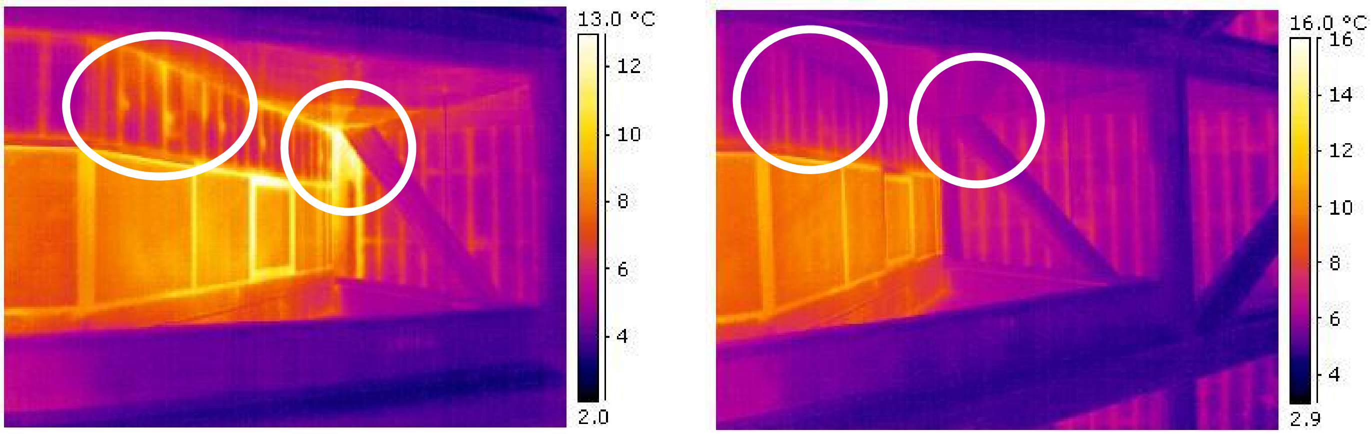


Fig.5.4 Infrared Images of MURBs from Exterior Showing Air Leakage at Operable Windows and Defects in Air Barrier Continuity

The skill and knowledge of the infrared camera operator (thermographer) is fundamental to achieving accurate and informative results using this type of qualitative testing. Beyond a knowledge of the specific camera and lens that is being used, the thermographer should also have a thorough understating of building science and construction, as well as an understanding of the construction of the particular building that is being reviewed. It should also be noted that thermographers that are accustomed to and qualified to perform infrared testing of houses are not necessarily qualified to perform testing on larger buildings such as MURBs due to the additional complexity and different construction practices. (Gonçalves, Gendron and Colantonio 2007) Inaccurate use of infrared thermography tools and misinterpretation of the results can lead to the misidentification of or alternatively to the overlooking of air leakage locations.

Smoke Tracers

The use of smoke tracers is done by pressurizing or depressurizing the building using either fans or the building's mechanical system. Non-toxic smoke is produced using a smoke generator (often a theatrical smoke machine) on the high-pressure side of the building enclosure. The pressure differential causes the smoke to flow through the building enclosure and become visible from the low-pressure side, thereby identifying the location of air leaks.

The standard also describes a version of this test where instead of pressurizing or depressurizing the whole building, a smaller section of the building (test chamber) is created and that section is pressurized or depressurized.

Fig.5.5 Diagnostic smoke testing of a window and window to wall interface while the suite is under positive pressure differential (Photo by Patenaude Trempe Inc.)

Airflow Measurement Devices

This technique is similar to the smoke tracer test except that instead of using smoke to visually identify the leaks, an airflow measurement device, such as anemometer, is moved over the low pressure side of the building enclosure to detect locations of high air velocity. These locations indicate likely air leakage locations.

Sound Transmission

This test is described in the standard as a qualitative method, but similar tests can be used for quantitative acoustic testing. In this test the building does not need to be depressurized or pressurized. A sound generation device is placed in the building and then a sound detection device is moved over the exterior of the building. Locations where more sounds are noted indicate potential air leakage locations. The sound generation device could alternatively be placed on the exterior of the building and the survey performed on the interior.

Tracer Gas

Tracer gas testing can be performed as a quantitative measure of airtightness; however, this standard describes it for qualitative testing only. In this standard, tracer gas is released on one side of the building enclosure and then a detector is used to measure tracer gas concentration on the exterior of the building enclosure. Locations of increased tracer gas concentration could indicate an air leakage location. The standard also indicates that pressurizing or depressurizing the building can make this method more effective.

Leak Detection Liquid

This qualitative test is performed by applying a leak detecting liquid to the face of the building enclosure on the side that will be at lower pressure once fans or the building’s mechanical systems are used to pressurize or depressurize the building. While not specified in the standard, typically this leak detection liquid is a soapy substance. When air flows through the enclosure it will cause the liquid to bubble, creating a visible indication of air leakage.

5.4.2 Smoke Tracer - Smoke Wand

A variation of the smoke tracer method described in ASTM E 1186 is the use of a smoke wand which are sometimes also referred to as smoke pencils. Smoke wands produce a relatively small amount of smoke that can be used during building in-service conditions to detect the direction and magnitude of airflows. Frequently this technique can be used to visualize airflows through door undercuts or to detect small drafts.

Fig.5.6 Smoke Wand to Detect Leak and Direction of Airflow at Interface Detail

5.5. Costs

Costs associated with airtightness testing will vary widely depending on characteristics specific to each project. Some of the factors that will affect the cost of these tests include: distance of test agency to test location, size of building, complexity of building, type of testing required, accuracy of testing required, and level of documentation required. Approximate costs for various types of testing are provided in Table 5.3.

Table 5.3 Airtightness Testing Costs

Airtightness Test	Approximate Cost
Quantitative Testing Procedures	
Whole Building Airtightness Test (CGSB 149.10, ASTM E 779, ASTM 1827 or USACE) - Single large blower unit or multiple smaller blower units to pressurize/depressurize whole building with multiple zones	Depends on Building Size and Timing of Test, $2,000 to $25,000+
Whole Building Airtightness Test (CGSB 149.15) - Use of building ventilation system to pressurize/depressurize whole building with multiple zones	Depends on Available Equipment (unlikely within a MURB) $8,000 to $12,000
Balanced Fan Depressurization/Pressurization Test of Single Zone - Determination of interior separator and exterior building enclosure airtightness characteristics of a single zone within a multi-zone building	$3,000 to $6,000
Constant Decay Tracer Gas Testing (ASTM E 741)	$5,000 to 10,000+
Constant Injection Tracer Gas Testing (ASTM E 741)	
Constant Concentration Tracer Gas Testing (ASTM E 741)	

Component Airtightness Test (ASTM E 783) - Field test of airtightness of single component such as a door or a window	Depends largely on access to component $1,000 to $2,000
Detached House Blower Door Airtightness Test	$150 to $500
Qualitative Testing Procedures	
Performance Verification Infrared Photography - Infrared photography to identify air leakage locations while building is pressurized/depressurized	$1,000 to $2,000 as an add to whole building pressurization test
Performance Verification Smoke Test - Smoke testing to identify air leakage locations while building is pressurized/depressurized	$1,000 as an add to whole building pressurization test
Diagnostic Infrared Photography - Infrared photography to identify air leakage locations in response to an identified issue at a discrete location	$2,000 as an add to whole building pressurization test
Diagnostic Smoke Test - Smoke testing to identify air leakage locations in response to an identified issue at a discrete location	$500 to $1,000

5.6. Test Equipment

5.6.1 High Capacity Blower Systems

For testing larger buildings such as MURBs, very high flow rates are often required to achieve the necessary pressure differences. To provide these large flow rates, high capacity blower systems have been created. Due to the size and expense associated with these systems, they are relatively uncommon. In the 1970's and 80's the National Research Council of Canada (NRC) developed a trailer-mounted system that can deliver 23 m^3/s (48,737 cfm). The United States National Bureau of Standards has a system that can produce 7.55 m^3/s (16,000 cfm), and the British Research Establishment has 4 "BREFAN" units that can each produce 7.55 m^3/s (16,000 cfm). In addition to the BREFAN units, the British Research Establishment has a larger trailer mounted unit, capable of supplying 30 m^3/s (64,000 cfm). (Proskiw and Phillips, Air Leakage Characteristics, Test Methods, and Specifications for Large Buildings 2001)

Due to the limited availability of these systems their use is relatively uncommon within the building industry. Additionally, these fans often require an independent power source or generator because they draw too much power to run on conventional domestic circuits. Where high flow rates are needed, industry more commonly uses multiple smaller fans used for blower door systems as discussed in the following section. Using multiple smaller fans of up to 4 m^3/s (8,500 cfm), also allows for placement of fans around a large building to avoid issues with congestion and restrictions caused by a single large fan. Only 6 fans are needed to make up the total flow rate of the NRC trailer mounted fan.

Fig.5.7 BREFAN Unit (Lovatt 2008)

5.6.2 Fan-door Systems

Commonly used in single family detached residential applications, fan-door (or blower door) systems are the most common type of pressurization/depressurization equipment. These systems consist of a calibrated fan mounted in a door cover that is installed in a doorway that separates the space to be tested from the adjacent space. Air is then forced into or out of the test space and the flow rate through the fan is determined by pressure measurement and the use of calibrated orifice plates. Typically, the fan unit will come with a control device that incorporates a manometer and is able to make the flow calculation.

Fig.5.8 Fan-door System Installed in a Doorway with Single and Multiple Fans (Retrotec 2012)

The fan-door system can be powered off of either a 120V or a 240V system and typically can produce flow rates of 10 L/s to 4,000 L/s (20 to 8,500 cfm). The systems are typically equipped with digital manometers that provide accuracy of approximately 1% of the reading or 0.15 Pa, whichever is greater. The fans typically use orifice plates of a variety of sizes combined with pressure measurements from the manometer to determine flow rates.

The primary advantages of these systems are provided below:

- There are a number of manufacturers in North America.
- The system is small and light enough that it can easily be transported to site in a small vehicle.
- The system can be installed by one person in about 30 minutes (not including other components of testing set-up).
- It can be powered on a standard residential electrical circuit.
- The unit can fit in a standard doorway (and adjustable to larger industrial and commercial man doors).
- It requires only one operator (although more may be needed depending on the application).
- Multiple fans can be installed (maximum two or three fans per doorway in most cases) and distributed throughout a building to test larger buildings and achieve even pressure distribution.
- The versatility to test discrete spaces within a building is provided.
- The process is reasonably affordable (approximately $5,000 per blower door assembly with digital control gauge).

The primary disadvantage is that in some cases many fans are required to achieve the necessary flow rate, which increases the complexity of the test and may require additional personnel.

5.6.3 Infrared Cameras

Infrared cameras allow the infrared radiation produced by an object to be visualized. Infrared radiation provides an indication of an object's temperature; consequently, by using an infrared camera with the appropriate calibrations for emissivity (the ability of an object to emit radiation) the surface temperature of an object can be determined. More importantly, in most air leakage cases, the relative surface temperatures can be identified in order to highlight anomalies. While infrared cameras are readily available to industry, they are still fairly expensive. Some models can be found for approximately $1,250, but typical costs range from approximately $2,000 to $10,000. It is important that a camera with appropriate specifications be used including the resolution, temperature accuracy, temperature range, and temperature resolution. The appropriate lens for the application should also be used. (Gonçalves, Gendron and Colantonio 2007) An image of an infrared camera that is commonly used for airtightness testing is shown in Fig.5.9.

Fig.5.9 Typical Infrared Camera Used for Air leakage Diagnostic Testing

5.6.4 Smoke Generators

Smoke generators can be a very valuable tool in qualitative air leakage testing, as described in Section 5.4. They are available from theatrical and performance shops for approximately $200, though small cheaper units can be obtained for less than $50. Fig.5.10 shows use of a smoke generator for diagnostic testing.

Fig.5.10 Typical Smoke Generator Used for Testing

5.6.5 Smoke Wand

Smoke wands, also called smoke pencils or smoke puffers, produce a relatively small amount of smoke with virtually no disturbance to the air, so can be used during building in-service conditions to detect the direction and magnitude of airflows. The smoke is produced chemically and is often toxic so should not be inhaled directly; however, the quantities of smoke that are used are so small that this is not a major concern. Typically a smoke wand will cost less than $50 and provide from several hundred to a thousand puffs of smoke (Fig.5.11).

Fig.5.11 Smoke Wand Being Used to Show Airflow Out of Electrical Outlet

5.6.6 Tracer Gasses

Tracer gasses are inert gasses that are generally found at very low concentrations naturally and are not produced by respiration or by common processes found in buildings. Therefore, when added to the space under test conditions, the change in concentration from natural conditions can be easily measured. ASTM E 741 provides a table of common tracer gasses, ambient levels, measurement techniques, and at what level they can be detected.

Table 5.4 Tracer Gas Characteristics from ASTM E 741 - 06

Tracer Gas	Ambient Levels	Measurement Techniques	Detection Levels
Hydrogen	0.5 ppm	Katharometer	200 ppm
Helium	5.2 ppm	Katharometer	300 ppm
Carbon Monoxide	0.1-1 ppm	Infrared Absorption	5 ppm
Carbon Dioxide	320 ppm	Infrared Absorption	1 ppm
Sulfur Hexafluoride	1 ppt	Electron Capture Detector	2 ppt
Nitrous Oxide	0.3ppm	Infrared Absorption	1 ppm
Ethane	1.5ppb	Flame Ionization Detector	5 ppm
Methane	1.5ppb	Infrared Absorption	5 ppm
Octafluorocyclobutane (Halocarbon C-318)	Below Detection Limits	Electron Capture Detector	5 ppb
Bromotrifluoromethane (Halocarbon 13B1)	Below Detection Limits & Locally Variable	Electron Capture Detector	0.1 ppb

Dichlorodifluoromethane (Halocarbon 12)	Below Detection Limits	Electron Capture Detector & Flame Ionization Detector	0.6 ppm
Dichlorotetrafluoromethane (Halocarbon 116)	Below Detection Limits	Electron Capture Detector & Flame Ionization Detector	0.3 ppm
Legend: ppm = part per million (i.e. one particle of tracer gas for every million particles of air) ppb = part per billion ppt = part per trillion			

5.6.7 Flow measuring devices

Flow measuring devices are usually of one of two types: an orifice flow device or a velocity pressure measuring device.

An orifice flow device uses a calibrated set-sized orifice and measures pressure differences across the orifice to determine the flow rate. Blower door fans are a common example of this technique.

A velocity pressure measuring device measures the average velocity pressure or airflow through an opening (or often through an air duct), which, given the density of the air, can be converted to the flow rate. The average velocity pressure is found by measuring the total pressure (velocity pressure plus static pressure) and then subtracting a measurement of the static pressure. Average total pressure in the airflow is found either by using an array of total pressure measurements distributed evenly across the flow cross-section. Alternatively, velocity pressure could be measured by use of a pitot tube traverse.

5.6.8 Pressure Measuring Devices

Pressure measuring devices are called manometers, or for lower pressure differences, micromanometers. It is important to note that for airtightness testing, relative pressure measurements and not absolute pressure measurements are of interest. For example, it is important to know the relative pressure difference across a building enclosure component during a pressurization/depressurization test, but it is not important to know the absolute pressure inside the building. (A pressure measurement device that measures absolute pressure is called a barometer.)

Manometers are available in analog or digital varieties and range in price from $100 for basic analog gauges to over $1,000 for digital gauges with additional features. Good reliable digital gauges are available for under $300. Analog meters are typically practical for measurements of larger, stable pressure differences. Digital manometers can measure extremely low pressure differences. An advantage of digital manometers is that often they are equipped with built in time-averaging capabilities, which can be very useful as air pressure measurements can fluctuate significantly, especially due to wind. A digital manometer is shown in Fig.5.12.

To help reduce the frequency of pressure measurement fluctuations due to wind it is also possible to provide a volume of air to act as a buffer, or to use capillary tubing (very small tubing), which can also act as a buffer to high-frequency fluctuations. A number of manufacturers provide devices for this purpose (less than $100), and guidance with regard to their use is available in CGSB 149.10.

Fig.5.12 Digital Pressure Gauge used as part of Fan-Door Equipment

5.7. Testing During Construction

While it is readily apparent that the most accurate airtightness testing results will be obtained when testing is performed on the completed building as it will exist in-service, once the building has been completed it is often difficult and costly to remedy any air leakage problems as compared to fixing these problems during the construction phase of the project. Thus, it is also useful to perform airtightness testing on completed sections of a building during construction to predict the airtightness of the whole building once completed as well as to identify and remedy any deficiencies prior to the construction completion.

An opportunity presented itself to the authors in 2010 to experiment with various scaled-down versions of whole building air leakage tests that could be conducted during the course of construction, with minimal schedule impact. The goal of the exercise was to understand the challenges of such testing and determine if the results could prove useful in predicting the overall airtightness of the whole building on an early adopter of this code requirement. As a result of the collaboration, testing was performed on a 6-storey wood-framed MURB being constructed on the University of Washington Campus. The student residence building is a 5-storey, wood-framed structure over a concrete ground level, with a total gross floor area of approximately 97,000 square feet. The primary air barrier element at the walls is a sealed rigid sheathing approach (sealant between exterior gypsum sheathing). The various testing performed during construction included:

- Free-standing mock-up testing including individual glazing unit air leakage testing, and combined glazing and wall area air leakage testing. All components and assemblies met the specified project requirements of less than 0.004 cfm/ft^2 (0.02 L/s·m^2) at 75 Pa.
- Localized wall assembly air leakage testing of a 100 ft^2 wall area inclusive of windows at one combined wall/window area per residential floor for a total of 5 tests. These tests included both a quantitative (measured air leakage) and qualitative (visual smoke test) component. All 5 test areas resulted in measured air leakage below 0.02 cfm/ft^2 (0.10 L/s·m^2) at 75 Pa, meeting the target of less than 0.04 cfm/ft^2 (0.20 L/s·m^2) at 75 Pa for assemblies.
- Individual suite testing and full floor testing during the course of building construction. The purpose of the partial floor and full floor testing was three-fold:

  - First, to evaluate airtightness of the air barrier assemblies, locate any air leakage, and assist in the commissioning of the building enclosure air barrier.
  - Second, to determine if a scaled down version of a full building test, such as a full floor or partial floor test a) would be possible during building construction and b) would provide any useful results.
  - Third, to determine if the data collected could provide any insight into the likely result of a full building air leakage test conducted at the conclusion of construction.
- Whole building air leakage testing at completion of construction. The whole building air leakage was measured to be 0.29 cfm/ft^2 (1.47 L/s·m²) at 75 Pa using a 4 fan-door setup as determined by the current Seattle Energy Code and referenced US Army Corp of Engineers Protocol. Of interest, the current Seattle Energy Code target air leakage rate is less than 0.40 cfm/ft^2 (2.0 L/s·m²) at 75 Pa.

The results of the air leakage testing performed on a suite and on full floors during construction, and the results of the final whole building test are provided in Fig.5.13.

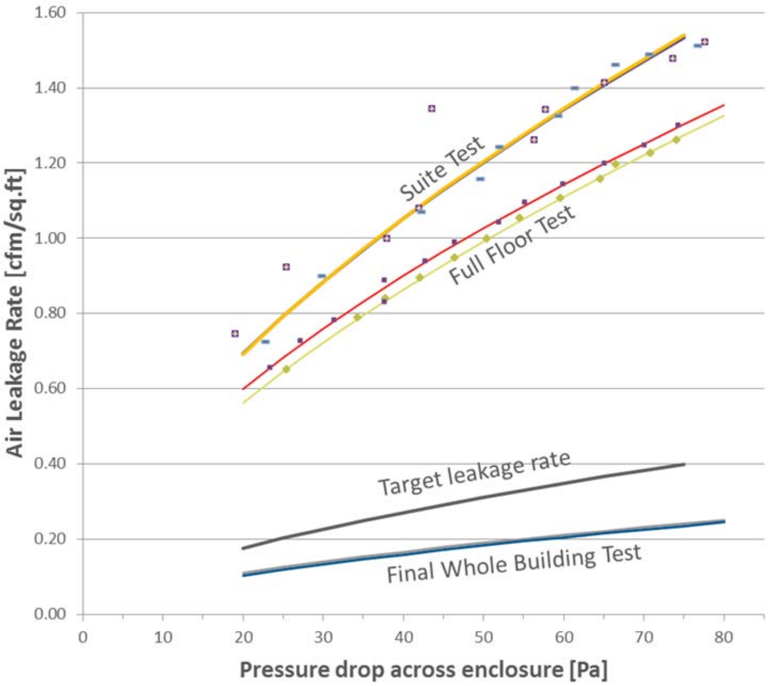


Fig.5.13 Results of Building Airtightness Testing From During Construction and After Completion

As a result of the exercise of conducting single suite and full floor air leakage testing of a building under construction, several lessons were learned and are summarized below:

- Buildings under construction are changing constantly, and attempting to establish an “area” (floor, unit or otherwise) to be tested requires significant coordination between the contractor and testing agency. Attempting to perform testing, without a defined stopping point is challenging, therefore, testing timeframes need to be included and accounted for in the construction schedule. Attempting to work after hours or on weekends is also challenging.
- The air barrier must be complete at the time of testing. This must be accounted for by the contractor, specifically understanding the sequencing of the work and trades with respect to the time frame of testing. At the building tested by the authors, it was assumed the exterior air barrier would be complete; however, sequencing of the floor line membrane installation by the mason, which was established before the airtightness testing plan, was overlooked.
- Quantitative measurements of full-floor air leakage tests during construction may be useful, if floors can be isolated during construction. This will likely vary from building to building and depend largely on sequencing of construction. Without isolation between floors, measured leakage rates may also prove useful for “predicting” whole building test results. For example, in the building tested, the floor and ceiling areas were not included in the air leakage rate

calculation. Had these areas been accounted for, the test results would have been more in line with the whole building test results.

- Qualitative testing (smoke testing and or thermographic scans) under pressurization and depressurization is a useful tool for immediately identifying air leakage paths that can be quickly remedied by the contractor. This type of testing is more easily achieved during the course of construction because complete isolation/neutralization between floors is not critical.

In summary, while qualitative testing to identify air leakage paths can provide significant value and help to ensure that air leakage targets are met upon completion of the building, it is difficult to adequately isolate areas of a building that is under construction so that useful quantitative data can be collected.

In follow-up to this case-study, as part of the same MURB development in Seattle, two companion buildings of similar size and identical assemblies were constructed in 2012 and 2013 by the same builder and design team. Applying the lessons learned from the testing at the first building, improvements to the air-barrier details were made to both newer buildings by the builder, particularly at HVAC equipment and the roof parapet detailing approaches. In all three buildings a sealed sheathing (silicone sealant between joints of exterior gypsum sheathing) was used as the primary wall air barrier strategy, integrated with the rest of the building (windows, roof, below grade etc.).

In the 2012 building, whole building airtightness testing performed prior to occupancy was measured using a 4-fan setup, and found to be 0.19 cfm/ft^2 at 75 Pa (0.96 L/s·m^2), a reduction of 34% from the first building at 0.29 cfm/ft^2. In the 2013 building, whole building airtightness testing was also performed prior to occupancy, and found to be even better at 0.13 cfm/ft^2 at 75 Pa (0.66 L/s·m^2), a reduction of 55% from the first building.

Infrared scans of all three buildings revealed very little leakage at the building enclosure details, with most occurring at double entry doors (even with weather-stripping) and HVAC equipment (even where fully bagged/sealed/dampered closed for the test). These case study buildings demonstrate the potential to construct very airtight MURBs using readily available and cost effective methods of residential construction. The case studies also demonstrated that the enclosures themselves were very airtight, with the majority of leaks occurring through HVAC equipment (dampers and connections), highlighting the need for research into improvements here.

6. Airtightness Regulatory Requirements and Targets

A wide range of airtightness testing requirements and performance targets exist both in Canada and internationally. Some of these requirements are mandatory, others voluntary, and others are part of third-party certification programs.

6.1. Canada

6.1.1 National Building Code for Canada (NBCC) and National Energy Code for Buildings (NECB)

Canadian construction codes including the 2010 NBCC (National Building Code of Canada) and 2011 NECB (National Energy Code for Buildings) contain general air barrier continuity requirements. The 2011 NECB states that “the building envelope shall be designed and constructed with a continuous air barrier system comprised of air barrier assemblies to control air leakage into and out of the conditioned space” and that “all opaque building assemblies that act as environmental separators shall include an air barrier assembly”. Materials used as part of the air barrier systems must be air impermeable (less than 0.02 L/s·m^2 (0.004 cfm/ft^2) at 75 Pa, normalized to enclosure area, not floor area), free of holes and cracks, and compatible with adjoining materials. Prescriptive air-sealing measures are included to ensure air barrier continuity.

In addition to opaque enclosure assemblies, the airtightness of manufactured fenestration must meet certain testing requirements as tested to AAMA/WDMA/ASTM/CSA requirements, which range from 0.2 L/s·m^2 (0.04 cfm/ft^2) at 75 Pa to 0.5 L/s·m^2 (0.1 cfm/ft^2) at 75 Pa, again normalized to enclosure area, not floor area, and air barrier continuity between opaque assemblies and fenestration must be maintained.

Within Canada there are currently no building or energy code requirements for the measurement or quantitative testing of whole building airtightness of MURBs.

6.1.2 Leadership in Energy and Environmental Design (LEED) Canada 2009

The LEED green building rating systems as administered in Canada by the Canada Green Building Council is a points system for evaluating the performance of buildings with respect to environmental targets and has gained significant traction in industry. This standard, however, does not contain any prescriptive requirement for airtightness for energy consumption or durability purposes. Instead, LEED’s airtightness requirements are included for containment of indoor pollutants – primarily tobacco smoke.

One of the requirements of the standard, mandatory to obtain any LEED certification, is that individual suites in a multi-unit residential building achieve an Equivalent Normalized Leakage Area (Normalized EqLA) of 1.65 cm^2/m^2 of enclosure when calculated using the CGSB 149.10 method. In this case, the “enclosure” includes both the exterior enclosure and interior separating elements. (LEED Canada 2009)

This requirement is the same for new construction, major renovations, and existing buildings.

6.2. United States

6.2.1 ASHRAE Standards 90.1

Section 5.4.3 of ASHRAE Standard 90.1 provides general airtightness requirements for a variety of components of the building enclosure including doors and windows; however, no guidance is provided on the overall airtightness target of the building enclosure.

6.2.2 ASHRAE Standard 189.1 – 2011

Compliance with the newest version of *ASHRAE Standard 189.1 Standard for the Design of High-Performance, Green Buildings* provides a variety requirements for airtightness performance of materials used as part of the air barrier, of the air barrier assemblies, and of the building as a whole. For the building as a whole the standard requires that air leakage be less than 0.40 cfm/ft^2 tested at 75 Pa in accordance with ASTM E779.

6.2.3 ASHRAE Handbook of Fundamentals 2009

The ASHRAE Handbook of Fundamentals produced by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers covers a wide range of issues relevant to building design. It provides values from a Tamura and Shaw study (Tamura and Shaw 1976) which proposes that 0.10 cfm/ft^2, 0.30 cfm/ft^2 and 0.60 cfm/ft^2 of enclosure area (0.5 L/s·m^2, 1.5 L/s·m^2, and 3.0 L/s·m^2) at 75 Pa should be considered tight, average, and leaky values respectively.

6.2.4 Energy Star®

The Energy Star® system is a rating system for building and provides some guidance for airtightness of high-rise buildings. This system requires that buildings be tested in accordance with ASTM E 779 or ASTM E 1827 and achieve a target of 0.30 cfm/ft^2 (1.5 L/s·m^2) of enclosure area at a 50 Pa pressure differential. (Note that if the ASTM E 1827 standard is followed, only a single point test is required.) This requirement applies to both the exterior enclosure and interior separation elements. Additionally, the airtightness target is a requirement for both the prescriptive and performance paths in the Energy Star® system. (Energy Star 2011)

Energy Star® has extensive requirements related to the sample size of the apartments tested in a multi-unit residential building. First, there is a preliminary testing phase in which at least one corner unit and one middle unit are tested as early in the construction process as possible to provide an early check of design and installation. If the units fail, the air barrier system must be improved until it meets the prescribed target, and changes noted and applied to subsequent areas of the building. The final testing phase requires that one in every seven suites be tested to ensure achievement of the airtightness requirement. If the one tested suite does not pass the test, an additional two suites from the seven must be tested. If either of those two suites does not meet the requirement, the remaining four suites of the seven must also be tested. During the course of this procedure, any suite that fails to meet the test must have the deficiencies corrected and be retested until it meets the specified target. (Energy Star 2011)

6.3. International

6.3.1 International Energy Conservation Code (IECC)

The 2012 IECC has requirements for air barrier assemblies and air leakage control in residential and commercial buildings.

For residential buildings including those less than 3 stories and some small MURBs, Section R402.4 states that "the building envelope shall be constructed to limit air leakage" and includes performance based requirements for whole building air leakage testing. A whole house or dwelling unit fan-door test to meet an air leakage rate of 5 ACH@ 50 Pa or less in climate zones 1-3 and 3 ACH @ 50 Pa or less in climate zones 4-8 is required. A map indicating these climate zones in North America is provided in Fig.6.1. Testing, where required by the code official, is to be performed by an approved third party to inspect all building enclosure components and verify compliance.

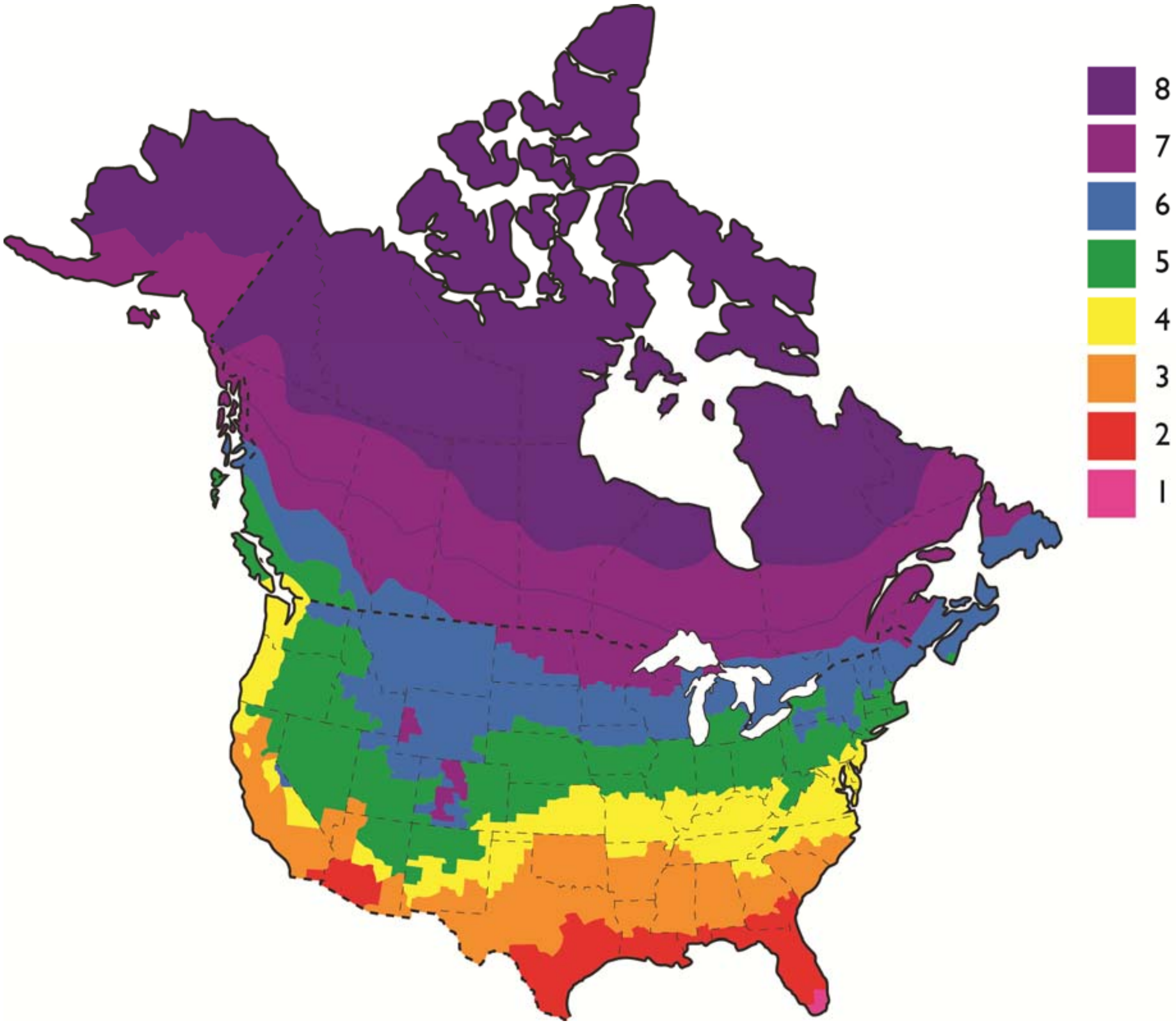


Fig.6.1 ASHRAE/IECC Climate Zone Map – Based on Current DOE US and Canadian Climate Zones 1 through 8

For commercial buildings including most taller MURBs, Section C402.4 states in Climate Zones 4-8, "a continuous air barrier shall be provided throughout the building thermal envelope". In Climate Zones 1-3, air barriers are not required in buildings following the commercial requirements of the IECC. The air barrier may be installed inside or outside, or within the building enclosure; however, it must be continuous and sealed. For compliance with the air barrier system requirements: materials must be air impermeable (<0.004 (0.02 L/s·m²) cfm/ft^2 @75 Pa); assemblies of materials and component must have an average air leakage rate not exceeding 0.04 cfm/ft^2 (0.20 L/s·m²) at 75 Pa; the completed building shall be tested; and the air leakage rate of the building enclosure must not exceed 0.40 cfm/ft^2 of enclosure area at 75 Pa when tested in accordance to ASTM E779 or equivalent method (i.e. the USACE Standard)

6.3.2 International Green Construction Code (IGCC)

It should also be noted that a new International Green Conservation Code is currently under development (iccsafe.org/cs/igcc) by the International Code Council. Building Enclosure requirements within the IGCC have not been finalized; however, Draft Version 2 currently proposes mandatory airtightness testing with a target of 0.25 cfm/ft^2 (1.27 L/s·m²) @ 75 Pa to be required for all buildings.

6.3.3 International Building Code (IBC)

The International Building Code simply specifies that buildings be built in accordance with the IECC.

6.3.4 International Residential Code for One- and Two-Family Dwellings (IRC)

The International Residential Code for One- and Two-Family Dwellings (IRC) is an international code for residential buildings, but does not include MURBs. This standard specifies that in climate zones 1 and 2, buildings must meet 5 ACH_{50} and in climate zones 3-8 they must meet 3 ACH_{50}.

6.3.5 Passivhaus

Passivhaus (or Passive House) is an energy efficient house program developed in Germany that has since gained significant international recognition. Among one of its many requirements is an airtightness performance requirement of 0.6 ACH (air changes per hour) at 50Pa. While originally intended for application to detached homes, the Passivhaus standard has also been applied to the construction of other building types including multi-unit residential. While it is difficult to compare ACH values directly with normalized airflow rate, 0.6 ACH corresponds with a very airtight building. The program, in fact, has received some criticism for section of this value as many industry professionals feel that this represents an arbitrarily tight airtightness requirement and that relaxation of this requirement would not significantly impact the energy performance of the buildings built using Passivhaus.

6.4. Summary of Airtightness Requirements

For ease of comparison, airtightness requirements from the various sources discussed above as well as some additional sources are provided below in Table 6.1, Table 6.2, Table 6.3, and Table 6.4. These tables have been adapted with permission from the tables provided in the Residential Pressure and Air Leakage Testing Manual produced by Retrotec. (Retrotec 2012)

Table 6.1 Residential Airtightness Requirements in Canada and the United States (Retrotec 2012)

Program	Standard	Region	Comments	Requirement	
R-2000	CGSB 149.10	Canada		1.5 or 0.07	ACH_{50} $EqLA_{10}$
LEED ETS	ASTM E779	US	Air quality standard used for apartments	1.25	in² EfLA /100 ft²
EEBA		US	Energy and Environmental Building Association Guidelines	0.25	cfm/ft² @ 50 Pa
LEED for Homes 2012 (1 point)		US & Canada	hot areas, Climate Zones 1 and 2	4.25	ACH_{50}
			Climate Zones 3 and 4	3.5	ACH_{50}
			Climate Zones 5 to 7	2.75	ACH_{50}
			Climate Zone 8	2	ACH_{50}
LEED for Homes 2012 (2 points)		US & Canada	hot areas, Climate Zones 1 and 2	3	ACH_{50}
			Climate Zones 3 and 4	2.5	ACH_{50}
			Climate Zones 5 to 7	2.0	ACH_{50}
			Climate Zone 8	1.5	ACH_{50}
Energy Star v2.0		US	hot areas, Climate Zones 1 and 2	7	ACH_{50}
			Climate Zones 3 and 4	6	ACH_{50}
			Climate Zones 5 to 7	5	ACH_{50}
			Climate Zone 8	4	ACH_{50}
Energy Star v3.0		US	hot areas, Climate Zones 1 and 2	6	ACH_{50}
			Climate Zones 3 and 4	5	ACH_{50}
			Climate Zones 5 to 7	4	ACH_{50}
			Climate Zone 8	3	ACH_{50}
IECC		US	Climate Zones 1 and 2	5	ACH_{50}
			Climate Zones 3 to 8	3	ACH_{50}

ORSC / OEESC		Oregon, US	3.5 to 5 is Tight, great	3.5 ACH_{50}
			5 to 7 is good	7 ACH_{50}
Pennsylvania Housing		Pennsylvania, US	Tight < 5 PHRC	5 ACH_{50}
			Moderate < 10, Leaky > 10 PHRC	10 ACH_{50}
IECC		Georgia, US		7 ACH_{50}

EEBA = Energy and Environmental Building Association
LEED ETS = Leadership in Energy and Environmental Design Environmental Tobacco Smoke (requirement is for tobacco smoke control)
ORSC / OEESC = Oregon Residential Specialty Code / Oregon Energy Efficiency Specialty Code
PHRC = Pennsylvania Housing Research Center

Table 6.2 Commercial Airtightness Requirements for Canada and the United States (Retrotec 2012)

Standard	Region	Comments	Requirement
LEED	US	All 6 surfaces enclosing an apartment.	0.23 cfm/ft^2 @ 50 Pa
ASHRAE 189.1	US	Assemblies (also for high-rise residential)	0.40 cfm/ft^2 @ 75 Pa
USACE	US	Large Buildings	0.25 cfm/ft^2 @ 75 Pa
		Large Buildings (proposed)	0.15 cfm/ft^2 @ 75 Pa
Washington State	US	State of Washington Energy Code	0.40 cfm/ft^2 @ 75 Pa

Table 6.3 International Residential Airtightness Requirements (Retrotec 2012)

Region	Program	Standard /Code	Applies to		Requirement
Austria			Naturally Ventilated		3.0 ACH_{50}
			Mechanically Ventilated		1.5 ACH_{50}
Bulgaria			Floor multi-dwelling	High	<2 ACH_{50}
				Med	2-5 ACH_{50}
				Low	>5 ACH_{50}
			Floor, single flats	High	<4 ACH_{50}
				Med	4-10 ACH_{50}
				Low	>10 ACH_{50}
Czech Republic		CSN 73 0540-2	Natural		4.5 ACH_{50}
			Forced		1.5 ACH_{50}
			Forced + heat recovery		1.0 ACH_{50}
			Forced + heat recovery passive house		0.6 ACH_{50}
		TNI 73 0329	Low energy house		1.5 ACH_{50}
			PassivHaus		0.6 ACH_{50}
		TNI 730330	Low energy residential building		1.5 ACH_{50}
			Passive apartment block		0.6 ACH_{50}
Denmark		EN13829	Residential		1.5 $L/s \cdot m^2$ @ 50 Pa
Finland					2.0 ACH_{50}
France			Single family houses		0.8 $m^3/h \cdot m^2$ @ 4 Pa
			Other residential houses		1.2 $m^3/h \cdot m^2$ @ 4 Pa
Germany			With Ventilation systems		1.5 ACH_{50}
			Without ventilation systems		3 ACH_{50}
Germany (Global)	Passivhaus				0.6 ACH_{50}
Japan	CGSB 149.10				2.24 cm^2 EqLA

Lithuania			Naturally ventilated		3 ACH$_{50}$
			Mechanically ventilated		1.5 ACH$_{50}$
Latvia			Dwellings		3 ACH$_{50}$
			Ventilated buildings		3 ACH$_{50}$
Netherlands			With Ventilation systems		2-3 ACH$_{50}$
			Without ventilation systems		4-6 ACH$_{50}$
Norway					3.0 ACH$_{50}$
Qatar	QSAS		Low		0.6 m^3/h·m^2 @ 4 Pa
			Med		1.1 m^3/h·m^2 @ 4 Pa
			High		2.2 m^3/h·m^2 @ 4 Pa
Turkey		TS 825	Floor multi-dwelling	High	<2 ACH$_{50}$
				Med	2-5 ACH$_{50}$
				Low	>5 ACH$_{50}$
			Floor, single flats	High	<4 ACH$_{50}$
				Med	4-10 ACH$_{50}$
				Low	>10 ACH$_{50}$
Slovenia			Naturally ventilated		3 ACH$_{50}$
			Mechanically ventilated		2 ACH$_{50}$
Slovakia			Single family house with high quality windows		4.0 ACH$_{50}$
			All other buildings		2.0 ACH$_{50}$
Dubai, UAE	Green Building Regulations		Building air Leakage:		10 m^3/hr·m^2 @ 50 Pa
Abu Dhabi, UAE	Abu Dhabi Building Code	Modified International Energy Conservation Code (i.e.CC)	Commercial building test		2.0 L/s·m^2 @ 75 Pa
United Kingdom	Part L Bldg Regs	ATTMA TS-L1	Best Practice, Naturally Ventilated Residential		5 m^3/hr·m^2 @ 50 Pa
	Part L Bldg Regs	ATTMA TS-L1	Best Practice, Mechanically Ventilated Residential		1 m^3/hr·m^2 @ 50 Pa
	Part L Bldg Regs	ATTMA TS-L1	Best Practice, Naturally Ventilated Residential		7 m^3/hr·m^2 @ 50 Pa
	Part L Bldg Regs	ATTMA TS-L1	Normal, Mechanically Ventilated Residential		5 m^3/hr·m^2 @ 50 Pa
Global	IECC				5.6 m^3/hr·m^2 @ 50 Pa
Global		International Residential Code (IRC)	Residential Buildings (1 and 2 family dwellings, thus excluding MURBs)	Zone 1 to 2	5 ACH$_{50}$
				Zones 3 to 8	3 ACH$_{50}$

Table 6.4 International Commercial Airtightness Requirements (Retrotec 2012)

Region	Program	Standard /Code	Applies to	Requirement
Austria			Naturally Ventilated	3.0 ACH$_{50}$
			Mechanically Ventilated	1.5 ACH$_{50}$
Belgium				12 m^3/hr·m^2 @ 50 Pa
Czech Republic			Common buildings maximum	4.5 ACH$_{50}$
			Low energy buildings	1.5 ACH$_{50}$

			Passive Houses		0.6	ACH_{50}
			Mechanically ventilated without heat recovery		1.5	ACH_{50}
			Mechanically ventilated with heat recovery		1.0	ACH_{50}
Denmark (current)			Normal	New Buildings	1.5	ACH_{50}
				Low Energy Buildings	1.0	ACH_{50}
			Buildings with high ceilings	New Buildings	0.5	ACH_{50}
				Low Energy Buildings	0.3	ACH_{50}
Denmark (new in 2020)			Normal	New buildings	0.5	ACH_{50}
			Buildings with high ceilings		0.15	ACH_{50}
Estonia			Small buildings, new		6.0	$m^3/hr\cdot m^2$ @ 50 Pa
			Small buildings, existing		9.0	$m^3/hr\cdot m^2$ @ 50 Pa
			Large buildings, new		3.0	$m^3/hr\cdot m^2$ @ 50 Pa
			Large buildings, existing		6.0	$m^3/hr\cdot m^2$ @ 50 Pa
Finland			Building heat loss reference		2.0	ACH_{50}
			Energy Performance Certificate (EPC)		4.0	ACH_{50}
France			Offices, hotels, educational and health care buildings		1.2	$m^3/hr\cdot m^2$ @ 4 Pa
			Other buildings		2.5	$m^3/hr\cdot m^2$ @ 4 Pa
Germany		DN 4108-7	Naturally ventilated		3	ACH_{50}
			Mechanically ventilated		1.5	ACH_{50}
India	Energy Conservation Code				0.4	cfm/ft² @ 75 Pa
Japan			Level A		7.5	ACH_{50}
			Level B		3.0	ACH_{50}
			Level C		1.5	ACH_{50}
Lithuania			Naturally ventilated		3	ACH_{50}
			Mechanically ventilated		1.5	ACH_{50}
Latvia			Public and Industrial Buildings		4.0	ACH_{50}
			Ventilated Buildings		3.0	ACH_{50}
Norway					3.0	ACH_{50}
Qatar			Low		0.6	$m^3/hr\cdot m^2$ @ 4 Pa
			Medium		1.1	$m^3/hr\cdot m^2$ @ 4 Pa
			High		2.2	$m^3/hr\cdot m^2$ @ 4 Pa
Slovenia			Naturally ventilated		3.0	ACH_{50}
			Mechanically ventilated		2.0	ACH_{50}
Scotland			Current Regulation		5.0	$m^3/hr\cdot m^2$ @ 50 Pa
			New Regulation		1.0	$m^3/hr\cdot m^2$ @ 50 Pa
Slovakia					2.0	ACH_{50}
Abu Dhabi, UAE	Abu Dhabi Building Code		Commercial buildings		2.0	$L/s\cdot m^2$ @ 75 Pa
Dubai, UAE	Green Building Regulations				10	$m^3/hr\cdot m^2$ @ 50 Pa

United Kingdom		ATTMA TS-L2	Best Practice	Office – Natural Ventilation	3.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Office – Mixed Ventilation	2.5	$m^3/hr \cdot m^2$ @ 50 Pa
				Office – AC/low energy	2.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Factories/Warehouses	2.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Supermarkets	1.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Schools	3.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Hospitals	5.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Museums/archives	1.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Cold stores	0.2	$m^3/hr \cdot m^2$ @ 50 Pa
			Normal Practice	Office – Natural Ventilation	7.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Office – Mixed Ventilation	5.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Office – AC/low energy	5.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Factories/Warehouses	6.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Supermarkets	5.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Schools	9.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Hospitals	9.0	$m^3/hr \cdot m^2$ @ 50 Pa
				Museums/archives	1.5	$m^3/hr \cdot m^2$ @ 50 Pa
				Cold stores	0.35	$m^3/hr \cdot m^2$ @ 50 Pa
		Current Regulations	New Building		10	$m^3/hr \cdot m^2$ @ 50 Pa
			Small Building (less than 500 m³)		15	$m^3/hr \cdot m^2$ @ 50 Pa
			Large Building		5	$m^3/hr \cdot m^2$ @ 50 Pa
		New Regulations	With cooling requirement		3	$m^3/hr \cdot m^2$ @ 50 Pa
			Without cooling requirement		5	$m^3/hr \cdot m^2$ @ 50 Pa
Global	IECC				5.6	$m^3/hr \cdot m^2$ @ 50 Pa

7. Existing MURB Data Summary and Analysis

MURB airtightness data was compiled in a database to enable assessment of the current building stock, benchmarking of building airtightness performance, and development of appropriate airtightness performance targets. The database is populated with data from the previous study (Proskiw and Phillips, Air Leakage Characteristics, Test Methods, and Specifications for Large Buildings 2001), published and non-published data provided by the project team and other organizations, and information identified as part of the literature review process.

The database includes a total of 296 unique buildings with a total of 375 tests as in numerous cases building were tested multiple times. Of these buildings, 245 are from USACE testing and 52 of those are barracks. There are 43 unique MURBs in the database.

Airtightness data was converted to variety of different metrics including permeability [cfm/ft² or L/s·m² at a given pressure differential], air changes per hour [h^{-1}], flow rate [cfm or L/s], and equivalent leakage area [in² or cm²] using the appropriate characteristics of the buildings such as enclosure area, building volume, flow coefficient, and flow exponent value. In general, airtightness performance data of the buildings is discussed using units of cfm/ft² to conform with industry convention. A flow exponent value of 0.6 was assumed if insufficient data was available to determine it using regression analysis.

7.1. MURBs

The data collected and discussed in this section is for 43 MURBs distributed across North America, but primarily located in Canada as shown in Fig.7.1. The data includes all MURB buildings for which sufficient airtightness testing data was available to make valid comparisons except for buildings tested as part of the USACE program which are discussed separately in Section 7.3.

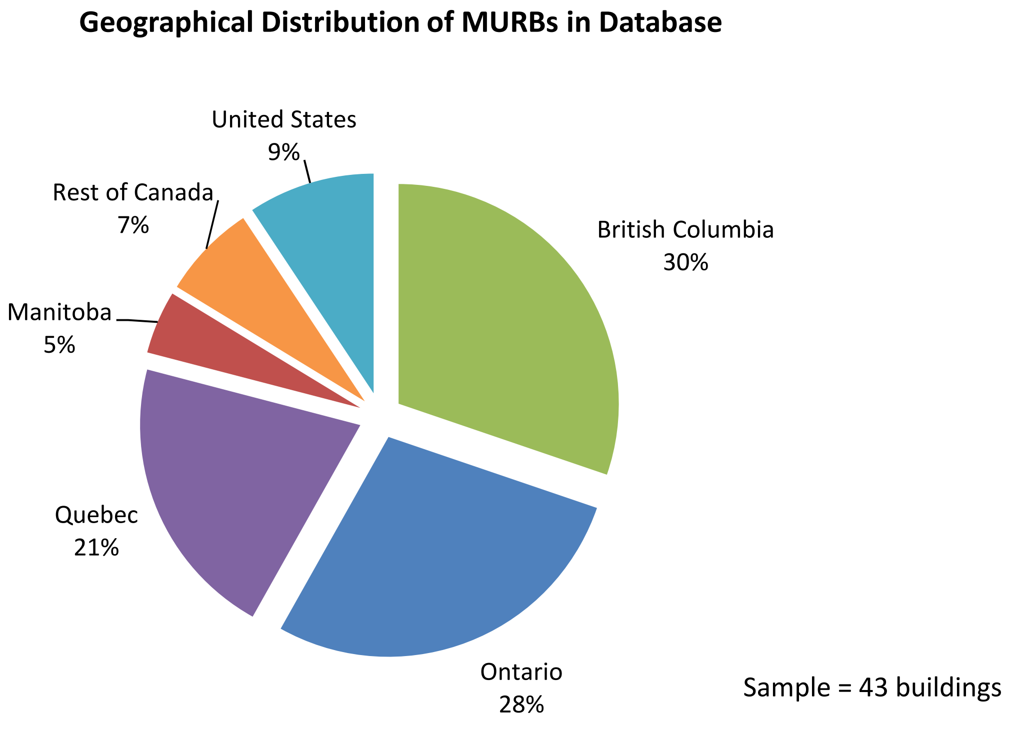


Fig.7.1 Geographical Distribution of MURBs in Database

The age of the buildings in the database varies from new to over 50 years in age. The oldest building was constructed in 1956 and the newest in 2011. The distribution of buildings in each age category is shown in Fig.7.2.

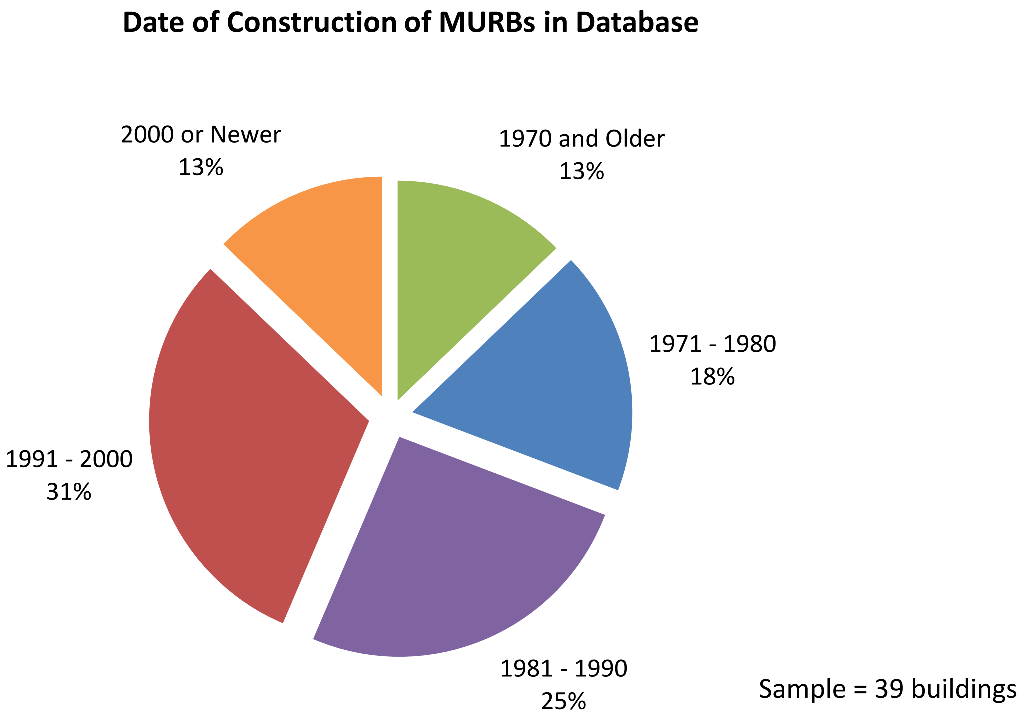


Fig.7.2 Date of Construction of MURBs in Database

The height of the buildings in the database varies from 1 storey to 23 storeys. The distribution of building heights is illustrated in Fig.7.3.

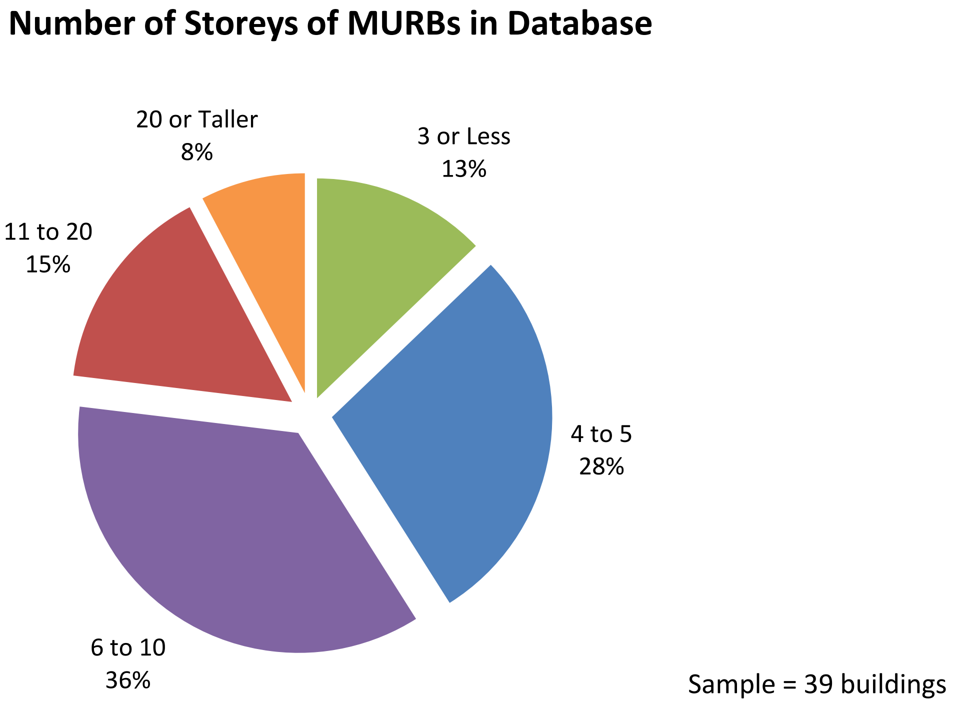


Fig.7.3 Number of Storeys of MURBs in Database

The airtightness performance data of the MURBs is shown in Fig.7.4 and the distribution of the airtightness testing performance is shown in Fig.7.5. The units of cfm/ft² at 75 Pa were selected for use in this report because this method of measurement is broadly used and recognized in industry, and it provides a direct measure of the airflow through an enclosure element.

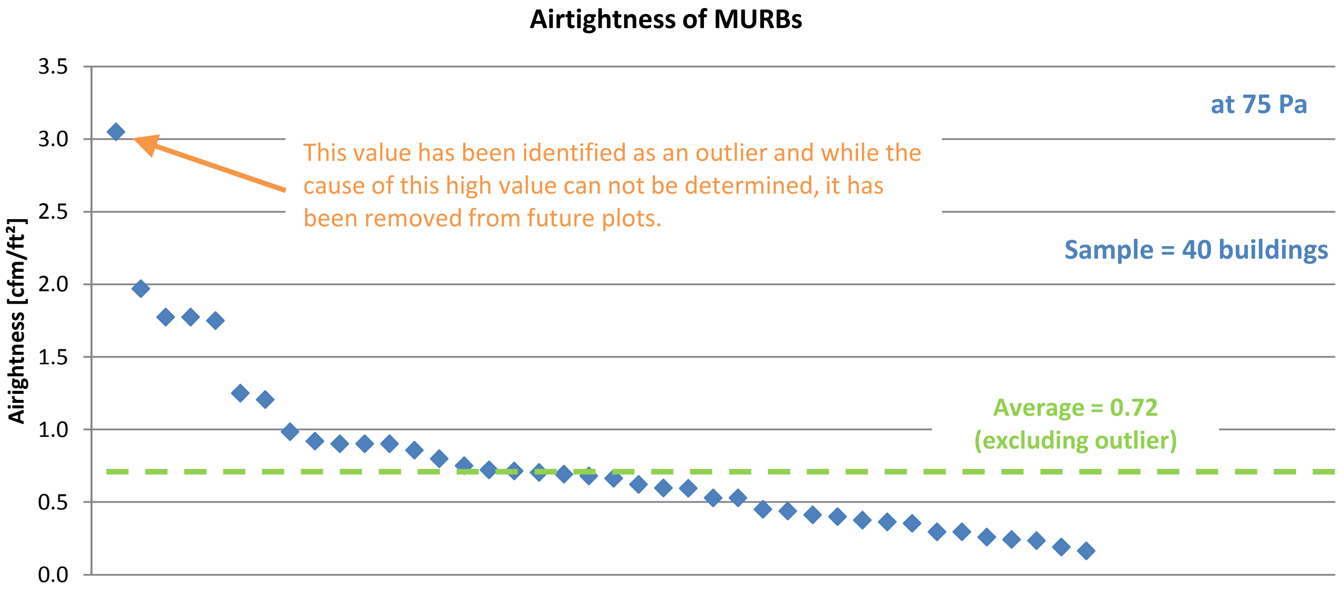


Fig.7.4 Airtightness of MURBs sorted from maximum (least airtight) to minimum (most airtight)

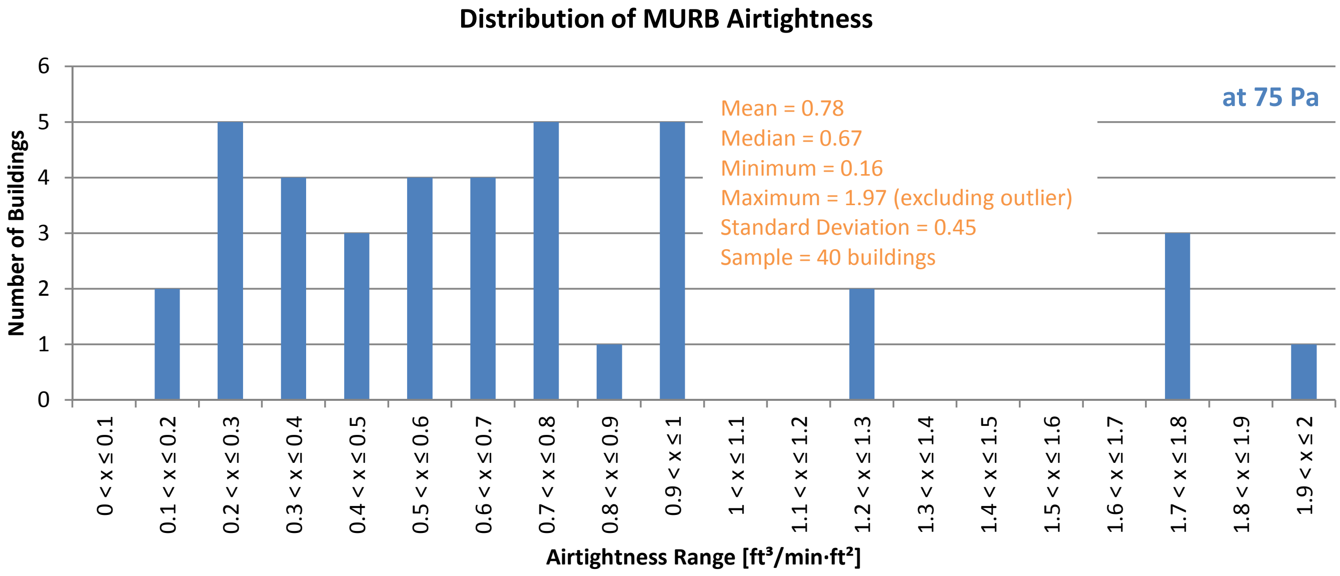


Fig.7.5 Distribution of MURB Airtightness Data

As shown above, the average (mean) airtightness value for the MURBs in the database is 0.72 cfm/ft² (with the outlier it is 0.80) (3.66 L/s·m²). From the distribution it is clear that most of the buildings performed between approximately 0.2 and 1.0 cfm/ft² at 75 Pa. For reference, recall that the tight, average, and leaky values proposed by Tamura and Shaw (1976) and referenced in the ASHRAE Handbook of Fundamentals are 0.1 cfm/ft², 0.3 cfm/ft² and 0.6 cfm/ft² (0.5 L/s·m², 1.5 L/s·m², and 3.0 L/s·m²), respectively.

The previous study by Proskiw and Phillips (2001) determined an average of 0.63 cfm/ft² (3.2 L/s·m²) which is slightly lower than the average determined by this study.

The MURB airtightness data was also graphed versus original year of building construction, age of the building's air barrier (including retrofits), and building height as shown in Fig.7.6, Fig.7.7, and Fig.7.8 respectively.

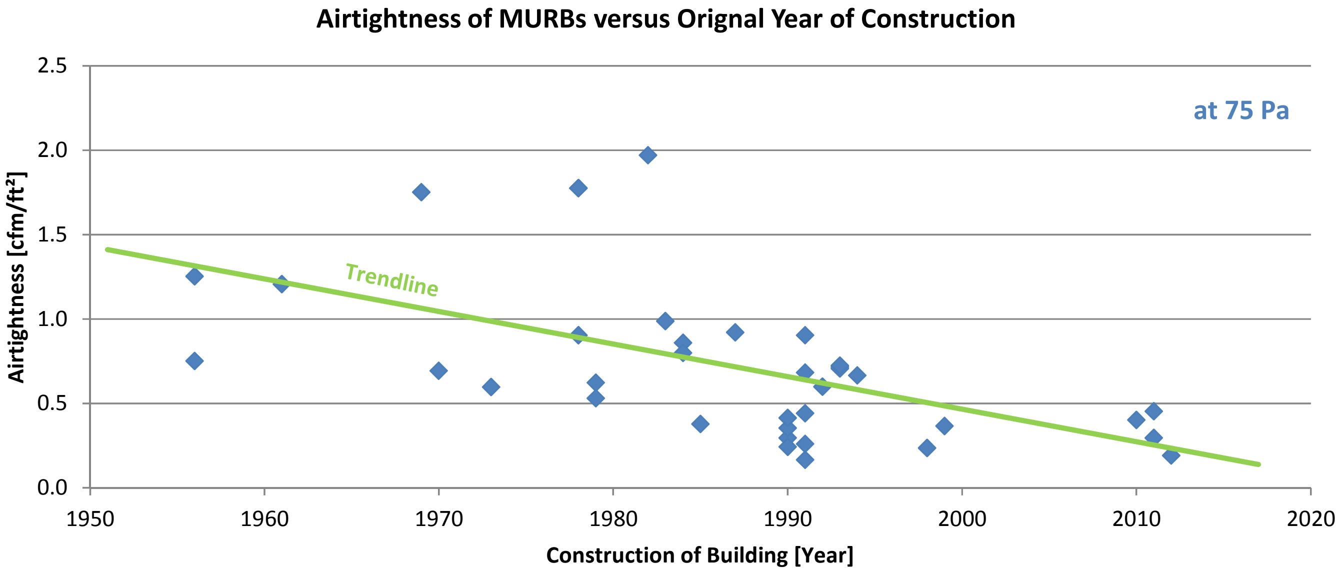


Fig.7.6 Airtightness versus Original Year of Construction

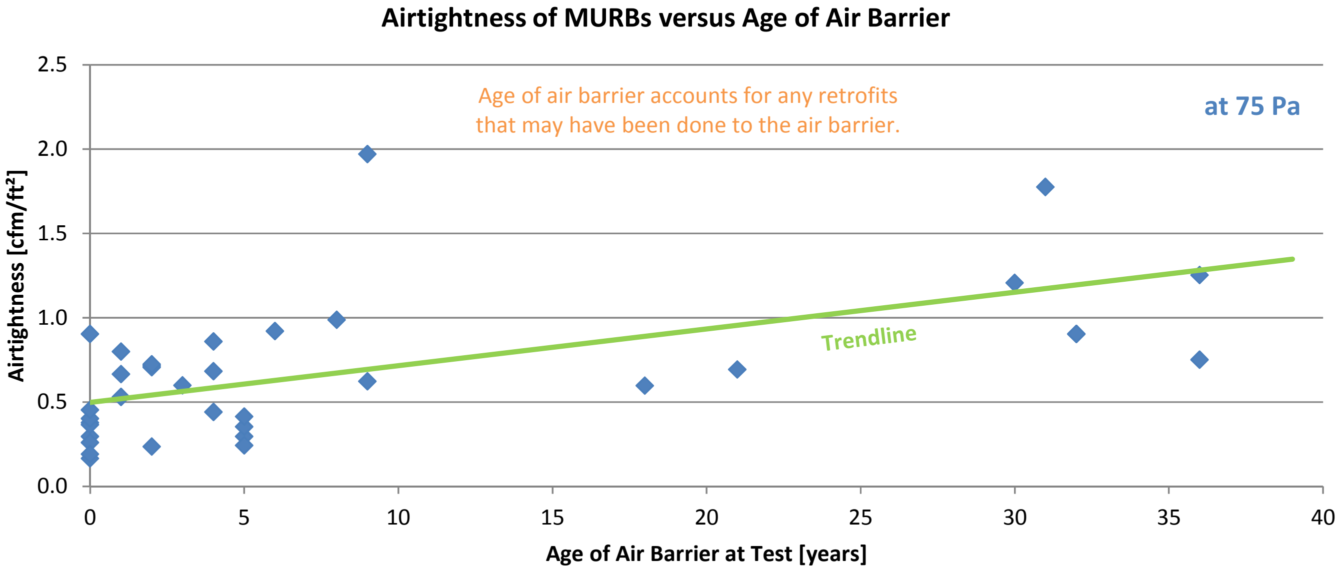


Fig.7.7 MURB Airtightness versus Age of the Air Barrier

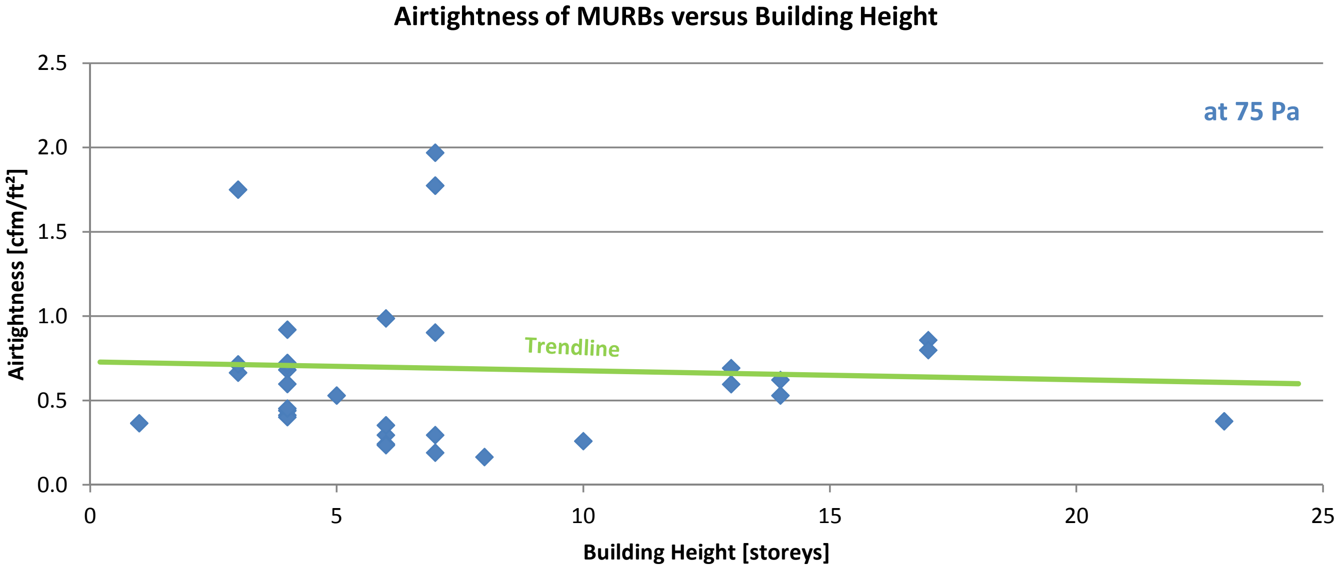


Fig.7.8 MURB Airtightness versus Building Height

Based on this analysis, a few trends in airtightness performance are apparent. More recently constructed MURBs are generally more airtight, as reflected in both the graph versus year of construction (Fig.7.6) and the graph versus age of air barrier (Fig.7.7). Also, the airtightness of MURBs is generally observed to increase (i.e. improve) with building height; however, this trend is more subtle. In reality, the trend of increasing airtightness with building height may actually be a function of the construction type rather than the height of the building. Taller buildings often use higher performance air barrier systems, such as self-adhered membranes instead of stapled sheathing membrane with taped joints. To assess this relationship between wall construction type and airtightness, wood-frame, concrete with steel studs, and brick veneer over steel studs were analysed separately and are shown in Fig.7.9.

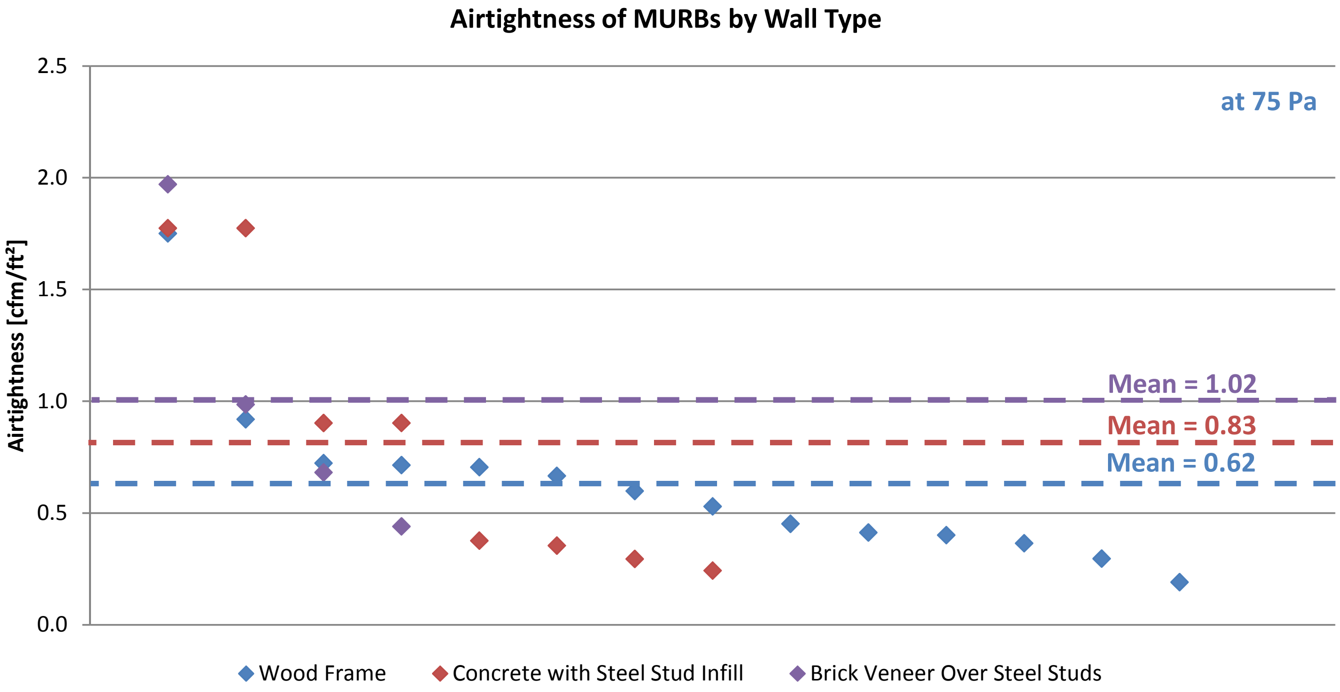


Fig.7.9 Airtightness of MURBs by Wall Type

While the maximum and minimum airtightness values for these three wall types are approximately the same, the mean do change. The data suggests that wood-frame MURBs are generally more airtight than concrete MURBs with steel stud infill walls and MURBs with brick veneer are the least airtight. This finding is somewhat contradictory to the idea presented above that taller MURBs may be more airtight as a result of different wall systems. Both trends, however, are not significant in magnitude and may only be the result of a limited data set.

As building airtightness is often expressed in air changes per hour, the air changes per hour at 75 Pa of the MURBs in the data base is provided in Fig.7.10. This data is essentially the same set of buildings as is presented in Fig.7.4; however, because in some cases insufficient information was available to convert between metrics, a small number of buildings have been added and removed compared to that data set. There are 31 MURBs in this data set.

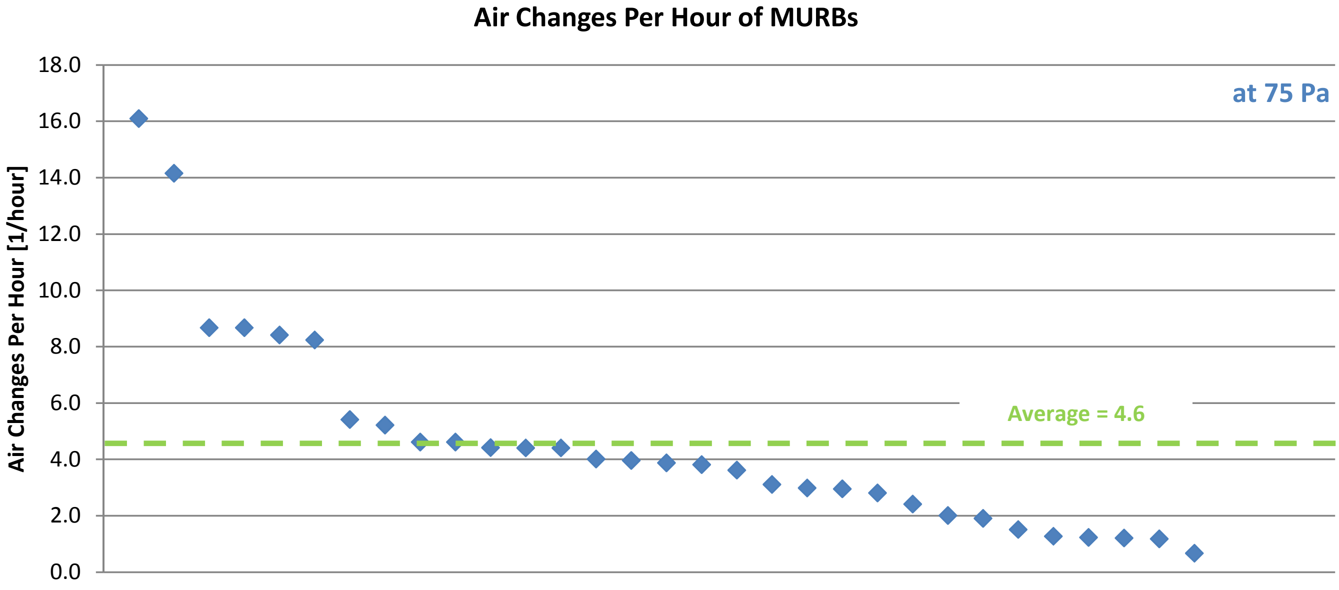


Fig.7.10 Air Changes Per Hour of MURBs Sorted from Maximum to Minimum

As air changes per hour is not a direct indication of building enclosure airtightness due its dependence on building volume, this measure is not generally recommended by this report as a measure of building airtightness; however, it is frequently used in industry and can be useful when considering ventilation.

A flow exponent (“n”) value of 0.60 or 0.65 has typically been assumed in industry when multi-point testing was not performed to allow the determination of the actual value for a specific building. To assess the appropriateness of these selections, the flow exponents measured for the MURBs in the database were analysed and are presented in Fig.7.11. There are 27 MURBs in this data set.

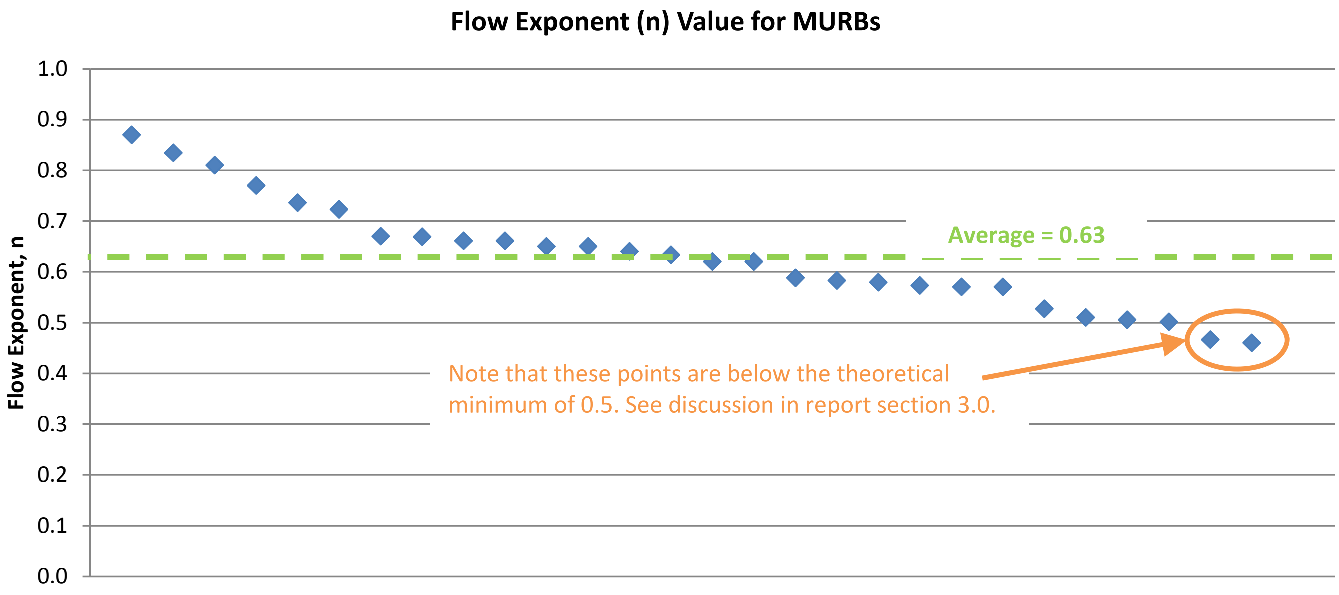


Fig.7.11 Flow Exponents of MURBs Sorted From Maximum to Minimum

The average of the flow exponents was found to be 0.63 which corresponds well with the commonly used values of 0.6 and 0.65. Based on the experience of the project team and on the literature review, a value of 0.6 is gaining wider industry acceptance.

7.2. Compartmentalization

While the data analysed above for MURBs dealt solely with the airtightness of the exterior building enclosure, the airtightness of interior compartmentalizing elements is also important for airflow control in MURBs. Therefore, results of testing six suites to determine the overall airtightness of the suite including leakage to other interior spaces using the 6-sided suite testing were compared with the results of the same suites being tested using the balanced suite testing methods to determine the airtightness of only the exterior enclosure. Frequently, 6-sided tests are performed as part of the LEED accreditation process to meet the environmental tobacco smoke requirement. The airtightness data from these tests is provided in Fig.7.12.

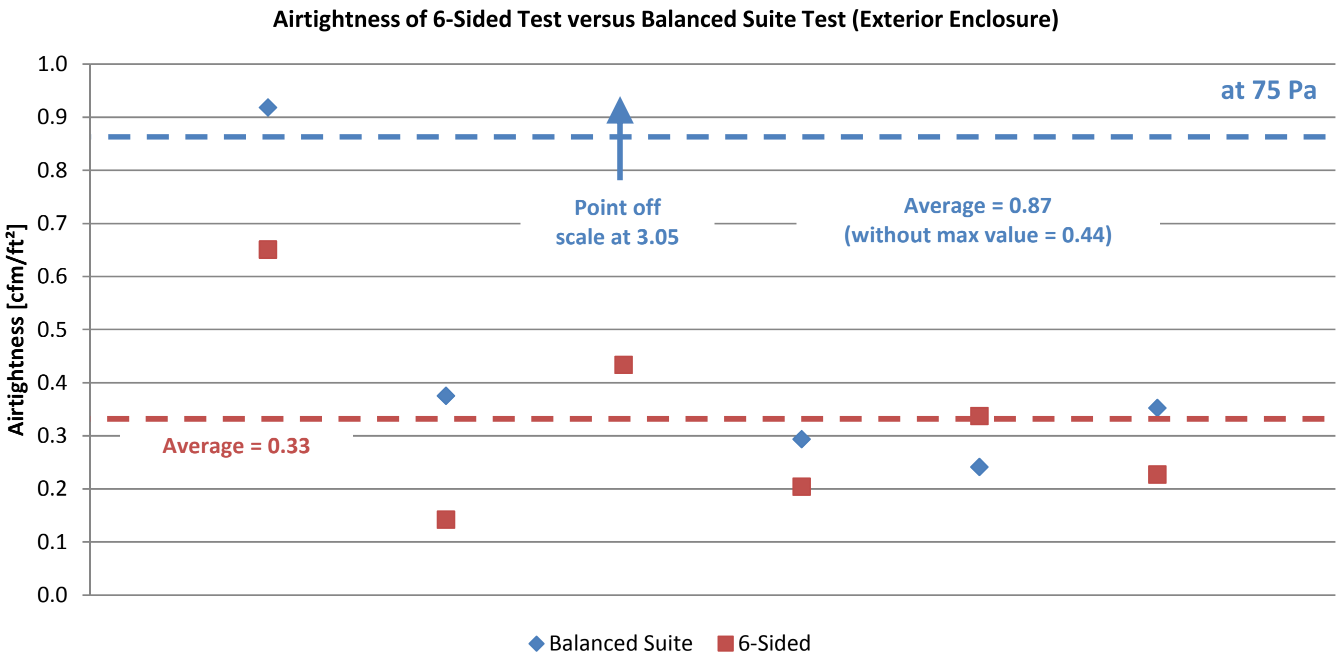


Fig.7.12 MURB Suites 6-Sided Airtightness versus Balanced Suite (Exterior Enclosure Only) Airtightness

The average of these 6-sided tests is 0.33 cfm/ft² (1.67 L/s·m²) which is significantly lower than the average of 0.87 cfm/ft² (4.42 L/s·m²) for exterior enclosure only airtightness. This increased airtightness of the interior compartmentalizing elements is likely due to the airtightness requirement for LEED buildings which makes improved airtightness necessary.

Additional data was available for the air changes per hour of suites when tested using a balanced method versus testing all six sides; however, it is not possible to compare these results because surface area information was unavailable.

7.3. United States Army Corps of Engineers

As discussed in Section 5.7, the US ACE requires airtightness testing of its large buildings and that they meet a performance standard of 0.25 cfm/ft² (1.27 L/s·m²) at 75 Pa. Barracks building data, of which there are 52 in the database, are useful to this report as these buildings are similar in form to typical MURBs. The barracks airtightness data is shown in Fig.7.13.

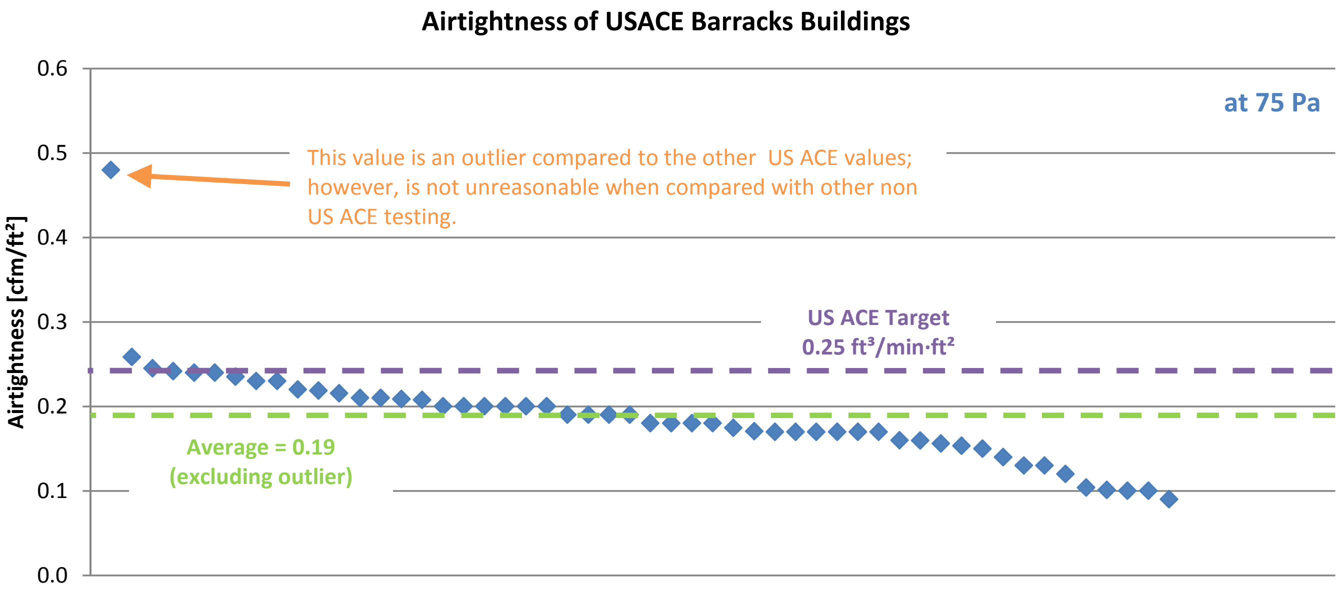


Fig.7.13 USACE Barracks Buildings Airtightness

The USACE has consistently been able to meet its airtightness requirement. The distribution of airtightness performance for the USACE barracks buildings is relatively small, with a low standard deviation, as shown in Fig.7.14.

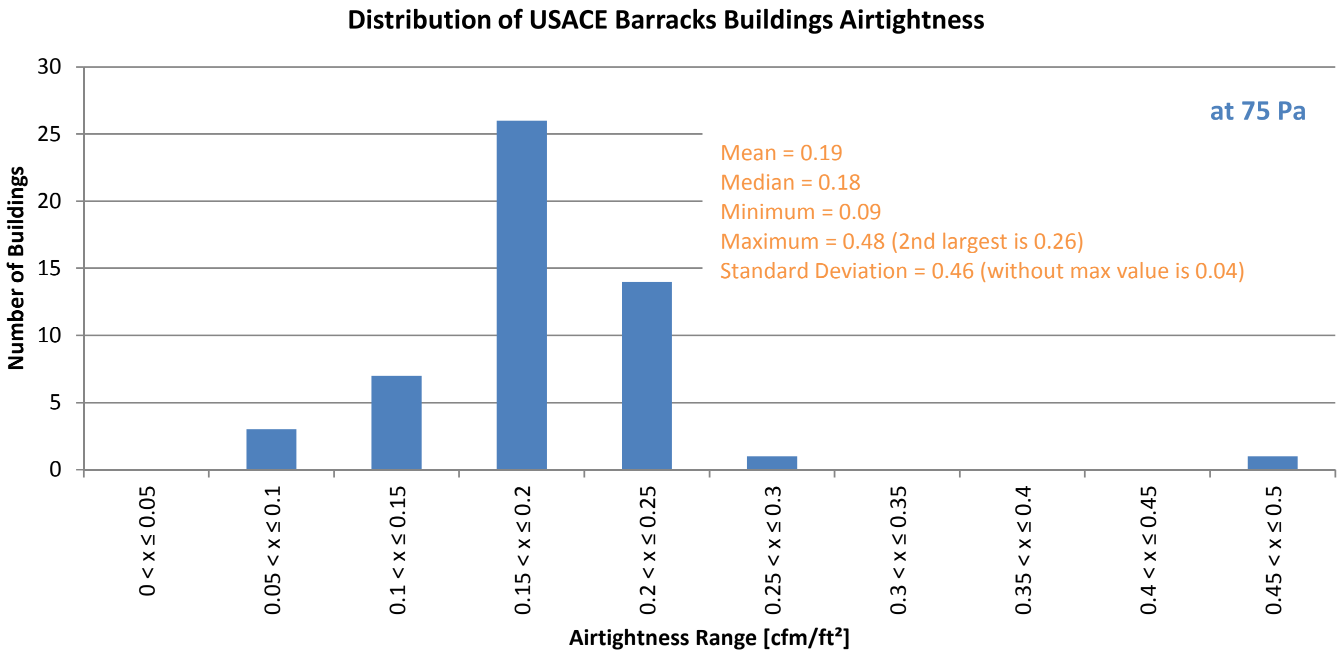


Fig.7.14 Distribution of USACE Barracks Buildings Airtightness

The ability of the USACE to achieve consistent results that almost always meet their relatively stringent airtightness performance target is an excellent example to industry of realistic requirements and construction methods.

7.4. Airtightness Retrofits

It is important to consider not only the airtightness of new construction, but also the ability to improve airtightness as part of the retrofit of an existing building. Six buildings for which there is airtightness performance data for both pre- and post-retrofits were analysed and are graphed in Fig.7.15. In these cases, the retrofits were conducted with the specific intent of air sealing and thus of improving airtightness.

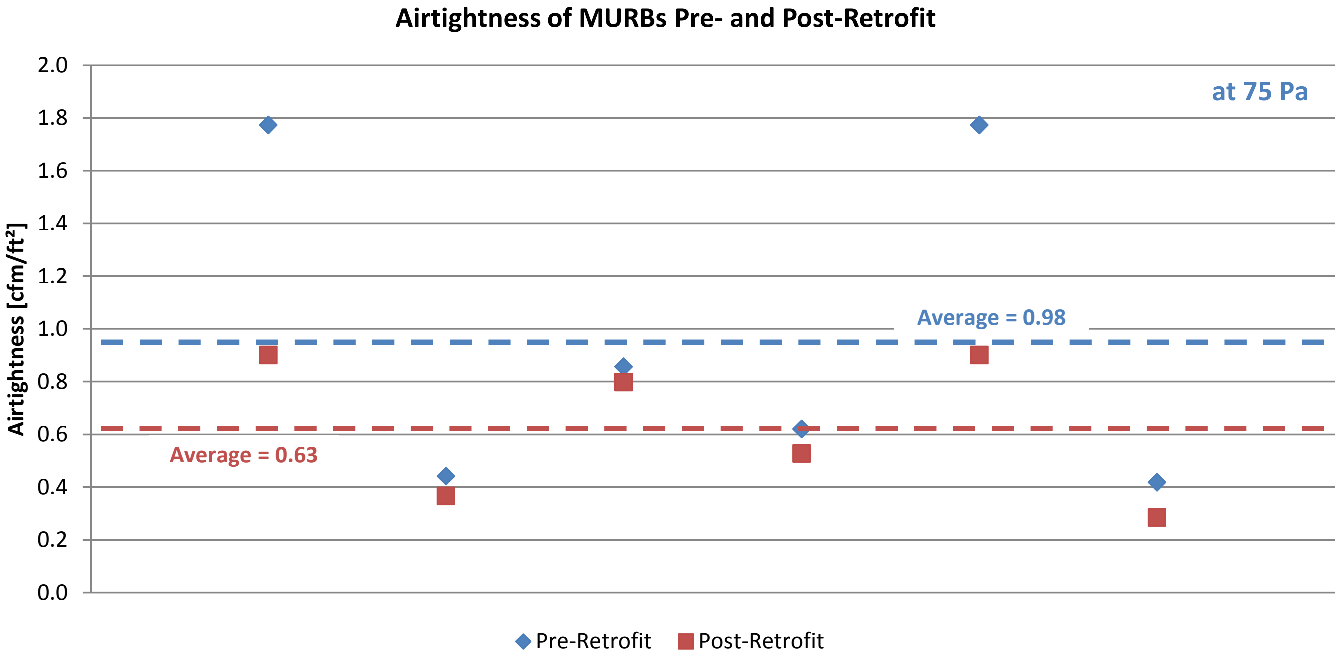


Fig.7.15 MURB Airtightness Pre- and Post-Retrofit

As shown in the graph, the average airtightness of the buildings improved from 0.98 cfm/ft² (4.99 L/s·m²) to 0.63 cfm/ft² (3.2 L/s·m²). The percent improvement due to these retrofits is shown in Fig.7.16.

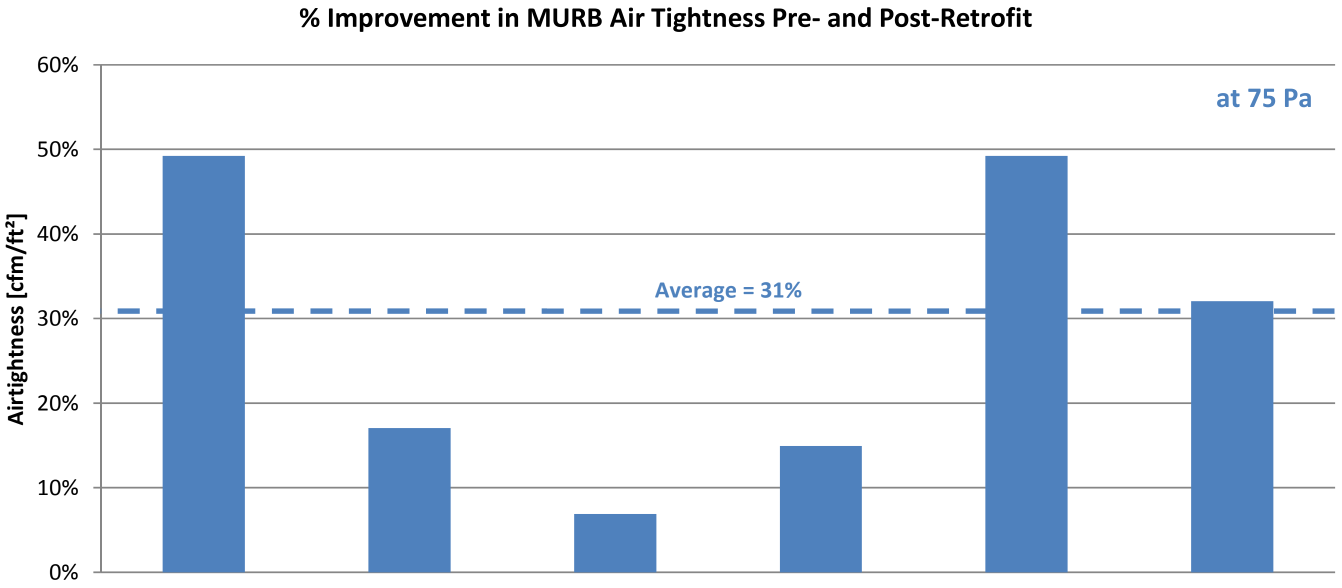


Fig.7.16 Graph of Percent Improvement of MURB Airtightness Pre- and Post-Retrofit

Analysis of the MURB retrofit data indicates that retrofits have the potential to significantly improve the airtightness of MURBs. The buildings in the database have mean improvement of 31% and a maximum improvement of 49%.

8. Industry Preparedness and Perception

Part of this study was to gauge the preparedness of the building industry in Canada to address air leakage control in MURBs and other large buildings. While the project team is collectively familiar with a range of jurisdictions in Canada and US, to achieve a more complete understanding of the industry, a survey was distributed to architects, engineers, and others responsible for the design, implementation and testing of air barrier systems in large buildings, with particular attention to MURBs. The survey helped to gauge the current level of work being performed in the control of air leakage for MURBs and where this work is being most commonly performed. The results also included information on the number of firms currently performing air leakage testing and their level of understanding of current codes and standards related to air leakage testing methods for large buildings, and if available costs. Additionally, the survey asked questions regarding the current perception of both quantitative and qualitative air leakage testing including whether it is effective, whether it provides a value, and whether the costs are justified. The survey is provided in its entirety in Appendix C. It was distributed through the following channels:

- National Building Envelope Council of Canada (NBEC)
- Provincial Building Envelope Councils (BECs)
- National Building Envelope Council (NBEC)
- State Building Envelope Councils in the US
- Air Barrier Association of America (AABA) Website
- US Army Corps of Engineers (USACE)
- Retrotec and Minneapolis Blower Door Customer Lists

While effort was made by this research group to reach as broad of a sample group as possible, it is likely that the respondents to this survey provide some bias that would not be present in the industry as a whole. For example, industry members that responded to this survey are likely more involved with airtightness of buildings than is the average industry member because those who are not involved with airtightness are less likely to have responded to the survey. While it is felt that the survey results provide a good indication of the state of the industry, the potential bias such as this should be considered when analyzing and using the results.

8.1. Survey Results

Sixty-seven individuals responded to the survey from a range of geographical locations primarily in North America. Fig.8.1 shows the geographical distribution of survey respondents.

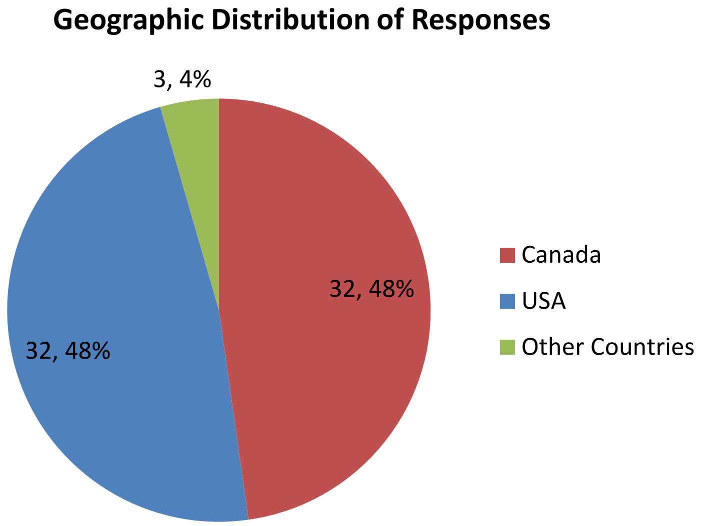


Fig.8.1 Geographical Distribution of Survey Respondents

These responses came from individuals with a variety of different backgrounds and qualifications. The distribution of qualifications of the survey respondents is illustrated in Fig.8.2.

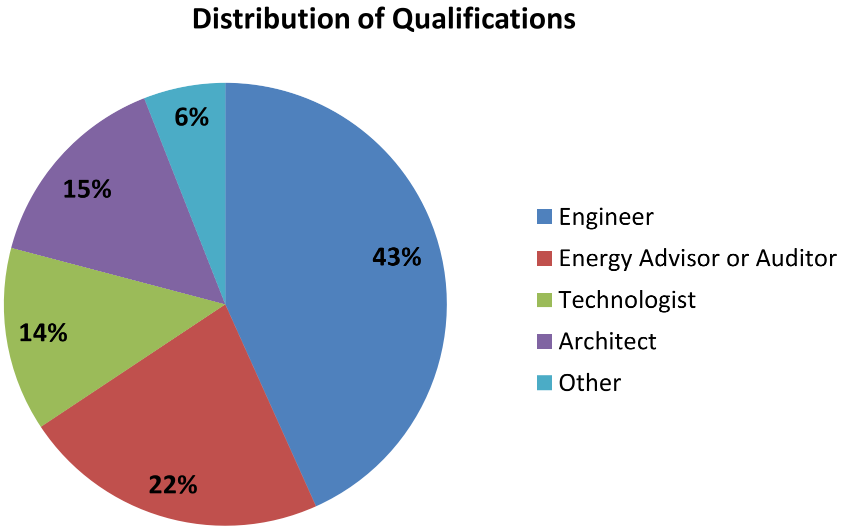


Fig.8.2 Distribution of Survey Respondent Qualifications

In some of the following analyses, the responses to these survey questions are split into respondents involved with design and those involved with testing and construction. In these cases, Engineers and Architects are classified as design, and testing agencies and contractors are classified as testing and construction.

One of the key survey questions asked respondents to rank the reasons they would address airtightness in buildings. Fig.8.3 shows the percentage of respondents that ranked each response first, second, third, etcetera (with a rank of 1 being most important and a rank of 5 being least important) which provides an indication of their relative overall importance. Note that not all categories reach 100% because some respondents chose not to rank all of the options; additionally, it was possible to provide the same rank for multiple responses.

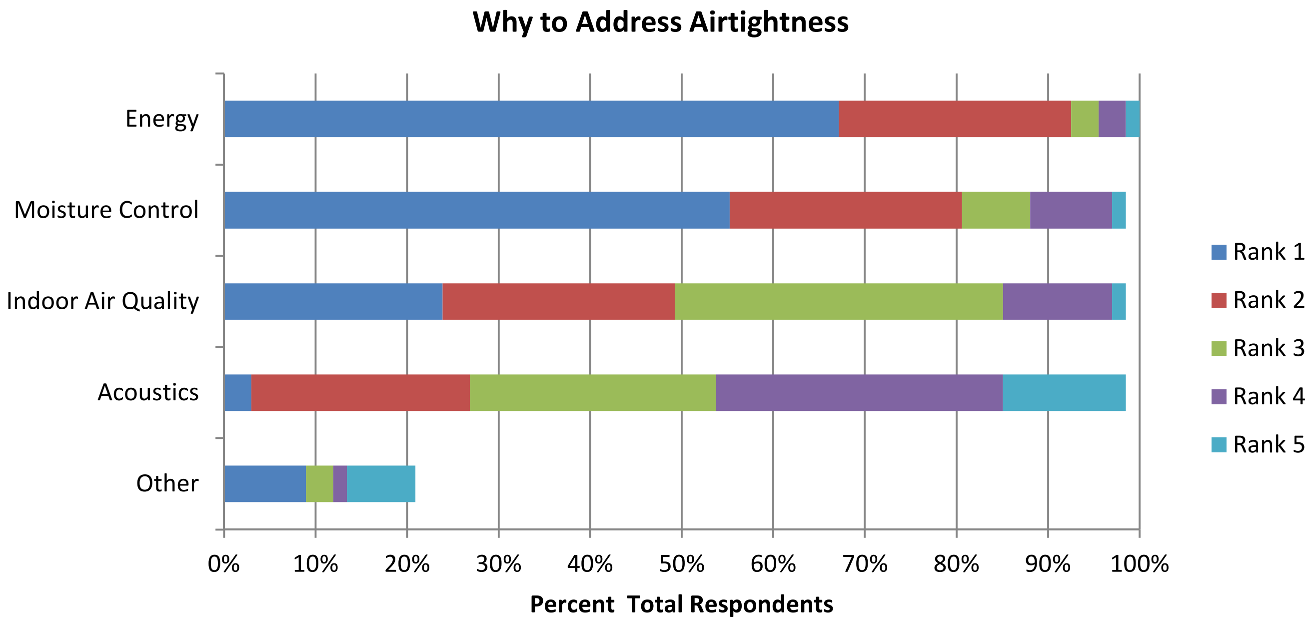


Fig.8.3 Why To Address Airtightness

This graph clearly illustrates that energy and moisture control are of primary concern in industry with respect to airtightness. Some of the responses provided as “Other” included occupant comfort, disease control, odour control, and to provide accurate data for mechanical system sizing. Interestingly, respondents that ranked energy and moisture control as less important tended to be from warmer regions.

The survey also sought to determine what types of performance issues are commonly observed in buildings. The responses to this question are provided graphically in Fig.8.4.

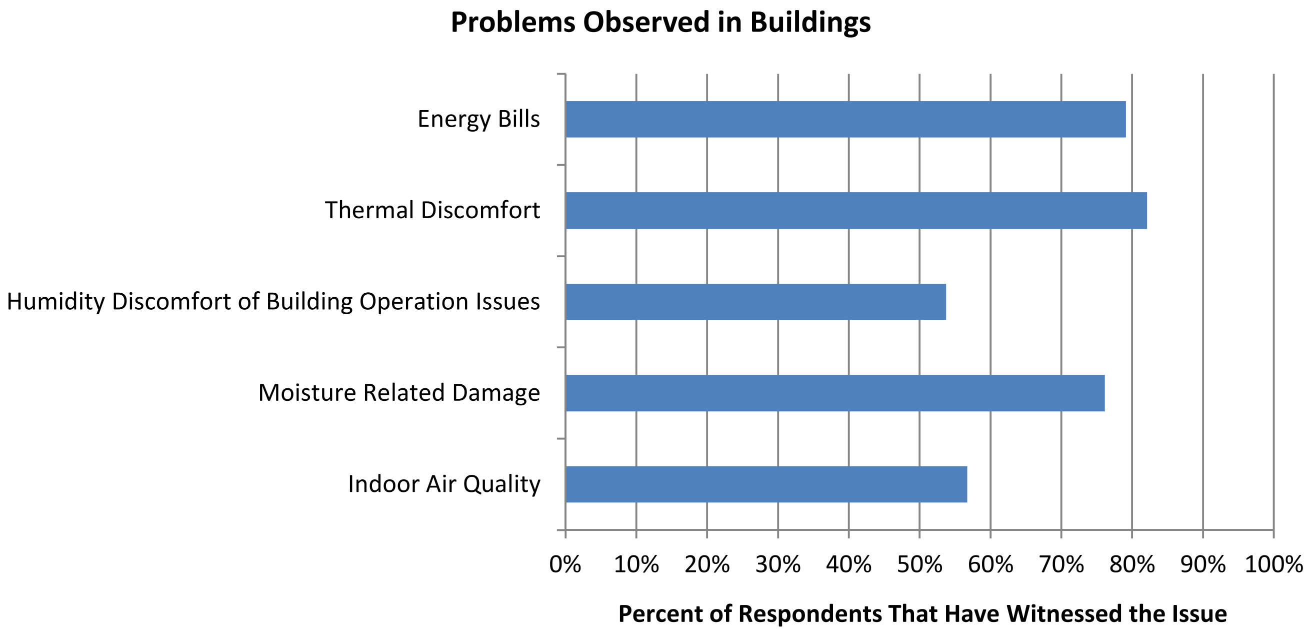


Fig.8.4 Airtightness Problems Observed in Buildings

From the results of this question, it is clear that a wide range of performance issues related to airtightness have been observed throughout industry which reaffirms the value in determining appropriate airtightness requirements and test methods.

To gain further understanding of current industry practices, respondents were asked to rank on a scale of 1 to 5 (with a rank of 1 being most important and a rank of 5 being least important) which methods of airtightness quality assurance and control they most commonly use to meet the current airtightness requirements. The responses to this question are summarized in Fig.8.5.

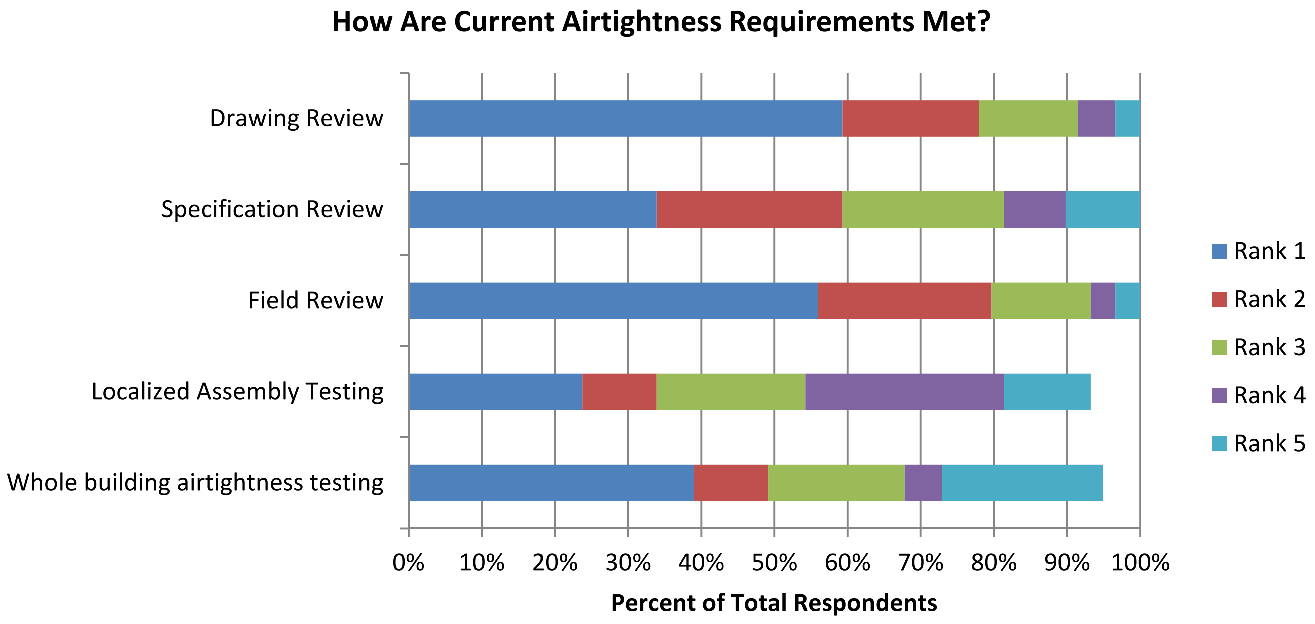


Fig.8.5 How Are Current Airtightness Requirements Met?

The results of this question indicate that currently the primary methods used to achieve airtightness targets are drawing review and field review, while whole building airtightness testing, specification review and localized assembly airtightness testing are less common forms of quality control for airtightness.

While the survey suggests that non-testing techniques are more commonly being used in industry to achieve airtightness, it was important to also determine which types of testing were being used for different sizes of buildings. A graph illustrating the relative use of each type of testing compared with building size is provided in Fig.8.6.

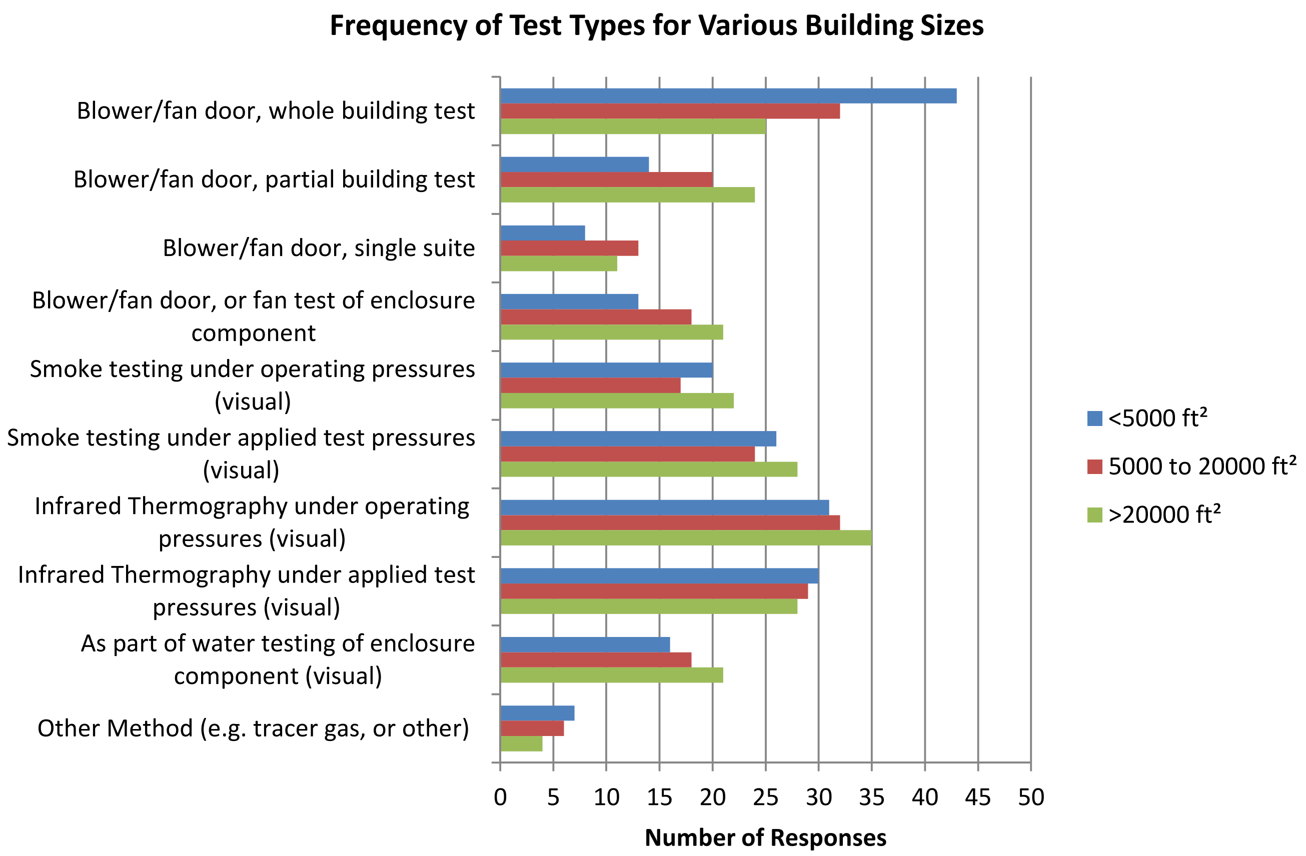


Fig.8.6 Frequency of Test Types for Various Buildings Sizes

This graph indicates that for smaller buildings blower/fan-door testing of the whole building is relatively common, while partial building tests are more common for larger buildings. Infrared thermography techniques are also relatively popular, likely due to the relative ease with which this qualitative testing can be performed. (Note that in this case relative ease refers to physically performing the test; however, obtaining and correctly interpreting infrared thermographic results can often be difficult.)

As this report is focused on MURBs, the same question was posed with respect to only MURBs and the results are provided graphically in Fig.8.7.

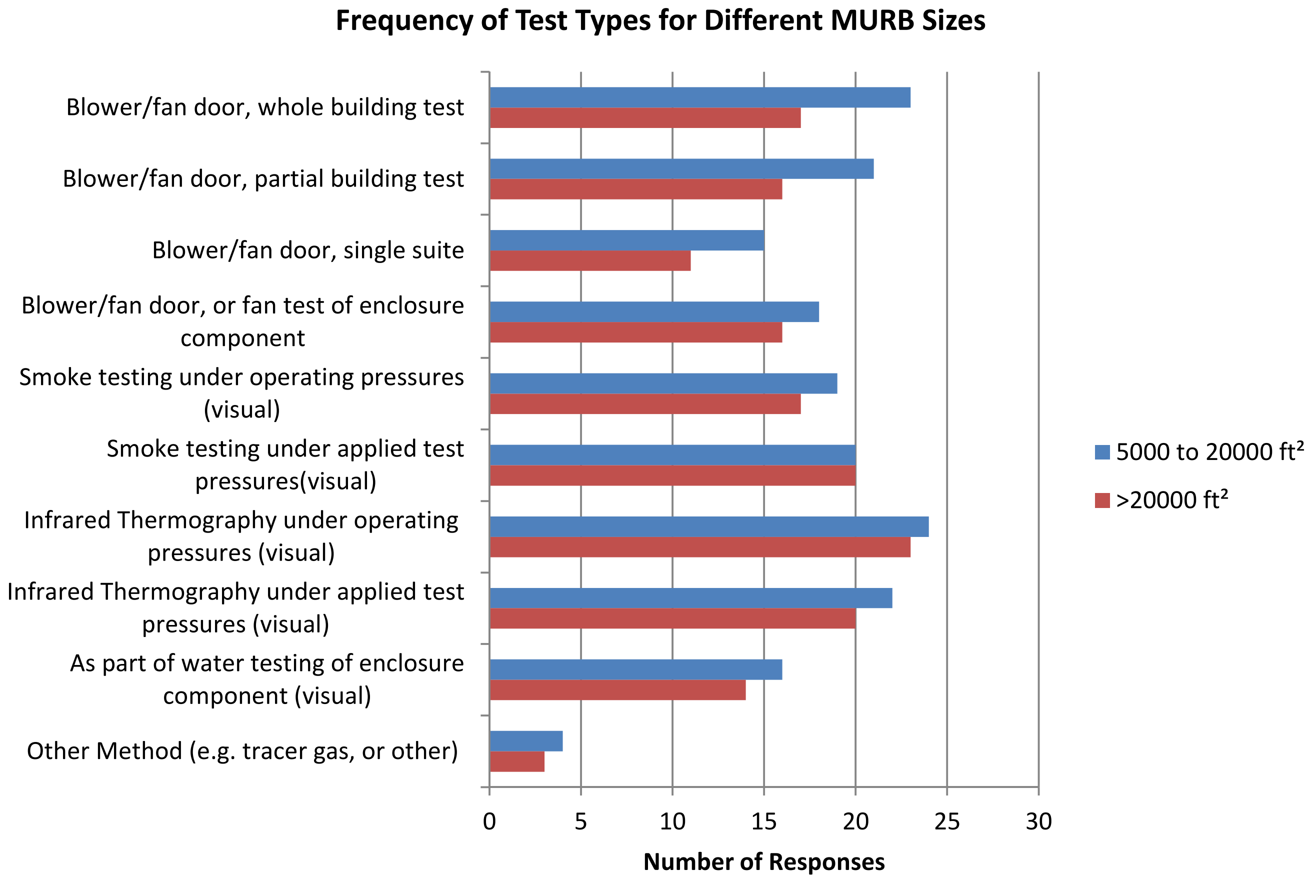


Fig.8.7 Frequency of Test Types for Various Buildings Sizes

Interestingly, a significant difference in the standards used for testing was found between Canadian and American respondents. This difference is shown in Fig.8.8.

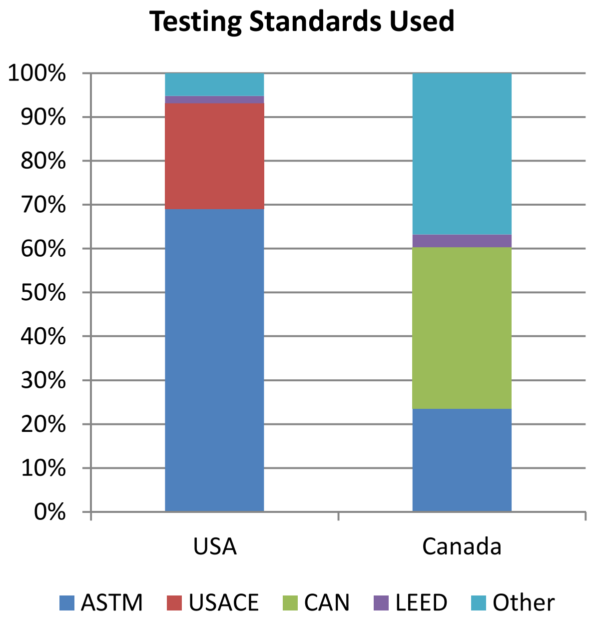


Fig.8.8 Testing Standards Used in Canada and the US

This figure shows that in the USA a significant portion of testing is performed following the USACE and ASTM testing standards; however, in Canada most testing follows CGSB standards or does not follows a test procedure listed in the question.

Respondents who had not performed airtightness testing on their projects were asked to explain their rationale. The most common responses to this question were that the testing was not required and/or that the client was unwilling to pay for the testing.

The survey was also used to determine the perceived airtightness of the buildings with which respondents were involved. Respondents were therefore asked whether they felt the buildings that they worked on were airtight and how much control they felt they had over the airtightness of these buildings. The results of this question are shown in a bar graph in Fig.8.9.

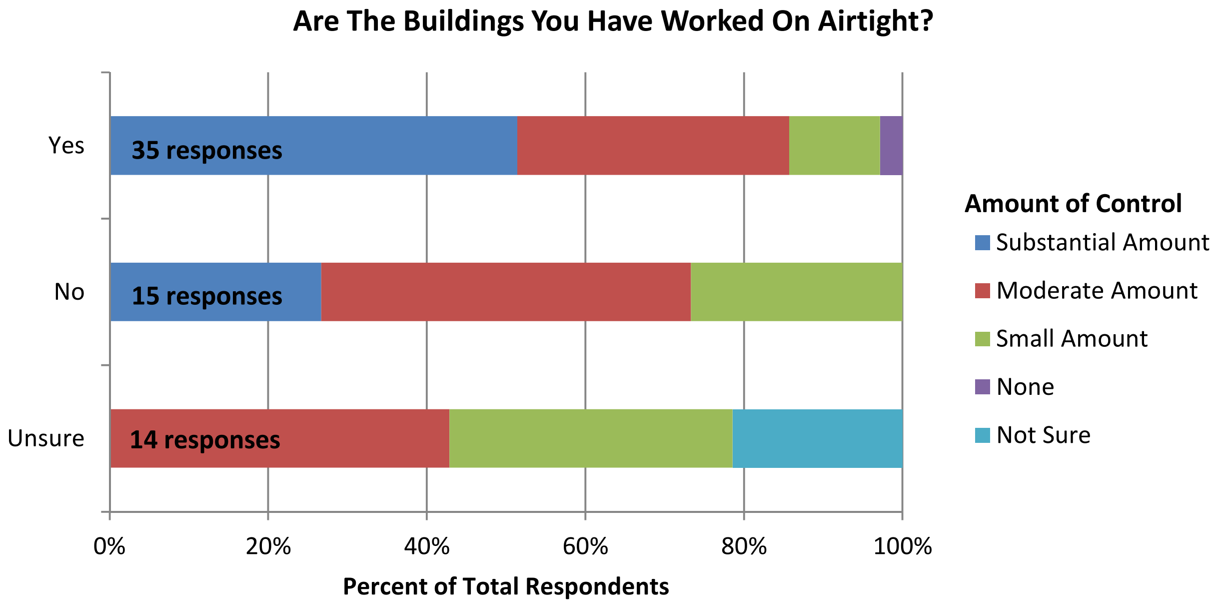


Fig.8.9 Perceived Airtightness of Buildings Correlated with Perceived Control of Building Airtightness

Unsurprisingly, this graph shows that as respondents felt more in control of the airtightness of the buildings, they had a higher level of confidence that these buildings were airtight.

Interestingly, Fig.8.10 shows that a significant proportion (77%) of respondents felt that they had either substantial or moderate control over the airtightness of these buildings.

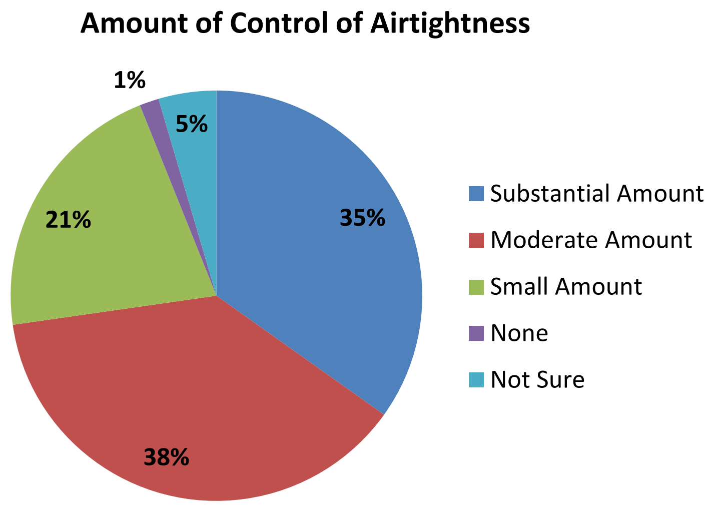


Fig.8.10 Respondents' Perceived Control of Building Airtightness

This is an indication that industry members are generally accepting responsibility for the airtightness of buildings and feel that in their roles they have the capacity to impact the airtightness of the buildings with which they are involved. This is important to note because it identifies that if these individuals, or organizations, were provided with airtightness requirements and testing methodologies, it would be within their control to implement these measures in practice.

One of the key goals of this study was to determine whether qualitative testing or quantitative testing is most effective with respect to achieving airtightness. The survey asked this question directly and determined that 68% of respondents felt that quantitative testing is most effective. Additionally, the survey asked respondents to rank the different types of testing with respect to their effectiveness at achieving airtightness and identifying air leakage locations. The results of this question are shown graphically in Fig.8.11.

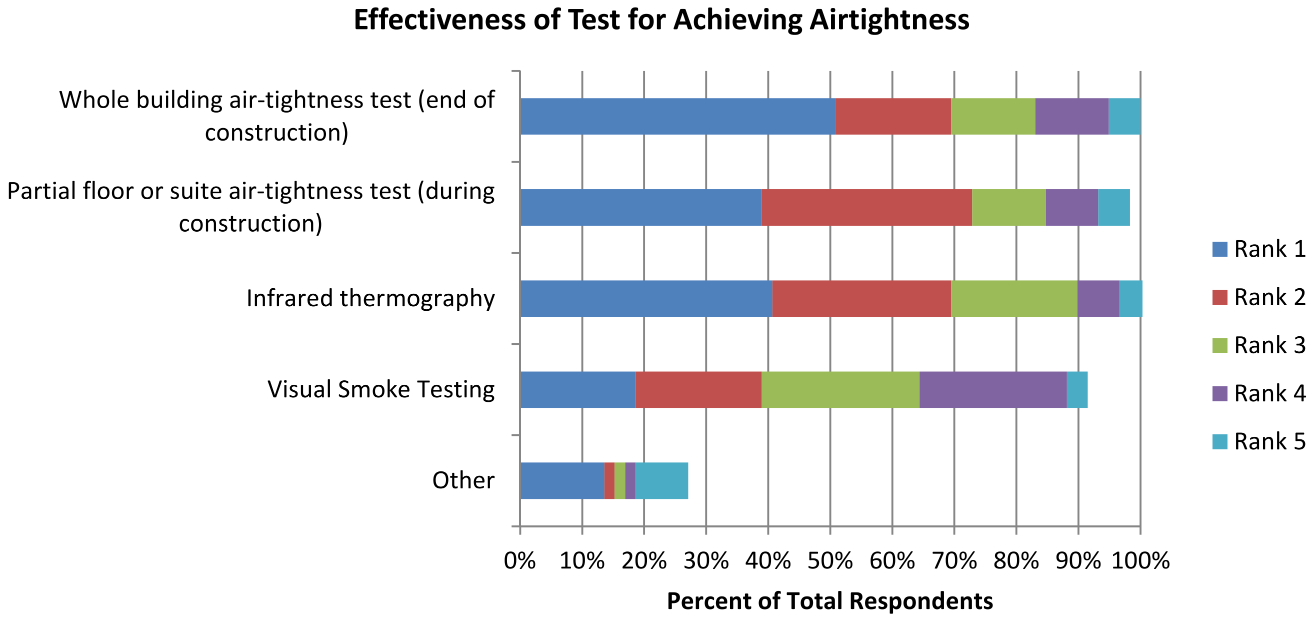


Fig.8.11 Ranks of Effectiveness for Achieving Airtightness

This graph shows that respondents generally felt that whole building airtightness testing was the most effective testing method for achieving airtightness and that partial floor or suite airtightness testing was the next most effective. This result is consistent with the results of the earlier question, which indicated that respondents generally feel that quantitative test methods are the most effective for achieving airtightness. Some of the methods identified as "Other" for this question included feeling for air leakage using one's hand, visual inspections and field review, and construction document review. It should be noted that while field review and construction document review are clearly important steps in achieving airtightness, they are not test methods which is why they were not included in the original responses to the question.

Respondents were also asked if they felt qualitative or quantitative testing were necessary for the construction of an airtight building. The results of these questions are shown below in Fig.8.12.

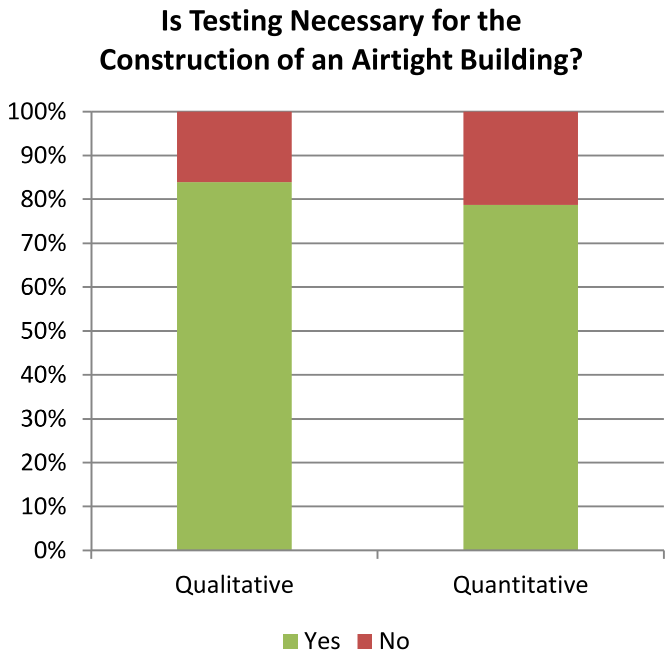


Fig.8.12 Is Testing Necessary for the Construction of an Airtight Building

The results in this graph seem somewhat contradictory to the earlier indication that quantitative testing is more effective than qualitative testing, but the high rate of "yes" responses for both qualitative and quantitative testing does highlight the general concern for airtightness exhibited by the respondents. The comment responses to these questions generally indicated that respondents felt that whole building quantitative tests were necessary to provide a check of performance and to develop baselines for comparison. Alternatively, qualitative testing was described as more appropriate for quality control of difficult details and transitions.

Respondents were also asked to rank the same testing options with respect to cost effectiveness. The results of this question are shown in Fig.8.13.

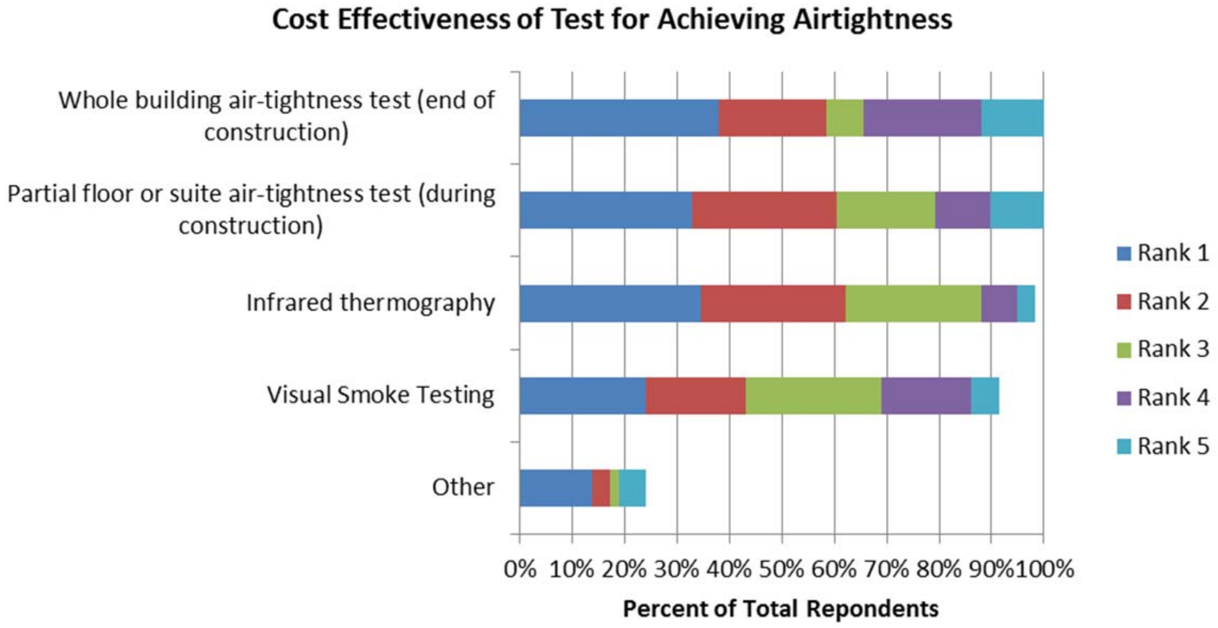


Fig.8.13 Graph of Ranks of Effectiveness for Achieving Airtightness

This graph generally illustrates a similar distribution as for the question regarding the effectiveness of these tests. This correlation could be due to a tendency of respondents to indicate that the most effective tests are also the most cost-effective.

To conclude the survey, a set of questions were asked with respect to implementation of airtightness standards and testing requirements in to building codes and the industry's ability to accommodate the new requirements. To begin with, respondents were asked if they felt that mandatory quantitative testing should be included in the building code, and whether this testing should have meet enforceable performance targets. Additionally, respondents were asked if qualitative testing should be required in the building code. Responses to these questions are summarized in Fig.8.14.

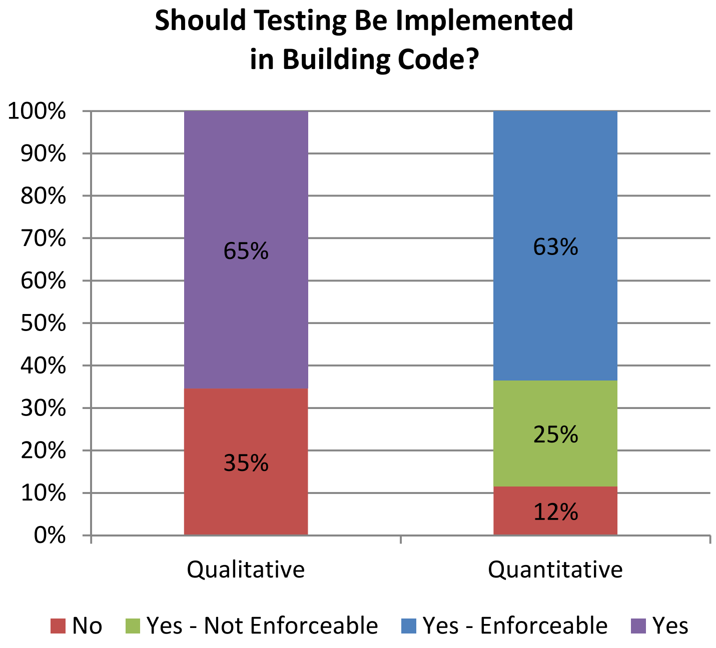


Fig.8.14 Should Quantitative/Qualitative Airtightness Testing be Required by the Building Code

From the responses to this question it is clear that the majority of respondents feel that quantitative airtightness testing should be required by the building code, and most people feel that it should include an enforceable performance target. Respondents were also asked to provide some guidance with respect to what level of airtightness should be considered for use in a code. The average of the values provided is approximately 0.3 cfm/ft² (1.5 L/s·m²) at 75 Pa with the range of values falling mostly between 0.25 cfm/ft² and 0.4 cfm/ft² (1.25 L/s·m² and 2.0 L/s·m²) at a standardized test pressure of 75 Pa. The responses also indicated that qualitative testing should be required as part of the Building Code.

To gain an understanding of the ability of the broader building industry to accommodate the implementation of airtightness requirements, survey respondents were asked how difficult it would be to implement airtightness requirements on their projects if they became part of the building code. The results of this question are illustrated in Fig.8.15.

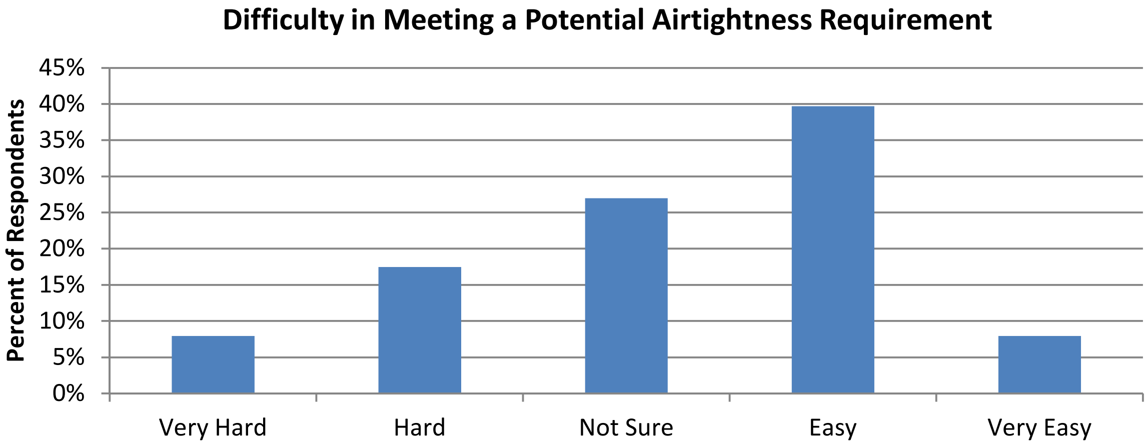


Fig.8.15 Difficulty in Meeting Potential Airtightness Requirements in Building Code

The responses to this question indicate that most (67%) of survey respondents feel that they could accommodate new airtightness requirements in the building code easily or very easily; however, approximately 25% of respondents felt it would be hard or very hard. From a follow-up question, 63% of respondents felt that the industry capacity to perform testing related with new building code requirements could be achieved in less than two years. 62% of people indicated that either the capacity to do this testing already exists in industry in their area, or that it could be easily met if it became a requirement. Only 25% felt that there is no local capacity for airtightness testing at this time.

To develop local capacity, survey respondents indicated that training and education of local companies to perform the testing is the most essential measure needed to improve/develop capacity. This was found to be significantly more important than the development/purchase of testing equipment and the bringing in of consultants or testing agencies from out of the area with capacity for this testing. Fig.8.16 shows that the majority of survey respondents felt that industry capacity could be developed in their area within 2 years (64%) while only 36% of respondents feel it would take longer.

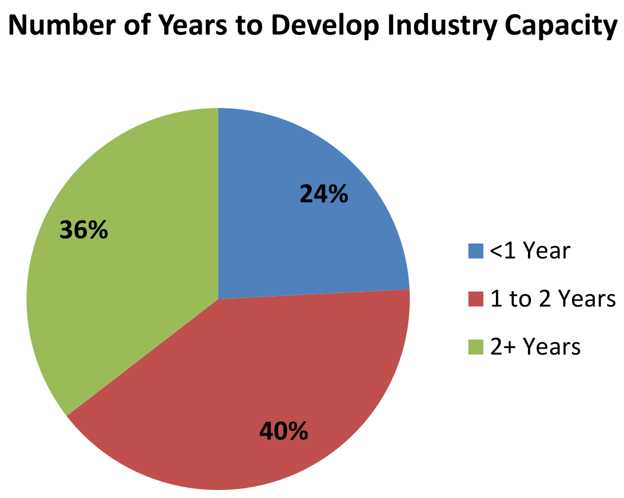


Fig.8.16 Number of Years Required to Develop Industry Capacity

A significant difference between Canadians and Americans was noted in the perception of the ability to develop industry capacity.

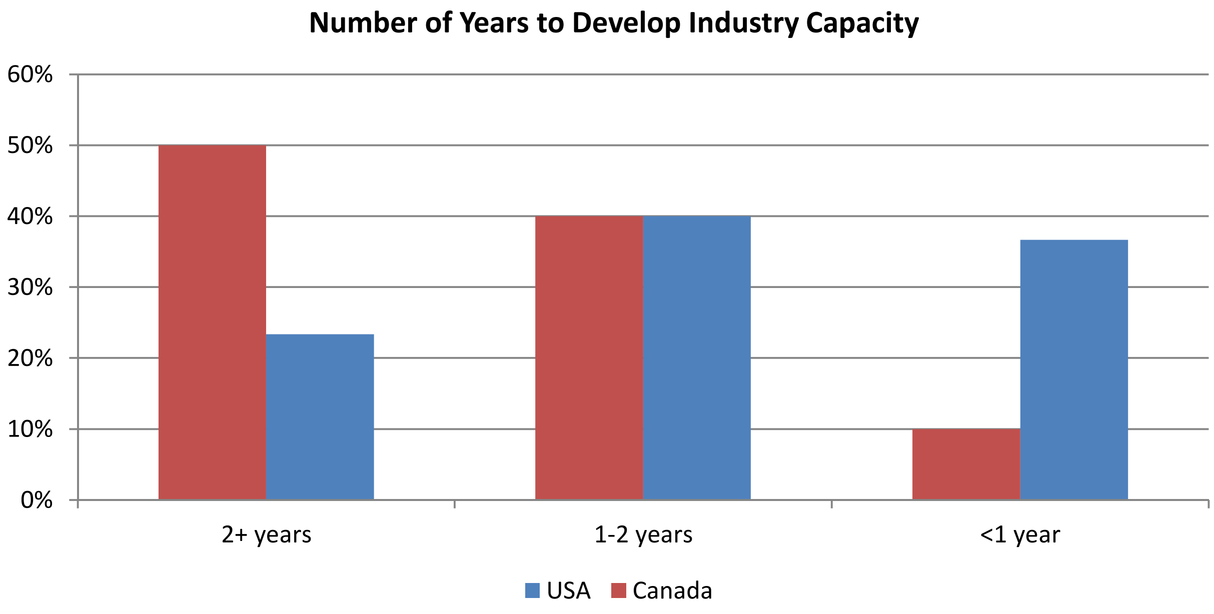


Fig.8.17 Number of Years to Develop Industry Capacity in Canada versus USA

Fig.8.17 shows that while the majority of Americans feel that capacity could be developed in less than two years, Canadian respondents were split evenly with 50% feeling it would take longer than two years to develop the necessary capacity. This would tend to indicate that industry capacity for airtightness testing is currently further developed in the USA than it is Canada. This is further illustrated in Fig.8.18, which compares the perception of local capacity between the two countries.

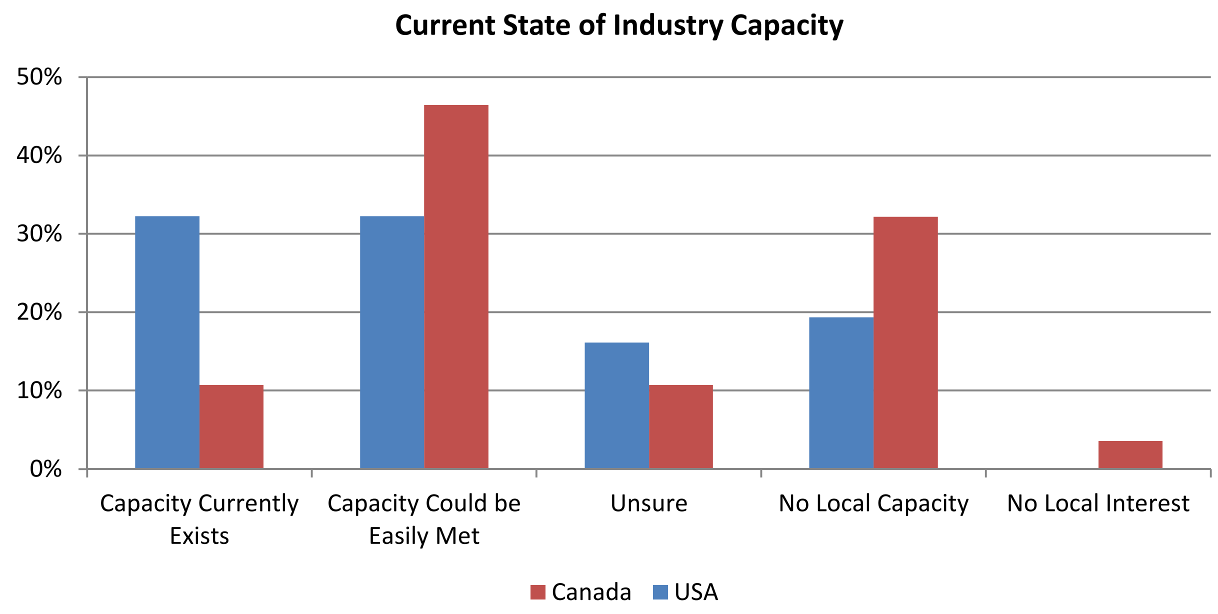


Fig.8.18 State of Industry Capacity in Canada versus the USA

This graph clearly shows that while approximately 64% of American respondents felt that industry capacity either currently exists or could be easily met, significantly less Canadian respondents felt that way. Only 11% of Canadian respondents felt that the capacity already exists; however, 46% of Canadian respondents did feel that it could be easily met if required. The discrepancy between the perceptions of preparedness provided by different respondent groups was also noted between those involved with design versus those involved with testing and construction, as shown in Fig.8.19.

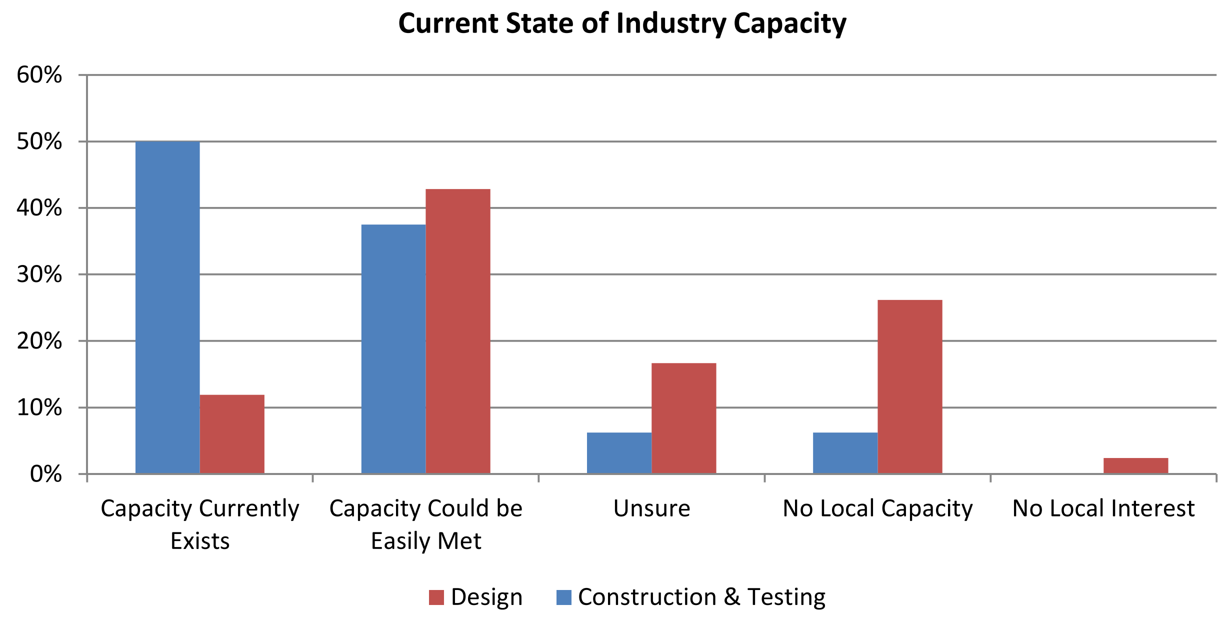


Fig.8.19 State of Industry Capacity According to Designers versus According to Testers and Builders

This graph shows that while designers generally feel that the capacity does not currently exist, 88% of testers and builders feel that either the capacity exists or could be easily met.

8.2. State of Washington and City of Seattle Experience

Recently, the State of Washington and the City of Seattle mandated new airtightness testing requirements; this implementation process can be used as a case study of the reaction and adaptation of industry. The 2009 Washington State Energy Code (WSEC) includes new requirements for the inclusion of an air barrier in the design and construction of the building enclosure as well as whole building air leakage testing for certain buildings. Furthermore, the 2009 WSEC with City of Seattle Amendments (Seattle Energy Code, SEC) includes the same, though slightly modified, requirements for the inclusion of the air barrier and whole building testing. Both Codes cover residential and non-residential buildings and have adopted the distinction between “Residential” and “Non-Residential” as buildings that are governed by the International Residential Code (IRC) and the International Building Code (IBC) respectively. Since MURBs are governed by the IBC and the non-residential sections of the WSEC and SEC, the following discussion focuses on these code requirements. The effective date for the WSEC was July 1, 2010 and SEC was January 1, 2011 for residential buildings, therefore the number of MURBs which have undergone testing is limited.

Table 8.1 WSEC and SEC Requirements for Air Barrier Testing and Pass/Fail or Report

Applicable Building Code; Number of Stories	2009 WSEC Section 502.4.5	2009 WSEC Section 1314.6.2	2009 SEC Section 1314.6.2
IRC	X (Pass)		
IBC Residential; ≤5 Stories			
IBC Residential; >5 Stories		X (Pass)	X (Pass or Report)
IBC Non-Residential; ≤5 Stories			
IBC Non-Residential; >5 Stories		X (Pass)	X (Pass or Report)

Buildings subject to the WSEC must be tested in accordance with ASTM E779 and must meet the prescribed maximum air leakage rate of 0.40 0.40 cfm/ft^2 (2.0 L/s·m²) at 75 Pa. For the SEC, there are two compliance options. The first is to test the whole building and comply with the prescribed maximum air leakage rate of 0.40 cfm/ft^2 (2.0 L/s·m²) at 75 Pa, or alternatively to test the building, report the results, and submit inspection reports reviewing the installation of air barrier components during the course of construction.

Within Washington State, and specifically the City of Seattle, the whole building testing and maximum allowable air leakage rate compliance portion of the code requirement came under scrutiny by many industry players. This was primarily due to a lack of sufficient historic supporting data on whether the contemplated target values were realistically achievable and the whole building test could only be reasonably conducted at or near project completion. Understandably, these two factors needed to be understood if there were to be ramifications for the design and/or construction team as a result of not meeting a code mandated air leakage rate.

Although many designers have been including air barriers as part of their standard design practice for all buildings, the design and construction of air barriers is still a new concept for many players in the industry in Seattle and the State of Washington. Furthermore, air barrier testing, specifically quantitative testing and particularly for whole buildings, has been for the most part non-existent prior to the implementation of the WESC and SEC requirements. As such, various entities have been seeking out opportunities to experiment with whole building air leakage testing to better understand the testing procedure, the impact of testing in terms of building preparation and construction schedule, and the how the results of testing currently constructed buildings compare with the code referenced value of 0.40 cfm/ft^2 (2.0 L/s·m²) at 75 Pa.

8.3. UK Experience

Lovatt authored his Master's Thesis in 2008 entitled *Regulating Whole-Building Airtightness: The UK Experience* which provides a detailed review of the impact of implementing an airtightness testing and performance requirement in to the building code requirement for large buildings. This section provides a summary of his findings.

- British office buildings were approximately 3 to 4 times leakier on average than comparable Canadian and American office buildings prior to the implementation of airtightness testing and performance requirements.
- The standard (UK Building Regulations Part L2) specifies that buildings with floor area greater than 500 m^2 must be tested and provide an air leakage rate of less than 10 $m^3/hr\cdot m^2$ (2.8 $L/s\cdot m^2$ or 0.55 cfm/ft^2) at 50 Pa.
- Prior to implementation of the regulation there was concern that there was not sufficient capacity to perform the testing required, that a requirement would constitute inappropriate interference in the market, and that testing would incur significant cost to building projects and potentially disrupt the building industry.
- The regulation does not require testing results to be saved or submitted once a building has met the required performance level, thus it is difficult to determine the effect of the regulation on the airtightness of buildings.
- Based on a sample of 48 buildings built prior to regulation and 46 buildings built after the regulation was implemented, the average airtightness of the buildings improved from approximately 17.7 $m^3/hr\cdot m^2$ (4.9 $L/s\cdot m^2$ or 1.0 cfm/ft^2) to 9 $m^3/hr\cdot m^2$ (2.3 $L/s\cdot m^2$ or 0.40 cfm/ft^2).
- Industry members interviewed as part of the research indicated that there was little difficulty in fixing buildings that did not meet the performance requirement when initially tested so that they would meet the performance requirement in a subsequent test. Qualitative testing is mentioned as a method of identifying air leakage locations.
- Perception of the regulation is that it is "fair, relatively easy to meet, and imparting value to the customer" (Lovatt 2008)
- Contractors were observed to have experienced a steep learning curve with few having "more than one of their buildings fail the test." (Lovatt 2008)
- Overall, the regulation has effectively reduced air leakage in buildings and has improved quality control beyond airtightness.
- Implementation of the regulation was reasonably straightforward.
- "… the implementation of the regulation has created a new industry of building air leakage testing and consulting, creating domestic jobs and investment in new technology." (Lovatt 2008)

Lovatt concludes his thesis by indicating that "other jurisdictions would be advised to follow their [the UK's] lead." (Lovatt 2008)

8.4. Summary of Industry Preparedness and Perception

Based on the results of the industry survey as well as the project team's experience and involvement within the building industry, a number of conclusions can be drawn regarding the industry perception of and preparedness with respect to airtightness.

- The responsibility for airtightness of buildings currently falls on a wide range of disciplines including Architects, Engineers, and Energy Advisors.
- Airtightness is important to building performance primarily with respect to energy consumption and moisture related damage, but should also be considered with respect to indoor air quality, acoustics, and thermal comfort.
- While construction document review and visual field review of air barrier construction is an important component of the construction of an airtight building, the use of airtightness testing procedures can provide valuable information regarding the airtightness of a building.

- Qualitative testing is useful for diagnostics and for the testing of individual complicated details; however, quantitative testing provides the added benefit of providing values that can be compared to baselines, between buildings, as well as to set requirements.
- Blower door testing of smaller buildings is common in industry, so much of the equipment for the testing of larger buildings is readily available.
- In Canada, there is currently limited capacity to perform airtightness testing; however, many industry participants feel that capacity could be easily developed if it became a requirement. About half of the industry feels that this capacity could be developed in less than two years, while the other half feels it would take longer.
- Airtightness requirements including mandatory testing for verification should be implemented in the building code; industry would likely be able to adapt in the next two years to accommodate these new requirements.

Experience with the implementation of airtightness testing and performance requirements in the United Kingdom suggest that despite a perceived lack of industry capacity and apprehension with respect to the impact on industry, the building industry is able to adapt remarkably quickly to changes in regulation. Furthermore, the implementation of regulation in that jurisdiction has led to a significant improvement in airtightness performance. The experience within Washington State has…

These insights into the industry preparedness and perception of airtightness in buildings will help to guide future decision with respect to the potential implementation of airtightness requirements.

9. Conclusions

The information collected and analysed in this report provides valuable insight in the state of airtightness in the building industry and in particular with respect the multi-unit residential buildings.

Airtightness is an important component of building performance. The control of air exfiltration and infiltration through the exterior building enclosure impacts building energy efficiency, the potential for moisture related damage, interior comfort, and indoor air quality. Compartmentalization, which is dependent upon airtightness of interior building separators, also provides important airflow control within buildings. It reduces the magnitude of stack effect forces which can create large sustained pressure differences that drive airflow in taller buildings. Additionally, compartmentalization can reduce energy consumption and help to control air contamination, including odours, from transferring between spaces in the building. The combination of exfiltration and infiltration control with compartmentalization also provides a predictable system for the design of building ventilation systems which can significantly improve the ability of the system to provide fresh air to spaces and control airflows within the building.

To provide an airtight building enclosure or to seal interior spaces of a building (i.e., compartmentalize), a variety of systems and technologies are available and widely implemented on the market. It is important when selecting and designing building air barriers that adequately robust systems are selected to achieve the airtightness targets and maintain these targets over the service life of the air barrier systems.

To test the airtightness performance of buildings a variety of techniques have been developed both in Canada and internationally. These techniques share many similarities. For the testing of MURBs the pressurization or depressurization of the entire building to perform a test is frequently impractical or impossible, so the application of classical whole building pressurization and depressurization techniques is not practical. Instead alternative techniques need to be assessed. Based on the testing techniques reviewed, it is felt the pressure neutralized fan pressurization/depressurization technique is the most applicable test procedure for MURB airtightness testing at this time.

The balanced fan technique allows for the testing of a smaller space within a MURB in which the test pressures can more practically be achieved. Additionally, this technique is able to quantify the airtightness characteristics of both the exterior building enclosure and of interior compartmentalizing elements. Industry familiarity with this technique is somewhat less than with whole building techniques such as CGSB 149.10 or ASTM E 779; consequently, if the balanced fan pressurization/depressurization technique were to be used as a standardized procedure, training would need to be provided to members of industry.

Regardless of the airtightness test method selected, testing of new buildings should be implemented once the air barrier assemblies are complete but prior to occupation of the building. This limits many of the variables that come with testing an occupied building and also provides the opportunity to locate and seal any problematic air leakage locations before construction completion. The implementation of airtightness testing and performance requirements in other jurisdictions has led to significant improvements in building airtightness. In the UK, this improvement has been documented to be greater than 50%. Comparable impacts in Canada are anticipated if similar requirements are implemented.

It should be noted that qualitative airtightness testing can also be effective in locating air leakage locations and can be particularly effective in diagnosing causes of high air leakage rates and identifying areas to be air sealed. These qualitative techniques including infrared photography and smoke testing should be promoted as effective methods to be used in the airtightness commissioning of buildings.

As airtightness standards and codes were reviewed for this project, a wide range of metrics were identified to quantify airtightness. Of the metrics encountered during the review, it was found that the normalized airflow rate in units of litres per second meter squared (L/s·m²) at a specific test pressure is most applicable. (The inch-pound unit alternative is cubic feet per minute per square foot, cfm/ft², which are the more commonly used units in industry.) The normalized airflow rate is a direct measure of the permeance of the building enclosure or interior compartmentalizing elements and can be easily compared between buildings. Alternative measures such as air change rate account for the volume of the space, which can be relevant for ventilation calculations, but do not provide a fundamental indication of airtightness. Equivalent Leakage Area could potentially be used as an indicator; however, due to the confusion between Equivalent and Effective Leakage Areas it is practical to select a less ambiguous form.

The pressure at which measurements were provided also varied widely. Two approaches to the selection of a standard pressure should be considered. The first is to use a pressure indicative of potential in-service pressure differentials. Typically either 10 Pa (CGSB) or 4 Pa (ASTM) are used for these values. The second option is to select a pressure at which testing is actually performed. For use in a standard or code it is felt that the second option is preferable. With the equipment available and the adoption of a testing technique for compartmentalized sections of larger buildings, creating a pressure difference of 75 Pa should be possible. This pressure is of sufficient magnitude to largely overcome bias due to the driving forces of wind and stack effect and thus could potentially be used for a single point test when multi point testing and/or both pressurization and depressurization testing is not performed. Additionally this value could be obtained with little need for conversion which limits the potential for error.

The range of airtightness values found in standards and codes is quite large, and varies by a factor of approximately 10; however, a typical value of 0.40 cfm/ft^2 (2.0 L/s·m^2) at 75 Pa has been determined and this is consistent with the current value used in the Washington State testing standard. This value would provide a good target value for use in codes or standards. A higher performance target that could still realistic be achieved could be 0.25 cfm/ft^2 (1.27 m^3/s·m^2) at 75 Pa which is the current USACE requirement. Proposed future USACE requirements are targeting even lower levels, down to 0.15 cfm/ft^2 (0.76 m^3/s·m^2) at 75 Pa

The responses to the industry survey, primarily from those most likely involved in airtightness of buildings, indicated an appreciation of the importance of airtightness with respect to building performance and general support for the implementation of quantitative airtightness targets into building codes. Based on that industry sector feedback provided in the survey, it is felt the industry could likely achieve capacity for airtightness testing within two years.

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13. Glossary of Terms

air barrier	Refers to the materials and components of the building enclosure or of compartmentalizing elements that together control airflow through the assembly.
air changes per hour (ACH)	Refers to the number of times per hour that a volume of air (room, suite, etc) is replaced in an hour. Provides an indication of ventilation rates.
air leakage	Refers to air which unintentionally flows through building enclosure or compartmentalizing elements. This is often quantified as Normalized Leakage Rate [cfm/ft^2 or L/s·m^2] or simply Leakage Rate [cfm or L/s].
airtightness	Refers to the ability of building enclosure or compartmentalizing element to resist airflow. A system which is more airtight has higher resistance to airflow. This is often quantified as Normalized Leakage Rate [cfm/ft^2 or L/s·m^2] or simply Leakage Rate [cfm or L/s].
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials (ASTM)
ATTMA	Airtightness Testing and Measurement Association
airflow	Refers to the movement of air from one space to another. Usually measure in cfm or L/s at a specific reference pressure.
baseline pressure	Refers to the pressure difference measured between the exterior and interior of the building when no fans are used to adjust the pressure. Baseline pressure is caused by the natural driving forces of stack effect and wind.
below-grade	Refers to the portion of the building that is below the level of the ground surface.
bias pressure	See “baseline pressure”
blower	Refers to a large fan.
blower door	See “fan-door”
building enclosure	Refers to the part of a building which separates the interior environmental conditions from the exterior environmental conditions including the control of precipitation, water vapour, air, and heat.
condensation	Refers to the change in state of water from vapour to liquid. Often materializes as water on a surface that is below the dewpoint temperature of the air.
condominium	Refers to a multi-unit residential building in which each unit is individually owned and the common areas are jointly owned.
cfm	cubic feet per minute (ft^3/min)
CGSB	Canadian General Standards Board
compartmentalization	Refers to separating a single building volume (floor, room, suite, office, etc) within a larger building volume with the primary intention of controlling airflows into and out of the space. Compartmentalization is typically performed for fire, smoke, odours, and acoustic separation; however, it can also be important for HVAC control.
compartmentalizing elements	Refers to any interior element of the building that is intentionally designed to limit the flow of air between adjacent spaces. Typically this would include walls between suites, walls between suites and the corridor, and floors.

depressurization	Refers to the process of creating negative pressure inside a building or space relative to the surrounding conditions by removing air from the space with a fan.
dewpoint	Refers to the temperature at which the air would be saturated with water vapour (100% RH)
driving forces	Refers to natural phenomena and mechanical systems which create pressure differentials and thus create airflow. Includes stack effect, wind, and ventilation equipment. Refer to Section 2.2.
effective leakage area (EfLA)	Refers to represents the size of an orifice which would produce the same net air flow at a given pressure differentials as would occur cumulatively through all leakage paths in the building enclosure. Calculated according to ASTM E779, it usually uses a pressure differential of 4Pa and a discharge coefficient of 1.0. See Section 3.1.5.
equivalent leakage area (EqLA)	Refers to represents the size of an orifice which would produce the same net air flow at a given pressure differentials as would occur cumulatively through all leakage paths in the building enclosure. Calculated according to CGSB 149.10, it usually uses a reference pressure of 10Pa and a discharge coefficient of 0.61. See Section 3.1.4.
exhaust air	Refers to air which is removed from a space by a mechanical system (fan) as part of the ventilation strategy.
fan-door	Refers to a system which incorporates a door cover and a calibrated blower fan into a system made specifically for installation in a doorway. This system is commonly used in the testing of detached houses and is gaining popularity for use in the testing of larger buildings by using multiple fan-door systems. See Section 5.6.2.
HVAC	Heating, Ventilation, and Air Conditioning. Refers to the equipment used to condition the interior spaces of a building.
IBC	International Building Code
IECC	International Green Construction Code
IGCC	International Green Construction Code
infrared	Refers to the spectrum of light with longer wavelengths than visible light (750 nm to 1 nm). Infrared radiation (light) is emitted by objects and is an indicator of surface temperature so can be used in building investigations to identify temperature anomalies on building surfaces.
IRC	International Residential Code for One- and Two- Family Dwellings
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
leakage rate	Refers to the rate at which air unintentionally flows through
MURB	Multi-unit Residential Building
NBCC	National Building Code of Canada
NECB	National Energy Code for Buildings
normalized airflow rate	Refers to the airflow rate divided by the relevant enclosure area. Usually measured in units of $L/s \cdot m^2$ at a given pressure differential.
normalized leakage area (NLA)	See “Specific Leakage Area”
pascal (Pa)	Is a metric unit of measure for pressure. 1 in H_2O = 249 Pa
permeability (air)	Is a material property measuring the ability of that material to allow airflow through it. Usually measured in cfm/ft^2 or $L/s \cdot m^2$ at a given pressure difference.

101permeance (air)	Is an enclosure system property measuring the ability of the system to allow airflow through it. This term is essentially the opposite of airtightness. Higher permeance means less airtight. Usually measured in cfm/ft^2 or L/s·m^2 at a given pressure difference.
pressurization	Refers to the process of creating positive pressure inside a building or space relative to the surrounding conditions by removing air from the space with a fan.
reference pressure	Refers to the pressure differential which is used for a test or the calculation of a quantity. 4 Pa and 10 Pa are commonly used as representative in-service reference pressures while 50 Pa and 75 Pa are common reference pressures used in testing.
relative humidity (RH)	Refers to the proportion of the moisture in the air compared to the amount of moisture the air could potentially hold at that temperature.
specific leakage area (SLA)	Refers to either the equivalent or effective leakage area normalized by dividing by the relevant enclosure area (similar to normalized airflow rate). Just as it is important to distinguish between EfLA and EqLA, it is also important to distinguish which of these quantities was used to calculate the SLA. For clarity, it is often convenient to refer to SLA as the Normalized Equivalent or Effective Leakage Area (as is appropriate) so that the distinction can be clearly made. See Section 3.1.6.
stack effect	Refers to the natural pressure differentials that are developed across the building enclosure as a result of buoyancy forces due to difference in temperature between the interior and exterior of a building. See Section 2.2.2.
supply air	Refers to air which provided to a space by a mechanical system (fan) as part of the ventilation strategy.
time averaging	Refers to the technique of taking multiple measurements at set intervals over a period of time and then averaging these measurements to obtain a more stable measurement.
tracer gas	Refers to gasses which are generally found at low concentration naturally and are not produced by respiration or by common processes found in buildings and thus can be used to indicate air flow. Generally, tracer gas use requires the release of the gas in to a space and the measurement of concentrations of the gas in the space and adjacent spaces over a period of time. See Sections 5.1.7 and 5.6.6.
USACE	United States Army Corps of Engineers
ventilation	Refers to the supply and exhaust of air from spaces to maintain indoor air quality by diluting and extracting contaminates.

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Appendix A

MURB Airtightness Database

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
Unique building ID. Suffix (a,b,c, etc) added for more than one test on a building.		*Database is intended for MURBs; however, if some other building with a MURB like enclosure is tested, data could be included and building type specified.*	*Condominium, social housing, seniors housing, student housing, commercial?*	*City, Province/State, Country*	*Year of construction if known*	*If the air-barrier was retrofit or rehabilitated at any point then date of retrofit included.*	*Number of stories above grade*	*Building Height*	*Gross Floor Area*	*Gross Enclosure Area*	*Does enclosure area include below grade walls and slab?*	*Building Volume*		*1- good - usable for database , 2- questionable - careful with database use, 3- for comparison purposes only, 4- test for a 6 sided suite (un-neutralized)*	*Whole building, floor of building, suite of building etc.*	*US ACE, ASTM, CAN CGSB, LEED, compartmentalized suite etc.?*	*Note whether tested suite or floor, if part building included roof/slab area*	*Year or approximate year of test*	*Comment on test type and area for normalization*	*This may be the whole building enclosure area, or just the wall area of a suite or a floor*	*This may be the whole building volume or just the volume of a suite or floor*	*Single or multipoint test performed?*	*comment on why testing was performed. Project requirement, LEED, USACE, Research*	*yes or no to passing*	*comment on requirement*	*if comparitive test results are shown, ie 1a, 1b etc.. Comment on differences.*	*Use measured value or assume an n value 0.60.*	*Measured (multi-point) or Assumed*						
1a	test performed by RDH as part of commissioning process. Comparative data also collected. Good new air-tight woodframe data	MURB	student housing w/ commercial ground floor	Seattle, WA, USA	2011	-	7	78	96882	76084	yes	1066200	air barrier commissioning performed during construction	1	Whole building enclosure	USACE 2011	n/a	2011	total enclosure area includes slab and below grade	76084	1066200	multipoint	Seattle - Code Requirement, USACE	yes	requirement <0.40 cfm/ft2 @75 Pa	-	0.58	measured	0.26	0.29	-	22369	1.26	2403
1b	comparative data with one window left open for test	MURB	student housing w/ commercial ground floor	Seattle, WA, USA	2011	-	7	78	96882	76084	yes	1066200	air barrier commissioning performed during construction	3	Whole building enclosure	USACE modified	n/a	2011	one 5 ft2 window opened	76084	1066200	single	look at impact of 1 open window	n/a	-	one window open increased air leakage 0.10 cfm/ft2 at 75 Pa, (5.56 sq ft hole)	0.58	measured	0.34	0.39	-	29673	1.67	3188
1c	comparative data for two windows left open for test	MURB	student housing w/ commercial ground floor	Seattle, WA, USA	2011	-	7	78	96882	76084	yes	1066200	air barrier commissioning performed during construction	3	Whole building enclosure	USACE modified	n/a	2011	two 5ft2 windows opened	76084	1066200	single	look at impact of 2 open window	n/a	-	two window open increased air leakage by 0.19 cfm/ft2 at 75 Pa. so leaky couldn't get past 50 Pa	0.58	measured	0.42	0.48	-	36622	2.06	3934
2a	research project - measured air-tightness of enclosure using representative suites. Performed pressure neutralizing	MURB	condo	Vancouver, BC, CANADA	1987	2000	4	40	-	-	n/a	-	research study - one suite tested. Fireplace in suite	1	Suite - Enclosure	Compartmentalized suite	roof	2006	enclosure only test	1404	5472	single	research study neutralizing method	n/a	-	81% of suite leakage to exterior	0.60	assumed	0.74	-	0.92	1289	14.14	139
2b	comparison for all six sides data	MURB	condo	Vancouver, BC, CANADA	1987	2000	4	40	-	-	n/a	-	research study - one suite tested. Fireplace in suite	4	Suite - 6 sides	LEED - 6 sides	roof	2006	all six sides test	2462	5472	single	research study neutralizing method	n/a	-	all six sides very leaky. However as enclosure was so leaky ratio of exterior to interior leakage was 81% exterior, 19% interior	0.60	assumed	0.52	-	0.65	1601	17.56	172
3a	research project - measured air-tightness of enclosure using representative suites. Performed pressure neutralizing	MURB	condo	Burnaby, BC, CANADA	1985	2006	23	207	-	-	n/a	-	research study - one suite tested	1	Suite - Enclosure	Compartmentalized suite	no, intermediate floor	2006	enclosure only test	450	8680	single	research study neutralizing method	n/a	-	35% of suite leakage to exterior	0.60	assumed	0.30	-	0.37	169	1.17	18
3b	comparison for all six sides data	MURB	condo	Burnaby, BC, CANADA	1985	2006	23	207	-	-	n/a	-	research study - one suite tested	4	Suite - 6 sides	LEED - 6 sides	no, intermediate floor	2006	all six sides test	3381	8680	single	research study neutralizing method	n/a	-	indoor partitions very leaky, particularily between floors	0.60	assumed	0.11	-	0.14	479	3.31	51
4a	research project - measured air-tightness of enclosure using representative suites. Performed pressure neutralizing	MURB	social housing	Vancouver, BC, CANADA	2001	-	4	40	-	-	n/a	-	research study - one suite tested	1	Suite - Enclosure	Compartmentalized suite	no, intermediate floor	2006	enclosure only test	136	3024	single	research study neutralizing method	n/a	-	66% of suite leakage to exterior (ducts likely)	0.60	assumed	2.46	-	3.05	415	8.23	45
4b	comparison for all six sides data	MURB	social housing	Vancouver, BC, CANADA	2001	-	4	40	-	-	n/a	-	research study - one suite tested	4	Suite - 6 sides	LEED - 6 sides	no, intermediate floor	2006	all six sides test	1428	3024	single	research study neutralizing method	n/a	-	no leakage between floors (conc. Topping on wood) all between suites	0.60	assumed	0.35	-	0.43	619	12.29	67
5a	research project - measured air-tightness of enclosure using representative suites. Performed pressure neutralizing	MURB	social housing	Vancouver, BC, CANADA	1990	2001	6	61	-	-	n/a	-	research study - one suite tested	1	Suite - Enclosure	Compartmentalized suite	no, intermediate floor	2006	enclosure only test	1330	5936	single	research study neutralizing method	n/a	-	78% of suite leakage to exterior (large proportion of exterior area as exterior corridor	0.60	assumed	0.24	-	0.29	390	3.94	42
5b	comparison for all six sides data	MURB	social housing	Vancouver, BC, CANADA	1990	2001	6	61	-	-	n/a	-	research study - one suite tested	4	Suite - 6 sides	LEED - 6 sides	no, intermediate floor	2006	all six sides test	2532	5936	single	research study neutralizing method	n/a	-	-	0.60	assumed	0.16	-	0.20	517	5.22	56
6a	research project - measured air-tightness of enclosure using representative suites. Performed pressure neutralizing	MURB	social housing	Vancouver, BC, CANADA	1990	2001	6	61	-	-	n/a	-	research study - one suite tested	1	Suite - Enclosure	Compartmentalized suite	no, intermediate floor	2006	enclosure only test	1170	5456	single	research study neutralizing method	n/a	-	33% of suite leakage to exterior, 67% to interior	0.60	assumed	0.19	-	0.24	282	3.10	30
6b	comparison for all six sides data	MURB	social housing	Vancouver, BC, CANADA	1990	2001	6	61	-	-	n/a	-	research study - one suite tested	4	Suite - 6 sides	LEED - 6 sides	no, intermediate floor	2006	all six sides test	2303	5456	single	research study neutralizing method	n/a	-	-	0.60	assumed	0.27	-	0.34	775	8.53	83
7a	research project - measured air-tightness of enclosure using representative suites. Performed pressure neutralizing	MURB	social housing	Vancouver, BC, CANADA	1990	2001	6	61	-	-	n/a	-	research study - one suite tested	1	Suite - Enclosure	Compartmentalized suite	no, intermediate floor	2006	enclosure only test	488	5456	single	research study neutralizing method	n/a	-	36% of suite leakage to exterior, 67% to interior	0.60	assumed	0.28	-	0.35	172	1.89	18
7b	comparison for all six sides data	MURB	social housing	Vancouver, BC, CANADA	1990	2001	6	61	-	-	n/a	-	research study - one suite tested	4	Suite - 6 sides	LEED - 6 sides	no, intermediate floor	2006	all six sides test	2303	5456	single	research study neutralizing method	n/a	-	-	0.60	assumed	0.18	-	0.23	523	5.75	56
8a	Test performed on whole building by Patenaude pre retrofit of air-sealing measures	MURB	condo	Montreal, QC, Canada	1978	-	7	-	-	-	n/a	-	-	1	Whole building	whole building	n/a	2009	total enclosure area	60579	744385	multipoint	research, pre air-sealing	n/a	-	pre air sealing case	0.65	measured	1.15	1.77	-	107407	8.66	11539
8b	Test performed on whole building by Patenaude post retrofit of air-sealing measures	MURB	condo	Montreal, QC, Canada	1978	2010	7	-	-	-	n/a	-	-	1	Whole building	whole building	n/a	2010	total enclosure area	60579	744385	multipoint	research, post air-sealing	n/a	-	49% reduction in air-leakage @75 Pa from measures, (40% at 10 Pa)	0.57	measured	0.83	0.90	-	54539	4.40	5859
9a	Test performed on selected suites pre-window replacement. Average results from 6 suites pre-post	MURB	social housing	Vancouver, BC, CANADA	1973	-	22	-	-	-	n/a	-	strip windows, very leaky, repetitive details, ducts large leakage area	4	Suite - 6 sides	LEED - 6 sides	no, intermediate floor	2008	all six sides test	1230	2617	single	research, pre air-sealing	n/a	-	-	0.60	measured	0.36	-	0.44	543	12.44	58
9b	Test performed on selected suites post-window replacement. Average results from 6 suites pre-post	MURB	social housing	Vancouver, BC, CANADA	1973	2008	22	-	-	-	n/a	-	strip windows, very leaky, repetitive details, ducts large leakage area	4	Suite - 6 sides	LEED - 6 sides	no, intermediate floor	2008	all six sides test	1230	2617	single	research, post air-sealing	n/a	-	new windows reduced air-leakage through 6 sides of suite by 17% (estimated >50% when removing interior walls/ducts from calc)	0.60	measured	0.30	-	0.37	450	10.32	48
10a	Testing prior to air leakage sealing	MURB	-	Ottawa, ON, Canada	-	-	21	-	-	-	-	1536718	-	1	Whole building enclosure	CGSB 149.10	-	1990	whole building	-	1536764	multipoint	research, pre air-sealing	n/a	-	Testing prior to air leakage sealing	0.81	measured	-	-	-	51223	2.00	5503
10b	Testing after air leakage sealing	MURB	-	Ottawa, ON, Canada	-	1991	21	-	-	-	-	1536718	-	1	Whole building enclosure	CGSB 149.10	-	1991	whole building	-	1536764	multipoint	research, post air-sealing	-	-	Testing after air leakage sealing	0.87	measured	-	-	-	38417	1.50	4127

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
11	-	MURB	-	Ottawa, ON, Canada	1990		4	-	-	15166	-	133772	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	15166	133776	multipoint	-	n/a	-	-	0.62	measured	0.30	0.41	-	6243	2.80	671
12	-	MURB	-	Ottawa, ON, Canada	1991		4	-	-	20656	-	226296	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	20656	226296	multipoint	-	n/a	-	-	0.74	measured	0.20	0.44	-	9052	2.40	972
13	-	MURB	-	Toronto, ON, Canada	1991		4	-	-	32313	-	366037	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	32313	366037	multipoint	-	n/a	-	-	0.83	measured	0.20	0.68	-	21962	3.60	2359
14	-	MURB	-	Toronto, ON, Canada	1994		3	-	-	9580	-	70665	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	9580	70665	multipoint	-	n/a	-	-	0.67	measured	0.40	0.66	-	6360	5.40	683
15	-	MURB	-	Vancouver, BC, CANADA	1992		4	-	-	27975	-	263659	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	27975	263659	multipoint	-	n/a	-	-	0.63	measured	0.42	0.60	-	16698	3.80	1794
16	-	MURB	-	Vancouver, BC, CANADA	1993		3	-	-	28955	-	281317	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	28955	281317	multipoint	-	n/a	-	-	0.59	measured	0.61	0.71	-	20630	4.40	2216
17	-	MURB	-	Vancouver, BC, CANADA	1993		4	-	-	25930	-	237986	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	25930	237986	multipoint	-	n/a	-	-	0.62	measured	0.52	0.70	-	18246	4.60	1960
18	-	MURB	-	Vancouver, BC, CANADA	1993		4	-	-	23024	-	216761	-	1	Whole building enclosure	CGSB 149.10	-	1995	whole building	23024	216761	multipoint	-	n/a	-	-	0.67	measured	0.43	0.72	-	16618	4.60	1785
19	-	MURB	-	Flin Flon, ON, Canada	1999		1	-	-	21000	-	114384	-	1	Whole building enclosure	CGSB 149.10	-	1999	One small common wall, but no leakage identified.	21000	114384	multipoint	-	n/a	-	-	0.66	measured	0.23	0.36	-	7626	4.00	819
20	Built as part of the C-2000 Program.	MURB	-	Dundas, ON, Canada	1998		6	-	-	73474	-	858853	-	1	Whole building enclosure	CGSB 149.10	-	2000	whole building	73474	858853	multipoint	-	n/a	-	-	0.51	measured	0.28	0.23	-	17177	1.20	1845
21	-	MURB	-	Montreal, QC, Canada	1956	-	-	37	-	21043	-	187909	-	1	Whole building enclosure	CGSB 149.10	-	1992	whole building	21043	187909	multipoint	-	n/a	-	-	0.77	measured	0.48	1.25	-	26307	8.40	2826
22	-	MURB	-	Montreal, QC, Canada	1956	-	-	37	-	19741	-	170605	-	1	Whole building enclosure	CGSB 149.10	-	1992	whole building	19741	170605	multipoint	-	n/a	-	-	0.64	measured	0.51	0.75	-	14786	5.20	1588
23	-	MURB	-	Ottawa, ON, Canada	1981	-	5	-	-	-	-	-	-	3	Whole building enclosure & a smaller area with balancing	CGSB 149.10 & Balanced	-	1989	whole building and compartmentalized area	-	-	multipoint	-	n/a	-	-	0.69	measured	-	-	0.89	-	-	-
24a	Pre-retrofit test	MURB	-	Toronto, ON, Canada	1984	-	17	-	-	-	-	-	-	1	Whole building enclosure	CGSB 149.10	no	1988	whole building	-	-	multipoint	-	n/a	-	Pre-retrofit test	0.50	measured	-	-	0.86	-	-	-
24b	Post-retrofit test	MURB	-	Toronto, ON, Canada	1984	1988	17	-	-	-	-	-	-	1	Whole building enclosure	CGSB 149.10	no	1988	whole building	-	-	multipoint	-	n/a	-	Post-retrofit test	0.51	measured	-	-	0.80	-	-	-
25a	Pre-retrofit test	MURB	-	Toronto, ON, Canada	1979	-	14	-	-	-	-	-	-	1	Whole building enclosure	CGSB 149.10	no	1988	whole building	-	-	multipoint	-	n/a	-	Pre-retrofit test	0.72	measured	-	-	0.62	-	-	-
25b	Post-retrofit test	MURB	-	Toronto, ON, Canada	1979	1988	14	-	-	-	-	-	-	1	Whole building enclosure	CGSB 149.10	no	1988	whole building	-	-	multipoint	-	n/a	-	Post-retrofit test	0.66	measured	-	-	0.53	-	-	-
26	-	MURB	-	Montreal, QC, Canada	1991	-	-	-	-	-	-	-	-	1	Suite	Balanced suite	no	1991	Suite	-	-	-	-	n/a	-	-	0.60	correlation provides error, so assumed	-	-	0.90	-	-	-
27	-	MURB	-	Montreal, QC, Canada	1961	-	-	-	-	-	-	-	-	1	Suite	Balanced suite	no	1991	Suite	-	-	-	-	n/a	-	-	0.60	correlation provides error, so assumed	-	-	1.20	-	-	-
28	-	MURB	-	Winnipeg, MB, Canada	1973	-	13	-	-	-	-	-	Building 28 and 29 very similar except 28 was reskinned with new air barrier.	1	Suite	Balanced suite	no	1991	Suite 405	305	-	multipoint	-	n/a	-	-	0.46	measured	0.88	-	0.59	181	-	19
29a	Average of tests on building	MURB	-	Winnipeg, MB, Canada	1970	-	13	-	-	-	-	-	Building 28 and 29 very similar except 28 was reskinned with new air barrier.	1	Suite	Balanced suite	no	1991	Average of suites	304	-	multipoint	-	n/a	-	Average of tests on building	0.57	measured	0.63	-	0.69	210	-	23
29b	-	MURB	-	Winnipeg, MB, Canada	1970	-	13	-	-	-	-	-	Building 28 and 29 very similar except 28 was reskinned with new air barrier.	3	Suite	Balanced suite	no	1991	Suite 509	304	-	multipoint	-	n/a	-	Different suite	0.53	measured	0.82	-	0.77	234	-	25
29c	-	MURB	-	Winnipeg, MB, Canada	1970	-	13	-	-	-	-	-	Building 28 and 29 very similar except 28 was reskinned with new air barrier.	3	Suite	Balanced suite	no	1991	Suite 609	304	-	multipoint	-	n/a	-	Different suite	0.66	measured	0.50	-	0.80	243	-	26
29d	-	MURB	-	Winnipeg, MB, Canada	1970	-	13	-	-	-	-	-	Building 28 and 29 very similar except 28 was reskinned with new air barrier.	3	Suite	Balanced suite	no	1991	Suite 1009	304	-	multipoint	-	n/a	-	Different suite	0.53	measured	0.56	-	0.50	153	-	16
30a	Average of tests on building	MURB	-	Victoria, BC, Canada	1991	-	8	-	-	-	-	-	-	1	Floor	Balanced floor	no	1991	Average of suites	3272	48558	multipoint	-	n/a	-	Average of tests on building	0.47	measured	0.24	-	0.16	535	0.66	57
30b	-	MURB	-	Victoria, BC, Canada	1991	-	8	-	-	-	-	-	-	3	Floor	Balanced floor	no	1991	Floor 4	3272	48558	multipoint	-	n/a	-	Different suite	0.44	measured	0.26	-	0.16	522	0.64	56
30c	-	MURB	-	Victoria, BC, Canada	1991	-	8	-	-	-	-	-	-	3	Floor	Balanced floor	no	1991	Floor 5	3272	48558	multipoint	-	n/a	-	Different suite	0.49	measured	0.21	-	0.17	548	0.68	59
31a	Average of tests on building	MURB	-	Victoria, BC, Canada	1991	-	10	-	-	-	-	-	-	1	Floor	Balanced floor	no	1991	Average of suites	2605	33019	multipoint	-	n/a	-	Average of tests on building	0.53	measured	0.28	-	0.26	672	1.22	72
31b	-	MURB	-	Victoria, BC, Canada	1991	-	10	-	-	-	-	-	-	3	Floor	Balanced floor	no	1991	Floor 5	2605	33019	multipoint	-	n/a	-	Different suite	0.49	measured	0.54	-	0.42	1092	1.98	117
31c	-	MURB	-	Victoria, BC, Canada	1991	-	10	-	-	-	-	-	-	3	Floor	Balanced floor	no	1991	Floor 6	2605	33019	multipoint	-	n/a	-	Different suite	0.58	measured	0.16	-	0.19	492	0.89	53
31d	-	MURB	-	Victoria, BC, Canada	1991	-	10	-	-	-	-	-	-	3	Floor	Balanced floor	no	1991	Floor 7	2605	33019	multipoint	-	n/a	-	-	0.51	measured	0.20	-	0.17	436	0.79	47
32	-	MURB	-	St. John's, NL, Canada	1982	-	7	-	-	-	-	-	-	1	Floor	Balanced floor	no	1991	-	-	-	-	-	n/a	-	-	0.60	assumed	-	-	1.97	-	-	-
33	-	MURB	-	St. John's, NL, Canada	1983	-	6	-	-	-	-	-	-	1	Floor	Balanced floor	no	1991	-	-	-	-	-	n/a	-	-	0.60	assumed	-	-	0.98	-	-	-
34a	Test performed by Patenaude-Trempe pre retrofit of air-sealing measures	MURB	OMHM	Montreal, QC, Canada	1978	none	7	70	11398	60579	no	744363	air quality testing	1	Whole building, floor of building and suite of building	CAN/CGSB-149.10-M86 and ASTM E779-03	when appropriate, the floor or roof was included in the exterior envelope area	2009	total enclosure area includes ground floor slab and roof	60579	744385	multipoint	research, pre air-sealing	no	-	-	0.65	measured	1.15	1.77	-	107407	8.66	11539

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
34b	Test performed by Patenaude-Trempe post retrofit of air-sealing measures	MURB	OMHM	Montreal, QC, Canada	1978	none	7	70	11398	60579	no	744363	air quality testing	1	Whole building, floor of building and suite of building	CAN/CGSB-149.10-M86 and ASTM E779-03	when appropriate, the floor or roof was included in the exterior envelope area	2010	total enclosure area includes ground floor slab and roof	60579	744385	multipoint	research, post air-sealing	showed a good improvement	improvement in air tighness	49% reduction in air-leakage @75 Pa from measures, (40% at 10 Pa)	0.57	measured	0.83	0.90	-	54539	4.40	5859
35a	-	MURB	-	Ottawa, ON, Canada	-	-	21	-	153816	80406	yes	1536718	Building reported at 105kWh/m2/year which seems quite low	2	whole building	References Magee and Shaw 1990	-	-	whole building depressurization	80406	1536718	-	research, pre air-sealing	n/a	-	-	0.60	assumed	0.34	0.42	-	33645	1.31	3615
35b	-	MURB	-	Ottawa, ON, Canada	-	-	21	-	153816	80406	yes	1536718	Building reported at 105kWh/m2/year which seems quite low	2	whole building	References Magee and Shaw 1990	-	-	whole building depressurization	80406	1536718	-	research, post air-sealing	n/a	-	-	0.60	assumed	0.23	0.28	-	22856	0.89	2455
36a	-	MURB	-	Toronto, ON, Canada	-	-	-	-	105755	273995	yes	898935	Building reported at 98.6kWh/m2/year which seems quite low	2	whole building	References Magee and Shaw 1990	-	-	whole building depressurization	273995	898935	-	research, pre air-sealing	n/a	-	-	0.60	assumed	0.05	0.06	-	16573	1.11	1780
36b	-	MURB	-	Toronto, ON, Canada	-	-	-	-	105755	273995	yes	898935	Building reported at 98.6kWh/m2/year which seems quite low	2	whole building	References Magee and Shaw 1990	-	-	whole building depressurization	273995	898935	-	research, post air-sealing	n/a	-	-	0.60	assumed	0.03	0.04	-	10243	0.68	1100
37	-	MURB	mixed (families, singles and elederly)	Halifax, NS, Canada	-	-	5	-	84540	-	-	-	Designed to meet CBIP requirements (35% below MNECB)	1	whole building	-	yes	-	-	-	-	-	-	n/a	-	-	0.60	assumed	-	0.53	-	-	-	-
38	-	MURB	-	Montreal, QC, Canada	1969		3	-	3821	4822	yes	31465	Only 3 units	1	whole building	Unique (used multiple unblanced test + algebra to determine whole building values)	yes	-	Used an unblanced test of each suite plus algebra to deduce the whole building air leakage	4822	31465	single	demonstration of testing technique	n/a	-	-	0.60	assumed	1.16	1.75	-	8434	16.08	906
39	PIE & BCRA USACE Test	EN TEMF	Military	Ft. Carson, CO, USA	-	-	1	-	8580	27500	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	27500	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	3244	-	348
40	PIE & BCRA USACE Test	CHSF	Military	Corpus Christi, TX, U	-	-	1	-	96600	227867	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	227867	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	16127	-	1733
41	PIE & BCRA USACE Test	HQ TEMF	Military	Ft. Carson, CO, USA	-	-	1	-	8580	27500	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	27500	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	2855	-	307
42	PIE & BCRA USACE Test	BCT 3 COF	Military	Ft. Bliss, TX, USA	-	-	2	-	15085	24632	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2009	-	24632	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	1511	-	162
43	PIE & BCRA USACE Test	BCT 3 UEPH 1	Military	Ft. Bliss, TX, USA	-	-	2	-	29538	72573	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	72573	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.09	-	3253	-	349
44	PIE & BCRA USACE Test	BCT 3 TEMF 1	Military	Ft. Bliss, TX, USA	-	-	1	-	6934	24363	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	24363	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	2529	-	272
45	PIE & BCRA USACE Test	BCT 3 UEPH 3	Military	Ft. Bliss, TX, USA	-	-	2	-	25186	72573	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	72573	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	5136	-	552
46	PIE & BCRA USACE Test	BRAC METC Dorm 1	Military	Ft. Sam Houston, TX,	-	-	4	-	329191	371099	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2009	-	371099	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	11731	-	1260
47	PIE & BCRA USACE Test	COF	Military	Ft. Riley, KS, USA	-	-	1	-	13581	43115	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2009	-	43115	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	2848	-	306
48	PIE & BCRA USACE Test	SOF Barracks	Military	Ft. Bragg, NC, USA	-	-	3	-	26650	39514	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	39514	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.18	0.48	-	8949	-	961
49	PIE & BCRA USACE Test	Brigade Combat Complex 1	Military	Ft. Lewis, WA, USA	-	-	1	-	24682	52308	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	52308	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	4936	-	530
50	PIE & BCRA USACE Test	Brigade Combat Complex 2	Military	Ft. Lewis, WA, USA	-	-	1	-	24682	52308	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	52308	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	5923	-	636
51	PIE & BCRA USACE Test	Brigade Combat Complex 3	Military	Ft. Lewis, WA, USA	-	-	1	-	52305	86420	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	86420	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	9378	-	1008
52	PIE & BCRA USACE Test	Brigade Combat Complex 4	Military	Ft. Lewis, WA, USA	-	-	1	-	52305	86420	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	86420	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	8563	-	920
53	PIE & BCRA USACE Test	Brigade Combat Complex 5	Military	Ft. Lewis, WA, USA	-	-	1	-	18940	36450	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	36450	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	3440	-	370
54	PIE & BCRA USACE Test	Brigade Combat Complex 6	Military	Ft. Lewis, WA, USA	-	-	1	-	32800	56830	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	56830	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	6435	-	691
55	PIE & BCRA USACE Test	BCOF 1	Military	Ft. Leonard Wood, M	-	-	3	-	72000	84309	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	84309	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	6763	-	727
56	PIE & BCRA USACE Test	BCOF 4	Military	Ft. Leonard Wood, M	-	-	3	-	72000	84309	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	84309	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	6763	-	727
57	PIE & BCRA USACE Test	BCOF 2	Military	Ft. Leonard Wood, M	-	-	3	-	72000	84309	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	84309	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	8354	-	897
58	PIE & BCRA USACE Test	BCOF 3	Military	Ft. Leonard Wood, M	-	-	3	-	72000	84309	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	84309	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	7956	-	855
59	PIE & BCRA USACE Test	Battalion HQ	Military	Ft. Leonard Wood, M	-	-	1	-	22172	63276	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	63276	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	4180	-	449
60	PIE & BCRA USACE Test	Ft. Bragg TUEPH	Military	Ft. Bragg, NC, USA	-	-	5	-	225461	207744	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2010	-	207744	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	16663	-	1790
61	PIE & BCRA USACE Test	Fires Brigade TEMF	Military	Ft. Bliss, TX, USA	-	-	1	-	7711	21307	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	21307	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	1910	-	205
62	PIE & BCRA USACE Test	47th BCT TEMF 1	Military	Ft. Carson, CO, USA	-	-	1	-	8580	28104	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2010	-	28104	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	2122	-	228

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
63	PIE & BCRA USACE Test	UOF TEMF	Military	White Sands MR, NM	-	-	1	-	7008	25924	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	25924	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	2324	-	250
64	PIE & BCRA USACE Test	Ft. Lewis Medical Dental	Military	Ft. Lewis, WA, USA	-	-	1	-	51815	119174	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	119174	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	11808	-	1269
65	PIE & BCRA USACE Test	47th BCT TEMF 2	Military	Ft. Carson, CO, USA	-	-	1	-	8580	25190	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	25190	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	1783	-	192
66	PIE & BCRA USACE Test	School Age Services Center	Military	Ft. Wainwright, AK, U	-	-	1	-	23000	58914	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	58914	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	2780	-	299
67	PIE & BCRA USACE Test	CDC	Military	Ft. Carson, CO, USA	-	-	1	-	19519	55411	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	55411	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	3922	-	421
68	PIE & BCRA USACE Test	47th BCT TEMF 3	Military	Ft. Carson, CO, USA	-	-	1	-	8580	28104	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	28104	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	1989	-	214
69	PIE & BCRA USACE Test	47th BCT TEMF 4	Military	Ft. Carson, CO, USA	-	-	1	-	8580	25190	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	25190	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	2021	-	217
70	PIE & BCRA USACE Test	192nd EOD COF	Military	Ft. Bragg, NC, USA	-	-	2	-	15108	29172	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	29172	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	3028	-	325
71	PIE & BCRA USACE Test	Barracks	Military	Ft. Benning, GA, USA	-	-	4	-	96570	110019	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	110019	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	11939	-	1283
72	PIE & BCRA USACE Test	IBCT 1 UEPH 2	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.02	0.06	-	2052	-	221
73	PIE & BCRA USACE Test	IBCT 1 UEPH 1	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.02	0.05	-	1581	-	170
74	PIE & BCRA USACE Test	MP COF 1	Military	Ft. Leavenworth, KS,	-	-	2	-	47197	44421	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	44421	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	2934	-	315
75	PIE & BCRA USACE Test	MP COF 2	Military	Ft. Leavenworth, KS,	-	-	2	-	47197	44421	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	44421	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	2725	-	293
76	PIE & BCRA USACE Test	Physical Fitness Center	Military	Ft. Bliss, TX, USA	-	-	2	-	119496	157326	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	157326	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	13362	-	1435
77	PIE & BCRA USACE Test	METC 3 Facility	Military	Ft. Sam Houston, TX,	-	-	4	-	170280	141893	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	141893	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	6695	-	719
78	PIE & BCRA USACE Test	Barracks (Renovation)	Military	Ft. Polk, LA, USA	-	-	3	-	34365	52476	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	52476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	2476	-	266
79	PIE & BCRA USACE Test	47th BCT TEMF 5	Military	Ft. Carson, CO, USA	-	-	1	-	5842	12855	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	12855	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	1334	-	143
80	PIE & BCRA USACE Test	47th BCT TEMF 6	Military	Ft. Carson, CO, USA	-	-	1	-	5842	12855	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	12855	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	1334	-	143
81	PIE & BCRA USACE Test	UMF TEMF	Military	Ft. Carson, CO, USA	-	-	1	-	3701	12855	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	12855	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	970	-	104
82	PIE & BCRA USACE Test	IBCT 1 UEPH 7	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
83	PIE & BCRA USACE Test	IBCT 1 UEPH 8	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	2692	-	289
84	PIE & BCRA USACE Test	Indoor Firing Range	Military	Ft. Lewis, WA, USA	-	-	1	-	4280	10169	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	10169	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	1152	-	124
85	PIE & BCRA USACE Test	COF 1	Military	Ft. Carson, CO, USA	-	-	1	-	14469	44980	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	44980	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.12	-	2547	-	274
86	PIE & BCRA USACE Test	47th COF #1	Military	Ft. Carson, CO, USA	-	-	1	-	14980	44980	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	44980	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	2759	-	296
87	PIE & BCRA USACE Test	IBCT 1 TEMF 2	Military	Ft. Bliss, TX, USA	-	-	1	-	6272	15927	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	15927	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	1503	-	161
88	PIE & BCRA USACE Test	BRAC METC Dorm 2	Military	Ft. Sam Houston, TX,	-	-	4	-	329191	371099	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	371099	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	11731	-	1260
89	PIE & BCRA USACE Test	IBCT 1 UEPH 13	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
90	PIE & BCRA USACE Test	IBCT 1 TEMF 3	Military	Ft. Bliss, TX, USA	-	-	1	-	6272	15927	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	15927	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	1653	-	178
91	PIE & BCRA USACE Test	IBCT 1 UEPH 14	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	2692	-	289
92	PIE & BCRA USACE Test	MP BNHQ 1	Military	Ft. Leavenworth, KS,	-	-	2	-	16145	29835	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	29835	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	1408	-	151
93	PIE & BCRA USACE Test	MP BNHQ 2	Military	Ft. Leavenworth, KS,	-	-	2	-	16145	29835	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	29835	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	1548	-	166
94	PIE & BCRA USACE Test	MP BNHQ 3	Military	Ft. Leavenworth, KS,	-	-	2	-	16145	29835	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	29835	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	1126	-	121
95	PIE & BCRA USACE Test	UEPH	Military	Ft. Hood, TX, USA	-	-	4	-	199808	207977	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	207977	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	10794	-	1160
96	PIE & BCRA USACE Test	IBCT 1 UEPH 22	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.09	-	3028	-	325
97	PIE & BCRA USACE Test	BCT3 UEPH 20635	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	72537	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	72537	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	3765	-	404
98	PIE & BCRA USACE Test	IBCT 1 UEPH 23	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	3365	-	361
99	PIE & BCRA USACE Test	BCT3 TEMF 20507	Military	Ft. Bliss, TX, USA	-	-	1	-	6934	24363	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	24363	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	1494	-	161
100	PIE & BCRA USACE Test	COF 3	Military	Ft. Carson, CO, USA	-	-	1	-	13626	47764	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	47764	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	2479	-	266

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
101	PIE & BCRA USACE Test	COF 2	Military	Ft. Carson, CO, USA	-	-	1	-	14593	44596	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	44596	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	2315	-	249
102	PIE & BCRA USACE Test	BCT3 COF 20505	Military	Ft. Bliss, TX, USA	-	-	2	-	15085	24632	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	24632	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	1278	-	137
103	PIE & BCRA USACE Test	Barracks Renovation, Bldg. 1150	Military	Ft. Polk, LA, USA	-	-	3	-	34365	52476	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	52476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.09	-	2228	-	239
104	PIE & BCRA USACE Test	Barracks Renovation, Bldg. 1154	Military	Ft. Polk, LA, USA	-	-	3	-	34365	52476	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	52476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	3219	-	346
105	PIE & BCRA USACE Test	Barracks Renovation, Bldg. 1156	Military	Ft. Polk, LA, USA	-	-	3	-	34365	52476	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	52476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	2476	-	266
106	PIE & BCRA USACE Test	ARC - Training Bldg	Military	Saginaw, MI, USA	-	-	1	-	30276	73588	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	73588	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	4514	-	485
107	PIE & BCRA USACE Test	IBCT 1 UEPH 28	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
108	PIE & BCRA USACE Test	IBCT 1 UEPH 29	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	2692	-	289
109	PIE & BCRA USACE Test	IBCT 1 UEPH 34	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	2692	-	289
110	PIE & BCRA USACE Test	IBCT 1 UEPH 35	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
111	PIE & BCRA USACE Test	IBCT 2 TEMF 6	Military	Ft. Bliss, TX, USA	-	-	1	-	6272	15927	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	15927	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	1653	-	178
112	PIE & BCRA USACE Test	Training Building	Military	AFRC McAlester, OK,	-	-	2	-	67032	91140	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	91140	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	4300	-	462
113	PIE & BCRA USACE Test	COF 4	Military	Ft. Carson, CO, USA	-	-	1	-	14593	43205	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	43205	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	2039	-	219
114	PIE & BCRA USACE Test	COF 5	Military	Ft. Carson, CO, USA	-	-	1	-	14593	43112	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	43112	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	2034	-	219
115	PIE & BCRA USACE Test	ARC - Training Bldg	Military	Butte, MT, USA	-	-	1	-	17548	50828	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	50828	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	2398	-	258
116	PIE & BCRA USACE Test	Fires Brigade COF 1 Admin	Military	Ft. Bliss, TX, USA	-	-	2	-	16940	25850	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	25850	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	2561	-	275
117	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 1	Military	Ft. Bliss, TX, USA	-	-	1	-	312	1860	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1860	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	211	-	23
118	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 2	Military	Ft. Bliss, TX, USA	-	-	1	-	320	1692	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1692	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	176	-	19
119	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 3	Military	Ft. Bliss, TX, USA	-	-	1	-	312	1860	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1860	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	167	-	18
120	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 4	Military	Ft. Bliss, TX, USA	-	-	1	-	320	1692	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1692	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	192	-	21
121	PIE & BCRA USACE Test	Fires Brigade COF 2 Admin	Military	Ft. Bliss, TX, USA	-	-	2	-	16940	25850	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	25850	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	2927	-	314
122	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 1	Military	Ft. Bliss, TX, USA	-	-	1	-	312	1860	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1860	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	211	-	23
123	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 2	Military	Ft. Bliss, TX, USA	-	-	1	-	633	2979	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	2979	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	337	-	36
124	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 3	Military	Ft. Bliss, TX, USA	-	-	1	-	320	1692	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1692	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	192	-	21
125	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 4	Military	Ft. Bliss, TX, USA	-	-	1	-	312	1860	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1860	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	193	-	21
126	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 5	Military	Ft. Bliss, TX, USA	-	-	1	-	633	2979	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	2979	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	337	-	36
127	PIE & BCRA USACE Test	Fires Brigade COF 1 Mezz Offices 6	Military	Ft. Bliss, TX, USA	-	-	1	-	320	1692	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	1692	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	192	-	21
128	PIE & BCRA USACE Test	AFRC - Training Bldg	Military	Yakima, WA, USA	-	-	1	-	40254	96611	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	96611	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	10940	-	1175
129	PIE & BCRA USACE Test	IBCT 2 UEPH 40	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	2692	-	289
130	PIE & BCRA USACE Test	IBCT 2 UEPH 41	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
131	PIE & BCRA USACE Test	Barracks Renovation, Bldg. 1346	Military	Ft. Polk, LA, USA	-	-	3	-	34365	52476	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	52476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	3219	-	346
132	PIE & BCRA USACE Test	IBCT 2 UEPH 46	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
133	PIE & BCRA USACE Test	IBCT 2 UEPH 47	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	2692	-	289
134	PIE & BCRA USACE Test	Barracks Renovation, Bldg. 1348	Military	Ft. Polk, LA, USA	-	-	3	-	45820	70715	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	70715	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	5005	-	538
135	PIE & BCRA USACE Test	IBCT 2 UEPH 52	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
136	PIE & BCRA USACE Test	IBCT 2 TEMF 8	Military	Ft. Bliss, TX, USA	-	-	1	-	6272	15927	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	15927	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	1428	-	153
137	PIE & BCRA USACE Test	IBCT 2 UEPH 53	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
138	PIE & BCRA USACE Test	METC 4 Facility	Military	Ft. Sam Houston, TX,	-	-	4	-	170280	181073	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	181073	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	5980	-	643

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
139	PIE & BCRA USACE Test	IBCT 2 UEPH 61	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
140	PIE & BCRA USACE Test	IBCT 2 UEPH 62	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
141	PIE & BCRA USACE Test	CCF	Military	Whiteman AFB, MO,	-	-	1	-	16635	52513	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	52513	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	3469	-	373
142	PIE & BCRA USACE Test	Admin Bldg 270	Military	Detroit Arsenal, MI, U	-	-	8	-	312720	144662	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	144662	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	10921	-	1173
143	PIE & BCRA USACE Test	Firing Range Control Tower	Military	Ft. Dix, NJ, USA	-	-	1	-	180	1122	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	1122	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	122	-	13
144	PIE & BCRA USACE Test	Firing Range Classroom	Military	Ft. Dix, NJ, USA	-	-	1	-	620	2680	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	2680	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	303	-	33
145	PIE & BCRA USACE Test	Firing Range Training/Storage	Military	Ft. Dix, NJ, USA	-	-	1	-	320	2680	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	2680	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	303	-	33
146	PIE & BCRA USACE Test	IBCT 2 UEPH 67	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.02	0.05	-	1682	-	181
147	PIE & BCRA USACE Test	IBCT 2 TEMF 9	Military	Ft. Bliss, TX, USA	-	-	2	-	6272	15927	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	15927	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	1503	-	161
148	PIE & BCRA USACE Test	IBCT 2 UEPH 68	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.02	0.05	-	1682	-	181
149	PIE & BCRA USACE Test	CDC - Megen	Military	Ft. Bliss, TX, USA	-	-	1	-	23936	70226	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	70226	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	5633	-	605
150	PIE & BCRA USACE Test	BRAC METC Dorm 3	Military	Ft. Sam Houston, TX,	-	-	4	-	329191	310461	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	310461	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.08	-	11719	-	1259
151	PIE & BCRA USACE Test	Dining Facility	Military	Ft. Carson, CO, USA	-	-	1	-	25900	64227	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	64227	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	3333	-	358
152	PIE & BCRA USACE Test	IBCT 2 UEPH 73	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
153	PIE & BCRA USACE Test	IBCT 2 UEPH 74	Military	Ft. Bliss, TX, USA	-	-	2	-	43355	71312	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	71312	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.07	-	2355	-	253
154	PIE & BCRA USACE Test	COF	Military	Ft. Drum, NY, USA	-	-	2	-	8412	24171	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	24171	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	2623	-	282
155	PIE & BCRA USACE Test	BSTB COF	Military	Ft. Stewart, GA, USA	-	-	1	-	15073	42158	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	42158	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	4774	-	513
156	PIE & BCRA USACE Test	HQ (Large)	Military	Ft. Leonard Wood, M	-	-	2	-	17749	31797	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	31797	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	1500	-	161
157	PIE & BCRA USACE Test	HQ (Medium)	Military	Ft. Leonard Wood, M	-	-	2	-	16183	30169	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	30169	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.11	-	1566	-	168
158	PIE & BCRA USACE Test	RSTA COF	Military	Ft. Stewart, GA, USA	-	-	1	-	15090	42075	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	42075	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	4963	-	533
159	PIE & BCRA USACE Test	TEMF 12	Military	Ft. Bliss, TX, USA	-	-	2	-	6272	15927	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	15927	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	1503	-	161
160	PIE & BCRA USACE Test	TEMF	Military	Ft. Drum, NY, USA	-	-	2	-	35290	28188	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	28188	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	2527	-	271
161	PIE & BCRA USACE Test	Phase A COF	Military	Ft. Campbell, KY, USA	-	-	2	-	36918	82347	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	82347	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	9713	-	1044
162	PIE & BCRA USACE Test	BBHQ	Military	Ft. Carson, CO, USA	-	-	4	-	139918	172572	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	172572	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.02	0.04	-	3257	-	350
163	PIE & BCRA USACE Test	BSTB TEMF	Military	Ft. Stewart, GA, USA	-	-	1	-	8064	26466	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	26466	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	2997	-	322
164	PIE & BCRA USACE Test	RSTA TEMF	Military	Ft. Stewart, GA, USA	-	-	1	-	8064	26466	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	26466	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	2997	-	322
165	PIE & BCRA USACE Test	FA COF	Military	Ft. Stewart, GA, USA	-	-	1	-	15082	42218	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	42218	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	4582	-	492
166	PIE & BCRA USACE Test	BSB COF	Military	Ft. Stewart, GA, USA	-	-	1	-	8064	26466	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	26466	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	3122	-	335
167	PIE & BCRA USACE Test	Weapons Repair Shop	Military	Ft. Benning, GA, USA	-	-	1	-	22868	64326	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	64326	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	4249	-	456
168	PIE & BCRA USACE Test	DFAC Test 1	Military	Ft. Sill, OK, USA	-	-	1	-	27960	71247	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	71247	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.34	0.90	-	30255	-	3250
169	PIE & BCRA USACE Test	MEB COF	Military	Ft. Leonard Wood, M	-	-	2	-	15585	26490	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	26490	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	2375	-	255
170	PIE & BCRA USACE Test	FIFTH IBCT Barracks 1	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	3542	-	381
171	PIE & BCRA USACE Test	FIFTH IBCT Barracks 2	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	3729	-	401
172	PIE & BCRA USACE Test	FIFTH IBCT Barracks 3	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	4102	-	441
173	PIE & BCRA USACE Test	FIFTH IBCT Barracks 4	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	3729	-	401
174	PIE & BCRA USACE Test	FA TEMF	Military	Ft. Stewart, GA, USA	-	-	1	-	3356	12686	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	12686	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	1496	-	161
175	PIE & BCRA USACE Test	MA1 TEMF	Military	Ft. Stewart, GA, USA	-	-	1	-	3356	12686	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	12686	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	1317	-	141
176	PIE & BCRA USACE Test	MA2 TEMF	Military	Ft. Stewart, GA, USA	-	-	1	-	3356	12686	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	12686	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	1377	-	148

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
177	PIE & BCRA USACE Test	BSB TEMF	Military	Ft. Stewart, GA, USA	-	-	1	-	8064	26466	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	26466	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	3122	-	335
178	PIE & BCRA USACE Test	MA1 COF	Military	Ft. Stewart, GA, USA	-	-	1	-	15767	45499	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	45499	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	5152	-	554
179	PIE & BCRA USACE Test	MA2 COF	Military	Ft. Stewart, GA, USA	-	-	1	-	15767	45499	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	45499	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	5367	-	577
180	PIE & BCRA USACE Test	General Instruction Building	Military	Ft. Benning, GA, USA	-	-	2	-	110653	168674	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	168674	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	11938	-	1283
181	PIE & BCRA USACE Test	WBR 222 Barracks 1	Military	Ft. Bragg, NC, USA	-	-	4	-	101072	93625	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	93625	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	8393	-	902
182	PIE & BCRA USACE Test	WBR 222 Barracks 2	Military	Ft. Bragg, NC, USA	-	-	4	-	101072	93625	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	93625	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	8393	-	902
183	PIE & BCRA USACE Test	WBR 288 Barracks	Military	Ft. Bragg, NC, USA	-	-	6	-	149108	118174	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	118174	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.12	-	6691	-	719
184	PIE & BCRA USACE Test	WBR COF 1	Military	Ft. Bragg, NC, USA	-	-	1	-	10988	40935	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	40935	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.12	-	2318	-	249
185	PIE & BCRA USACE Test	WBR COF 1 Mezz Offices 1	Military	Ft. Bragg, NC, USA	-	-	1	-	960	2902	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	2902	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	301	-	32
186	PIE & BCRA USACE Test	WBR COF 1 Mezz Offices 2	Military	Ft. Bragg, NC, USA	-	-	1	-	960	2902	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	2902	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	301	-	32
187	PIE & BCRA USACE Test	WBR COF 2	Military	Ft. Bragg, NC, USA	-	-	1	-	10206	39025	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39025	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	2394	-	257
188	PIE & BCRA USACE Test	FIFTH IBCT Barracks 5	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	3915	-	421
189	PIE & BCRA USACE Test	FIFTH IBCT Barracks 6	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	3542	-	381
190	PIE & BCRA USACE Test	FIFTH IBCT Barracks 7	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	4475	-	481
191	PIE & BCRA USACE Test	FIFTH IBCT Barracks 8	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	3729	-	401
192	PIE & BCRA USACE Test	FIFTH IBCT Barracks 9	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	3169	-	341
193	PIE & BCRA USACE Test	FIFTH IBCT Barracks 10	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	3169	-	341
194	PIE & BCRA USACE Test	FIFTH IBCT Barracks 11	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	3356	-	361
195	PIE & BCRA USACE Test	FIFTH IBCT Barracks 12	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	3729	-	401
196	PIE & BCRA USACE Test	CDC	Military	Ft. Bliss, TX, USA	-	-	1	-	23282	70226	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	70226	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	4308	-	463
197	PIE & BCRA USACE Test	BCOF Barracks 1	Military	Ft. Leonard Wood, M	-	-	3	-	62380	74476	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	74476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	8434	-	906
198	PIE & BCRA USACE Test	BCOF Barracks 4	Military	Ft. Leonard Wood, M	-	-	3	-	62380	74476	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	74476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	7028	-	755
199	PIE & BCRA USACE Test	ECS Warehouse	Military	Ft. Benning, GA, USA	-	-	1	-	7106	17377	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	17377	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	1312	-	141
200	PIE & BCRA USACE Test	CDC Arviso	Military	Ft. Carson, CO, USA	-	-	1	-	26372	67340	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	67340	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	4130	-	444
201	PIE & BCRA USACE Test	ECS TEMF	Military	Ft. Benning, GA, USA	-	-	1	-	4344	17127	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	17127	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.15	0.39	-	3152	-	339
202	PIE & BCRA USACE Test	MI COF	Military	Ft. Carson, CO, USA	-	-	1	-	13589	41844	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	41844	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	2764	-	297
203	PIE & BCRA USACE Test	AFRC Training Center	Military	Fargo, ND, USA	-	-	1	-	24091	62618	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	62618	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	4432	-	476
204	PIE & BCRA USACE Test	Barracks Renovation, Bldg. 293	Military	Ft. Polk, LA, USA	-	-	3	-	19383	25227	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	25227	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	2023	-	217
205	PIE & BCRA USACE Test	FIFTH IBCT Barracks 13	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	3169	-	341
206	PIE & BCRA USACE Test	FIFTH IBCT Barracks 14	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	3729	-	401
207	PIE & BCRA USACE Test	FIFTH IBCT Barracks 15	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	3169	-	341
208	PIE & BCRA USACE Test	FIFTH IBCT Barracks 16	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	3169	-	341
209	PIE & BCRA USACE Test	AFRC Training Center	Military	Amarillo, TX, USA	-	-	1	-	32694	85124	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	85124	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	10041	-	1079
210	PIE & BCRA USACE Test	AFRC Training Center	Military	Vancouver, WA, USA	-	-	1	-	44611	138908	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	138908	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	9831	-	1056
211	PIE & BCRA USACE Test	DFAC Test 2	Military	Ft. Sill, OK, USA	-	-	1	-	27960	71247	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	71247	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.25	0.66	-	22187	-	2384
212	PIE & BCRA USACE Test	UASTB COF	Military	Ft. Huachuca, AZ, USA	-	-	1	-	4045	15292	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	15292	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	1804	-	194
213	PIE & BCRA USACE Test	UASTB TEMF	Military	Ft. Huachuca, AZ, USA	-	-	1	-	3093	12784	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	12784	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	1508	-	162
214	PIE & BCRA USACE Test	FIFTH IBCT Barracks 17	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	3356	-	361

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
215	PIE & BCRA USACE Test	FIFTH IBCT Barracks 18	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	2983	-	320
216	PIE & BCRA USACE Test	FIFTH IBCT Barracks 19	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	3356	-	361
217	PIE & BCRA USACE Test	FIFTH IBCT Barracks 20	Military	Ft. Stewart, GA, USA	-	-	3	-	26650	39514	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	39514	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	3915	-	421
218	PIE & BCRA USACE Test	5-5 ADA COF	Military	Ft. Lewis, WA, USA	-	-	1	-	15130	51352	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	51352	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.02	0.06	-	1454	-	156
219	PIE & BCRA USACE Test	5-5 ADA COF Mezzanine Offices 1	Military	Ft. Lewis, WA, USA	-	-	1	-	150	4887	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	4887	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	484	-	52
220	PIE & BCRA USACE Test	5-5 ADA COF Mezzanine Offices 2	Military	Ft. Lewis, WA, USA	-	-	1	-	150	4887	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	4887	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	438	-	47
221	PIE & BCRA USACE Test	Reception Station Phase III Barracks	Military	Ft. Benning, GA, USA	-	-	3	-	124923	122724	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	122724	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	10423	-	1120
222	PIE & BCRA USACE Test	Reception Station Phase II Barracks	Military	Ft. Benning, GA, USA	-	-	3	-	179631	164106	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	164106	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	18970	-	2038
223	PIE & BCRA USACE Test	WT Barracks	Military	Ft. Carson, CO, USA	-	-	4	-	99776	104923	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	104923	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	6931	-	745
224	PIE & BCRA USACE Test	Barracks Renovation, Bldg, 2386	Military	Ft. Polk, LA, USA	-	-	3	-	34605	52476	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	52476	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	5695	-	612
225	PIE & BCRA USACE Test	Brigade Complex HQ	Military	Ft. Lewis, WA, USA	-	-	2	-	54415	75760	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	75760	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.02	0.05	-	1787	-	192
226	PIE & BCRA USACE Test	OMS	Military	Willow Grove ARC, P	-	-	2	-	13862	25844	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	25844	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	2927	-	314
227	PIE & BCRA USACE Test	OMS High Bay	Military	Willow Grove ARC, P	-	-	1	-	10338	20449	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	20449	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.26	0.69	-	6657	-	715
228	PIE & BCRA USACE Test	Training Building	Military	Willow Grove ARC, P	-	-	1	-	73080	107053	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	107053	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	9597	-	1031
229	PIE & BCRA USACE Test	Medical Examiner's Facility Rnovation	Military	Dover AFB, DE, USA	-	-	2	-	152684	179349	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	179349	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	16078	-	1727
230	PIE & BCRA USACE Test	Medical Examiner's Facility New	Military	Dover AFB, DE, USA	-	-	2	-	32560	64254	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	64254	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.19	-	5760	-	619
231	PIE & BCRA USACE Test	DFAC Test 3	Military	Ft. Sill, OK, USA	-	-	1	-	27960	71247	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	71247	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.19	0.51	-	17144	-	1842
232	SEM USACE Test	WIT Barracks Building A	Military	Ft. Belvoir, VA, USA	-	-	4	-	98296	99595	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	99595	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	10130	-	1088
233	SEM USACE Test	WIT Barracks Building B	Military	Ft. Belvoir, VA, USA	-	-	4	-	98296	99595	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	99595	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	11357	-	1220
234	SEM USACE Test	AIT Barracks #1	Military	Ft. Lee, VA, USA	-	-	5	-	180000	178962	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	178962	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	13186	-	1417
235	SEM USACE Test	AIT Barracks #2	Military	Ft. Lee, VA, USA	-	-	5	-	180000	178962	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	178962	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	8529	-	916
236	SEM USACE Test	UEPH Barracks	Military	Ft. Eustis, VA, USA	-	-	3	-	140010	169260	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	169260	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.04	0.10	-	8294	-	891
237	SEM USACE Test	Air Force/Navy Barracks	Military	Ft. Lee, VA, USA	-	-	5	-	181498	151952	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	151952	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	11005	-	1182
238	SEM USACE Test	AIT 1 Barracks-1	Military	Ft. Lee, VA, USA	-	-	5	-	173929	170401	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	170401	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.26	-	20793	-	2234
239	SEM USACE Test	AIT 1 Barracks-2	Military	Ft. Lee, VA, USA	-	-	5	-	173929	170401	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	170401	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	17570	-	1888
240	SEM USACE Test	AIT 1 Barracks-3	Military	Ft. Lee, VA, USA	-	-	5	-	173929	170401	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	170401	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	16774	-	1802
241	SEM USACE Test	AIT 2 Barracks-4	Military	Ft. Lee, VA, USA	-	-	5	-	193103	164768	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	164768	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	12393	-	1331
242	SEM USACE Test	AIT 2 Barracks-5	Military	Ft. Lee, VA, USA	-	-	5	-	193103	164768	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	164768	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	16146	-	1735
243	SEM USACE Test	AIT 2 Barracks-6	Military	Ft. Lee, VA, USA	-	-	5	-	193103	164768	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	164768	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.17	-	13569	-	1458
244	SEM USACE Test	POL Barracks	Military	Ft. Lee, VA, USA	-	-	3	-	27000	31305	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	31305	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	2519	-	271
245	SEM USACE Test	CDC 1	Military	Ft. Campbell, KY, USA	-	-	1	-	23508	55144	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2010	-	55144	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	3634	-	390
246	SEM USACE Test	CDC 2	Military	Ft. Campbell, KY, USA	-	-	1	-	22947	60293	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	60293	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.20	-	5598	-	601
247	SEM USACE Test	CDC 3	Military	Ft. Campbell, KY, USA	-	-	1	-	22947	60293	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2010	-	60293	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	7108	-	764
248	SEM USACE Test	CDC 1	Military	Ft. Bragg, NC, USA	-	-	1	-	23034	57418	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	57418	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.25	-	6764	-	727
249	SEM USACE Test	CDC 2	Military	Ft. Bragg, NC, USA	-	-	1	-	22947	60099	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	60099	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	6279	-	675
250	SEM USACE Test	CDC Expansion	Military	Columbus DSCC, OH,	-	-	1	-	13300	30360	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2010	-	30360	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	2275	-	244
251	SEM USACE Test	CDC 1	Military	Ft. Sill, OK, USA	-	-	1	-	25789	58805	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2010	-	58805	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	5118	-	550
252	SEM USACE Test	CDC	Military	Ft. Eustis, VA, USA	-	-	1	-	26123	63898	unknown	-	Air Barrier Consultan	3	whole building	USACE	yes	2011	-	63898	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	5406	-	581

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
253	SEM USACE Test	CDC	Military	Ft. Lee, VA, USA	-	-	1	-	20041	51412	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	51412	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	5225	-	561
254	SEM USACE Test	WIT COF	Military	Ft. Belvoir, VA, USA	-	-	2	-	21767	64586	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	64586	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	6861	-	737
255	SEM USACE Test	COF 09	Military	Ft. Eustis, VA, USA	-	-	2	-	14958	52258	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	52258	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	5465	-	587
256	SEM USACE Test	Company Operations Facility-Admin Building	Military	Ft. Eustis, VA, USA	-	-	2	-	16200	28165	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	28165	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.25	-	3281	-	352
257	SEM USACE Test	UEPH Barracks	Military	Ft. Myer, VA, USA	-	-	3	-	81117	91837	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	91837	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	10193	-	1095
258	SEM USACE Test	WIT BNHQ	Military	Ft. Campbell, KY, USA	-	-	1	-	7861	20342	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	20342	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.17	-	1616	-	174
259	SEM USACE Test	WIT Company HQ	Military	Ft. Campbell, KY, USA	-	-	3	-	9841	32683	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	32683	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	3771	-	405
260	SEM USACE Test	SOF Bat. HQ	Military	Ft. Bragg, NC, USA	-	-	2	-	59477	82095	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	82095	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	7823	-	840
261	SEM USACE Test	AIT 2 Battalion HQ	Military	Ft. Lee, VA, USA	-	-	1	-	12069	31866	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	31866	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	2030	-	218
262	SEM USACE Test	AIT BHQ	Military	Ft. Lee, VA, USA	-	-	1	-	12022	32684	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	32684	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	2837	-	305
263	SEM USACE Test	Basic Training Complex BNHQ	Military	Ft. Benning, GA, USA	-	-	1	-	22399	56999	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	56999	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	4789	-	515
264	SEM USACE Test	Company Operation Complex BHQ	Military	Ft. Eustis, VA, USA	-	-	2	-	13432	26600	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	26600	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.10	0.27	-	3433	-	369
265	SEM USACE Test	AIT 1 Battalion HQ	Military	Ft. Lee, VA, USA	-	-	1	-	13000	33791	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	33791	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.22	-	3572	-	384
266	SEM USACE Test	AIT 1, Brigade HQ	Military	Ft. Lee, VA, USA	-	-	1	-	9000	23945	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	23945	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	2590	-	278
267	SEM USACE Test	WIT SFAC	Military	Ft. Belvoir, VA, USA	-	-	1	-	13568	35020	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	35020	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.23	-	3869	-	416
268	SEM USACE Test	ATSC Building	Military	Ft. Eustis, VA, USA	-	-	2	-	56393	79979	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	79979	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.21	-	8095	-	870
269	SEM USACE Test	AFTMS Academic Building	Military	Ft. Lee, VA, USA	-	-	2	-	18285	54519	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	54519	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.18	0.47	-	12084	-	1298
270	SEM USACE Test	AFTMS Training Buildling	Military	Ft. Lee, VA, USA	-	-	1	-	3648	12973	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	12973	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.20	0.53	-	3244	-	348
271	SEM USACE Test	Central Campus II, Building C10	Military	Ft. Lee, VA, USA	-	-	4	-	16537	68296	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	68296	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	5002	-	537
272	SEM USACE Test	Central Campus II, Building C11	Military	Ft. Lee, VA, USA	-	-	2	-	34700	71802	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	71802	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.14	-	4808	-	517
273	SEM USACE Test	Central Campus II, Building C6	Military	Ft. Lee, VA, USA	-	-	3	-	41916	68652	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	68652	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.07	0.18	-	5877	-	631
274	SEM USACE Test	Central Campus II, Building C7	Military	Ft. Lee, VA, USA	-	-	4	-	49476	83907	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	83907	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	6496	-	698
275	SEM USACE Test	Central Campus II, Building C9	Military	Ft. Lee, VA, USA	-	-	4	-	55764	73839	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2011	-	73839	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.20	-	6867	-	738
276	SEM USACE Test	Culinary School Addition	Military	Ft. Lee, VA, USA	-	-	2	-	47815	77060	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	77060	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.16	-	5914	-	635
277	SEM USACE Test	SCoE Warrior Training	Military	Ft. Lee, VA, USA	-	-	2	-	16115	44246	unknown	-	Air Barrier Consultant	3	whole building	USACE	yes	2010	-	44246	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.06	0.15	-	3213	-	345
278	SEM USACE Test	New Soldier Community Center	Military	Ft. Benning, GA, USA	-	-	1	-	16834	44042	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	44042	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	5026	-	540
279	SEM USACE Test	Wilson Gym	Military	Ft. Benning, GA, USA	-	-	1	-	6731	23455	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	23455	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.08	0.22	-	2427	-	261
280	SEM USACE Test	Organizational Classroom and Storage Facilities	Military	Ft. Stewart, GA, USA	-	-	1	-	4793	14580	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2011	-	14580	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.09	0.24	-	1660	-	178
281	SEM USACE Test	AIT 1, North Range Facility	Military	Ft. Lee, VA, USA	-	-	1	-	33400	80397	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	80397	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.05	0.13	-	5016	-	539
282	SEM USACE Test	Liberty Chapel	Military	Ft. Lee, VA, USA	-	-	1	-	13300	46177	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2010	-	46177	-	-	-	No	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.49	1.29	-	28097	-	3019
283	SEM USACE Test	Soldier Support Center	Military	Ft. Lee, VA, USA	-	-	2	-	165177	165177	unknown	-	No Air Barrier Consul	3	whole building	USACE	yes	2009	-	165177	-	-	-	Yes	target of 0.25 cfm/ft^2 (1.27 L/s·m^2)	-	0.60	assumed	0.03	0.09	-	6717	-	722
284a	Average of tests on building	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Tests were carried out on a variety of suites and the values for normalization is the average of those suites and so are the values.	-	7183	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	2761	23.07	297
284b	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	3895	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	1351	20.81	145
284c	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	3895	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	1667	25.68	179
284d	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	6944	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	2167	18.72	233
284e	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	6944	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	3519	30.41	378

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft^2]	Enclosure Area [ft^2]	Below Grade?	Building Volume [ft^3]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft^2]	Volume for Test Result Normalization [ft^3]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Pa^n·m^2]	Air Permeablility [cfm/ft^2 @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft^2 @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in^2]
																								yes/no	comment									
284f	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	8449	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	2825	20.06	304
284g	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	8449	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	5196	36.90	558
284h	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	9443	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	2825	17.95	304
284i	One suite test	MURB	-	Charlotte, NC, USA	1960s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	9443	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	2541	16.14	273
285a	Average of tests on building	MURB	-	Granite Quarry, NC, USA	1980's	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Tests were carried out on a variety of suites and the values for normalization is the average of those suites and so are the values.	-	4704	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	1992	25.41	214
285b	One suite test	MURB	-	Granite Quarry, NC, USA	1980's	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	4704	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	1786	22.78	192
285c	One suite test	MURB	-	Granite Quarry, NC, USA	1980's	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	4704	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	2551	32.54	274
285d	One suite test	MURB	-	Granite Quarry, NC, USA	1980's	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	4704	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	1870	23.85	201
285e	One suite test	MURB	-	Granite Quarry, NC, USA	1980's	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	4704	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	1809	23.07	194
285f	One suite test	MURB	-	Granite Quarry, NC, USA	1980's	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2012	Individual suite test	-	4704	Single	Energy Assessment	-	-	-	0.60	assumed	-	-	-	1949	24.86	209
286a	Average of tests on building	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Tests were carried out on a variety of suites and the values for normalization is the average of those suites and so are the values.	-	14271	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	3872	16.28	416
286b	One suite test	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Individual suite test	-	13500	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	3380	15.02	363
286c	One suite test	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Individual suite test	-	18000	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	4847	16.16	521
286d	One suite test	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Individual suite test	-	18000	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	4209	14.03	452
286e	One suite test	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Individual suite test	-	10800	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	4018	22.32	432
286f	One suite test	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Individual suite test	-	10800	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	2551	14.17	274
286g	One suite test	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Individual suite test	-	13500	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	4081	18.14	438
286h	One suite test	MURB	-	Durham, NC, USA	1960's to 70s	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2011	Individual suite test	-	15300	multipoint	Energy Assessment	-	-	-	0.60	assumed	-	-	-	4018	15.76	432
287	-	MURB	-	Bellingham, WA, USA	2010	-	4	-	41359	52911	yes	427470	-	1	whole building	-	yes	2010	-	52911	427470	single	Identify air leaks	-	-	-	0.60	assumed	0.32	0.40	-	21164	2.97	2274
288	-	MURB	-	Seattle, WA, USA	2011	-	4	-	110822	121380	yes	1114163	-	1	whole building	-	yes	2011	-	121380	1114163	single	Research	no	target was 0.4 cfm/ft2 at 50 Pa	-	0.60	assumed	0.36	0.45	-	54621	2.94	5868
289	Suite 104 (Note data for Suite 305 not included since error in results)	MURB	-	Vancouver, BC, CANADA	-	-	4	-	-	-	-	-	-	4	Suite - 6 Sides	-	-	2009	took average of results since multiple points & both directions	-	-	multipoint	-	-	-	-	0.62	measured	-	-	-	1204	-	129
290a	For whole building based on cumulative total of the 5 suites	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	1	whole building	-	yes	-	one fan per suite, so all suites balanced	-	31093	single	research	-	-	-	0.60	Assumed	-	-	-	2005	3.87	215
290b	Balanced suite	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - Enclosure	CGSB	-	-	exterior enclosure of suites by balancing	-	5761	single	research	-	-	-	0.60	Assumed	-	-	-	367	3.83	39
290c	Balanced suite	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - Enclosure	CGSB	-	-	exterior enclosure of suites by balancing	-	5017	single	research	-	-	-	0.60	Assumed	-	-	-	213	2.55	23
290d	Balanced suite	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - Enclosure	CGSB	-	-	exterior enclosure of suites by balancing	-	5761	single	research	-	-	-	0.60	Assumed	-	-	-	306	3.19	33
290e	Balanced suite	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - Enclosure	CGSB	-	-	exterior enclosure of suites by balancing	-	5846	single	research	-	-	-	0.60	Assumed	-	-	-	547	5.61	59
290f	Balanced suite	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - Enclosure	CGSB	-	-	exterior enclosure of suites by balancing	-	5846	single	research	-	-	-	0.60	Assumed	-	-	-	572	5.87	61
290g	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doors to adjacent suites open	-	5761	single	research	-	-	-	0.60	Assumed	-	-	-	686	7.14	74
290h	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doors to adjacent suites open	-	5017	single	research	-	-	-	0.60	Assumed	-	-	-	619	7.40	66
290i	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doors to adjacent suites open	-	5761	single	research	-	-	-	0.60	Assumed	-	-	-	478	4.97	51
290j	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doors to adjacent suites open	-	5846	single	research	-	-	-	0.60	Assumed	-	-	-	683	7.01	73
290k	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doors to adjacent suites open	-	5846	single	research	-	-	-	0.60	Assumed	-	-	-	683	7.01	73
290l	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doorsto adjacent suites closed	-	5761	single	research	-	-	-	0.60	Assumed	-	-	-	600	6.25	64
290m	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doorsto adjacent suites closed	-	5017	single	research	-	-	-	0.60	Assumed	-	-	-	299	3.57	32
290n	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doorsto adjacent suites closed	-	5761	single	research	-	-	-	0.60	Assumed	-	-	-	490	5.10	53
290o	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doorsto adjacent suites closed	-	5846	single	research	-	-	-	0.60	Assumed	-	-	-	746	7.65	80
290p	All 6 sides of suite.	MURB	-	Golden, BC, Canada	-	-	2	-	-	-	-	-	-	4	Suite - 6 Sides	CGSB	-	-	exterior doorsto adjacent suites closed	-	5846	single	research	-	-	-	0.60	Assumed	-	-	-	621	6.38	67

Database Identifiers		Building Characteristics												Testing Characteristics								Original Testing information					Calculation Factors			Standardized Test Results at Standardized Test Pressure - 75 Pa				
Building ID	Notes	Building Type	Occupancy Classification	Location	Year of Construction	Year of Air Barrier Retrofit	Number of Stories	Height [ft]	Floor Area [ft²]	Enclosure Area [ft²]	Below Grade?	Building Volume [ft³]	Other Building Notes	Test Type Database Entry	Test of what?	Test Method	Test Includes Roof/Floor	Year Tested	Notes	Area for Test Result Normalization [ft²]	Volume for Test Result Normalization [ft³]	Single or Multi Point Test	Why Testing Performed?	Did Test Pass Project Requirement?		Comments on Comparison testing	Flow Exponent, n	How flow exponent determined?	Normalized Flow Coefficient, C [cfm/Paⁿ·m²]	Air Permeablility [cfm/ft² @ 75 Pa]	Air Permeablility Based on Alternate Enclosure Area [cfm/ft² @ 75 Pa]	Fan Flow Rate [cfm]	ACH [1/hour]	Equivalent Leakage Area at 75 Pa [in²]
																								yes/no	comment									
291a	Average of pressurized and depressurized test	Basic Training Complex II, Building 2	Military	Ft. Jackson, SC, USA	-	-	3	60	-	136820	-	-	-	3	whole building	USACE	yes	2010	average of pressurized and depressurized test	136820	-	multipoint	required USACE	yes	target of 0.25 cfm/ft² (1.27 L/s·m²)	-	0.60	measured	0.06	0.08	-	11036	-	1186
291b	Pressurized test	Basic Training Complex II, Building 2	Military	Ft. Jackson, SC, USA	-	-	3	60	-	136820	-	-	-	3	whole building	USACE	yes	2010	pressurized test	136820	-	multipoint	required USACE	yes	target of 0.25 cfm/ft² (1.27 L/s·m²)	-	0.62	measured	0.07	0.09	-	11901	-	1279
291c	Deperssurized test	Basic Training Complex II, Building 2	Military	Ft. Lewis, WA, USA	-	-	3	60	-	136820	-	-	-	3	whole building	USACE	yes	2010	depressurized test	136820	-	multipoint	required USACE	yes	target of 0.25 cfm/ft² (1.27 L/s·m²)	-	0.59	measured	0.06	0.07	-	10172	-	1093
292a	Average of pressurized and depressurized test	MURB	Mixed MURB and commerical space	Vancouver, BC, CANA	1996	-	6	-	-	5079	-	-	-	4	Suite - 6 Sides	USACE	-	-	average of pressurized and depressurized test	5079	-	multipoint	-	yes	target of 0.25 cfm/ft² (1.27 L/s·m²)	-	0.64	measured	0.17	0.25	-	1250	-	134
292b	Pressurized test	MURB	Mixed MURB and commerical space	Vancouver, BC, CANA	1996	-	6	-	-	5079	-	-	-	4	Suite - 6 Sides	USACE	-	-	pressurized test	5079	-	multipoint	-	yes	target of 0.25 cfm/ft² (1.27 L/s·m²)	-	0.64	measured	0.17	0.25	-	1250	-	134
292c	Deperssurized test	MURB	Mixed MURB and commerical space	Vancouver, BC, CANA	1996	-	6	-	-	5079	-	-	-	4	Suite - 6 Sides	USACE	-	-	depressurized test	5079	-	multipoint	-	yes	target of 0.25 cfm/ft² (1.27 L/s·m²)	-	0.65	measured	0.16	0.25	-	1250	-	134
293a	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Tests were carried out on a variety of suites and the values for normalization is the average of those suites and so are the values.	3866	11755	single	Energy Assessment	-	-	Average of tests on building	0.60	assumed	0.26	0.32	-	1228	6.27	48
293b	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	3872	13128	single	Energy Assessment	-	-	Unit 4417	0.60	assumed	0.24	0.29	-	1138	5.20	45
293c	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	3364	11214	single	Energy Assessment	-	-	Unit 4412	0.60	assumed	0.28	0.35	-	1172	6.27	46
293d	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	4278	15119	single	Energy Assessment	-	-	Unit 4404	0.60	assumed	0.22	0.27	-	1157	4.59	45
293e	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	4373	15869	single	Energy Assessment	-	-	Unit 4504	0.60	assumed	0.25	0.31	-	1369	5.17	54
293f	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	3443	3443	single	Energy Assessment	-	-	Unit 4512	0.60	assumed	0.31	0.38	-	1309	22.82	51
294a	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Tests were carried out on a variety of suites and the values for normalization is the average of those suites and so are the values.	4559	15113	single	Energy Assessment	-	-	Average of tests on building	0.60	assumed	0.27	0.34	-	1553	6.16	61
294b	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	4114	13633	single	Energy Assessment	-	-	Unit 3202	0.60	assumed	0.21	0.26	-	1072	4.72	42
294c	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	5471	17762	single	Energy Assessment	-	-	Unit 3204	0.60	assumed	0.32	0.39	-	2142	7.24	84
294d	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	2750	8179	single	Energy Assessment	-	-	Unit 3206	0.60	assumed	0.25	0.31	-	864	6.34	34
294e	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	5462	17690	single	Energy Assessment	-	-	Unit 3304	0.60	assumed	0.31	0.39	-	2108	7.15	83
294f	One suite test	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	4996	18299	single	Energy Assessment	-	-	Unit 3601	0.60	assumed	0.25	0.31	-	1571	5.15	62
295a	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Tests were carried out on a variety of suites and the values for normalization is the average of those suites and so are the values.	4392	14104	single	Energy Assessment	-	-	Average of tests on building	0.60	assumed	0.27	0.34	-	1472	6.26	58
295b	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	3156	9431	single	Energy Assessment	-	-	Unit 2201	0.60	assumed	0.31	0.38	-	1207	7.68	47
295c	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	4364	13479	single	Energy Assessment	-	-	Unit 2202	0.60	assumed	0.29	0.36	-	1559	6.94	61
295d	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	5173	17347	single	Energy Assessment	-	-	Unit 2204	0.60	assumed	0.25	0.31	-	1599	5.53	63
295e	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	5123	16874	single	Energy Assessment	-	-	Unit 2408	0.60	assumed	0.25	0.31	-	1606	5.71	63
295f	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	5123	16874	single	Energy Assessment	-	-	Unit 2504	0.60	assumed	0.25	0.31	-	1587	5.64	62
295g	Average of tests on building	MURB	-	Chapel Hill, NC, USA	2010	-	-	-	-	-	-	-	-	4	Suite - 6 Sides	LEED	-	2010	Individual suite test	3413	10620	single	Energy Assessment	-	-	Unit 2601	0.60	assumed	0.30	0.37	-	1266	7.15	50
296	Test performed by RDH as part of commissioning process. Comparative data also collected. Good new air-tight woodframe data	MURB	student housing w/ commercial ground floor	Seattle, WA, USA	2011	-	7	-	-	128000	yes	-	air barrier commissioning performed during construction	1	Whole building enclosure	USACE 2011	yes	2012	total enclosure area includes slab and below grade	128000	-	multipoint	Seattle - Code Requirement, USACE	yes	requirement <0.40 cfm/ft2 @75 Pa	-	0.58	measured	0.17	0.19	-	24192	-	2599

Appendix B

Industry Survey

MURB Air-Tightness Industry Survey

RDH Building Engineering Ltd. (RDH) is undertaking a research study into the Air Leakage Control of Multi-Unit Residential Buildings (MURBs) on behalf of Canada Mortgage and Housing Corporation (CMHC) and would like to get your feedback via an on-line survey to gauge the current level of work being performed in the control of air leakage within large buildings as part of this research study.

The intent of this survey is to determine which testing methods and current procedures, codes, and standards related to air-leakage testing for large buildings are being used by practitioners, which are most effective, and whether whole building air tightness testing is warranted for large buildings including MURBs. This survey is being distributed to building professionals in most jurisdictions throughout North America.

The results of this survey will be published later in 2012.

1. Please indicate your primary work location:

Country:

Province/State:

City:

2. Please indicate your qualifications:

☐ Engineer

☐ Architect

☐ Technologist

☐ Skilled Trade Contractor

☐ Energy Advisor or Energy Auditor

Other (please specify)

3. Please indicate your involvement in the construction of new buildings:

☐ Architecture

☐ Engineering - Mechanical/HVAC

☐ Engineering - Building Enclosure

☐ Engineering - Other

☐ Construction - GC or Sub trade

☐ Testing Agency

☐ Commissioning Agency

☐ Material or Product Supplier

☐ Owner/Developer

Other (please specify)

4. Please list the types of new buildings that you are typically involved with:

☐ Small Residential (Single Family, Duplex, Townhouses)
☐ Multi-unit Residential (low-rise up to 5 stories)
☐ Multi-unit Residential (high-rise greater than 5 stories)
☐ Commercial
☐ Institutional
☐ Industrial

Comments:

5. Please rank the following items in order of importance from 1-5 (1 is most important) as the reasons why you would address air-tightness in the buildings you work on:

	1	2	3	4	5
Energy (e.g. to reduce infiltration/exfiltration losses/gains)	○	○	○	○	○
Moisture Control (e.g. condensation or water penetration)	○	○	○	○	○
Indoor Air Quality (e.g. contaminant control)	○	○	○	○	○
Acoustics	○	○	○	○	○
Other	○	○	○	○	○

If you answered Other, please specify:

5a. If you do not think that air-tightness in buildings is important, why? (skip question if you think air-tightness is important)

6. In your experience, what types of air-leakage related performance problems have you witnessed in existing buildings?

☐ Energy Bills

☐ Thermal discomfort (too hot or too cold)

☐ Humidity discomfort or building operation issues (too dry or too wet)

☐ Moisture Related Damage (condensation, freeze-thaw damage, leaks)

☐ Indoor Air quality (pollutants, elevated CO2, mold)

Other (please specify)

7. What does your local building code require in terms of air-flow control in large buildings?

☐ No Air-barrier requirements

☐ General qualification for a Continuous Air barrier

☐ Requirement for a continuous air barrier plus testing but no reporting (i.e. no air-tightness target)

☐ Requirement for a continuous air barrier plus testing and reporting (i.e. some air-tightness target requirement)

Other (please specify)

7a. If you chose "Requirement for a continuous air barrier plus testing and reporting (i.e. some air-tightness target requirement)", what is the target requirement?

7b. Please provide the local building code reference you use:

8. Please rank the relative importance of the following items you perform in efforts to meet local building code requirements for air-leakage on your new construction projects (1 is most important):

	1	2	3	4	5
Drawing Review	○	○	○	○	○
Specification Review	○	○	○	○	○
Field Review	○	○	○	○	○
Localized Assembly Testing	○	○	○	○	○
Whole building air-tightness testing	○	○	○	○	○

9. How much control do you feel that you have on the final air-tightness of the buildings you work on?

○ A substantial amount
○ A moderate amount
○ Not sure
○ A small amount
○ None at all

Comments:

10. Would you consider the new buildings that you have worked on recently to be constructed air-tight?

○ Yes
○ Unsure
○ No

Comments:

11. Please estimate the number of buildings on which you have performed air-leakage testing according to building size: (Enter 0 in each box if you have not tested a building before)

<5000 square feet (i.e. single family houses)

5000-20000 square feet

>20000 square feet (large buildings)

12. For all types of buildings, what methods of air-leakage testing have you performed? Please indicate the types of air-leakage tests you have performed based on building size:

	<5000 square feet	5000-20000 square feet	>20000 square feet
Blower/fan door, whole building test	☐	☐	☐
Blower/fan door, partial building test	☐	☐	☐
Blower/fan door, single suite (LEED tobacco smoke control test)	☐	☐	☐
Blower/fan door, or fan test of enclosure component (e.g. window or wall)	☐	☐	☐
Smoke testing under operating pressures (visual)	☐	☐	☐
Smoke testing under applied test pressures, positive and/or negative (visual)	☐	☐	☐
Infrared Thermography under operating pressures (visual)	☐	☐	☐
Infrared Thermography under applied test pressures, positive and/or negative (visual)	☐	☐	☐
As part of water testing of enclosure component (e.g. window or door) (visual indicator)	☐	☐	☐
Other Method (e.g. tracer gas, or other not listed)	☐	☐	☐

12a. Comments on other testing types:

13. If you have not performed air-leakage testing on your projects before, can you please comment on why you haven't? (e.g. not required, too expensive, lack of equipment, lack of testing local agencies, etc..)

14. Specifically for Multi-Storey Multi-Unit Residential Buildings (MURBs), what types of air-leakage testing have you performed? Please indicate the types of air-leakage tests you have performed based on building size:

	5000-20000 square feet (small MURBs)	>20000 square feet (large MURBs)
Blower/fan door, whole building test	☐	☐
Blower/fan door, partial building test	☐	☐
Blower/fan door, single suite (LEED tobacco smoke control test)	☐	☐
Blower/fan door, or fan test of enclosure component (e.g. window or wall)	☐	☐
Smoke testing under operating pressures (visual)	☐	☐
Smoke testing under applied test pressures, positive and/or negative (visual)	☐	☐
Infrared Thermography under operating pressures (visual)	☐	☐
Infrared Thermography under applied test pressures, positive and/or negative (visual)	☐	☐
As part of water testing of enclosure component (e.g. window or door) (visual indicator)	☐	☐
Other Method (e.g. tracer gas, or other not listed)	☐	☐

14a. Comments on other testing methods:

14b. Specifically for Multi-Unit Residential Buildings, have you measured the air-tightness of interior surfaces and compartmentalization between suites and floors?

○ Yes

○ No

Comments

☐

15. For each type of test you have performed (all building types), please choose from the drop down box why the testing was performed: (Skip if no testing performed)

	<5000 square feet	5000-20000 square feet	>20000 square feet
Blower/fan door, whole building test	☐	☐	☐
Blower/fan door, partial building test	☐	☐	☐
Blower/fan door, single suite (LEED tobacco smoke control test)	☐	☐	☐
Blower/fan door, or fan test of enclosure component (e.g. window or wall)	☐	☐	☐
Smoke testing under operating pressures (visual)	☐	☐	☐
Smoke testing under applied test pressures, positive and/or negative (visual)	☐	☐	☐
Infrared Thermography under operating pressures (visual)	☐	☐	☐
Infrared Thermography under applied test pressures, positive and/or negative (visual)	☐	☐	☐
As part of water testing of enclosure component (e.g. window or door) (visual indicator)	☐	☐	☐
Other Method (e.g. tracer gas, or other not listed)	☐	☐	☐

15a. Comments:

☐

16. For each type of test you have performed (all building types), list relevant test protocols which you may have used (e.g. ASTM, USACE, CAN/CGSB, other): (Skip if no testing performed)

Blower/fan door, whole building test

Blower/fan door, partial building test

Blower/fan door, single suite (LEED tobacco smoke control test)

Blower/fan door, or fan test of enclosure component (e.g. window or wall)

Smoke testing under operating pressures (visual)

Smoke testing under applied test pressures, positive and/or negative (visual)

Infrared Thermography under operating pressures (visual)

Infrared Thermography under applied test pressures, positive and/or negative (visual)

As part of water testing of enclosure component (e.g. window or door) (visual indicator)

Other Method (e.g. tracer gas, or other not listed)

17a. Based on your experience, do you feel some sort of air-leakage testing during construction of a new building is necessary towards constructing an air-tight building?

○ Yes

○ No

Comments

17b. Based on your own experience, do you feel some sort of air-leakage testing during the rehabilitation or renovation of an existing building is useful towards making the existing building air-tight?

○ Yes

○ No

Comments

18. What test method do you find most effective towards the goal of constructing an air-tight building?

○ Qualitative Test Method (e.g. smoke, infrared, no numbers or numerical targets)

○ Quantitative Test Method (numbers and numerical targets using fan/blower door)

Comments:

19. Please rank the air-leakage test methods in terms of identifying air-leakage locations and contributing to a more air-tight building:

	1	2	3	4	5
Whole building air-tightness test (end of construction)	○	○	○	○	○
Partial floor or suite air-tightness test (during construction)	○	○	○	○	○
Infrared thermography	○	○	○	○	○
Visual Smoke testing	○	○	○	○	○
Other method	○	○	○	○	○

If Other method, please specify:

20. Please rank the air-leakage test methods in terms of cost effectiveness in terms of meeting the goal of an air-tight building:

	1	2	3	4	5
Whole building air-tightness test (end of construction)	○	○	○	○	○
Partial floor or suite air-tightness test (during construction)	○	○	○	○	○
Infrared thermography	○	○	○	○	○
Visual Smoke testing	○	○	○	○	○
Other method	○	○	○	○	○

If Other method, please specify:

21. If you perform whole large building quantitative air-leakage testing (i.e. for a number), what equipment do you typically use for the test?

○ Multiple fan/blower door setups

○ Large high volume fan (truck mounted air-plane style blower)

○ Building HVAC system with calibrated flow measurement

Other (please specify)

22. If you have performed whole large building quantitative air-leakage testing, what types of problems have you run into?

☐ Lack of support from design team or owner

☐ Lack of available equipment

☐ Lack of knowledge of large building test procedures

☐ Lack of trained personnel

☐ Lack of proper access to the building

☐ Lack of sufficient fees to perform the test

☐ Issues during testing achieving test pressures

☐ Issues during testing with wind and baseline pressures

☐ Issues during testing in locating air-leakage locations

Other (please specify)

23. If you perform whole large building quantitative air-leakage testing (e.g. for a final building air leakage rate), do you typically perform preliminary testing (e.g. partial building test, smoke, infrared etc.) prior to the final test?

○ Yes

○ No

Comments

24. In your experience, do you feel that whole building quantitative air-leakage testing (i.e. for a number) is necessary towards the construction of an air-tight building?

○ Yes

○ No

Comments

25. In your experience, do you feel that some level of qualitative air-leakage testing (e.g. visual using smoke, infrared etc.) during construction is necessary towards the construction of an air-tight building?

○ Yes

○ No

Comments:

26. Do you feel that some qualitative air-leakage testing procedure (e.g. infrared or smoke testing) should be required by your local building code to improve whole building air-tightness?

○ Yes

○ No

If so, what test procedure(s) would this include?

27. Do you feel that a quantitative whole building air-leakage target should be included in your local building code to improve whole building air-tightness?

○ Yes - and Enforceable

○ Yes - but not Enforceable

○ No

Is Yes, what maximum air-leakage rate would be appropriate? (ie 0.25 to 0.40 cfm/sqft @ 75 Pa)

28. If a whole building air leakage testing target were to be required by your local building code how difficult do you feel it would be to meet on your projects?

○ Very Easy

○ Easy

○ Not Sure

○ Hard

○ Very Hard

Comments

29. If whole building air-tightness testing were to be required by your local building code tomorrow, how long do you feel it would take your local industry to prepare and reach capacity to perform this testing?

○ <1 year

○ 1-2 years

○ 2+ years

Comments

30. Do you feel that local designers and builders are prepared for whole building air leakage testing of large buildings and the implications on their design or construction practices?

○ Yes

○ No

Comments:

31. Do you feel that your local air-leakage testing agencies and/or consultants are prepared to perform whole building air leakage testing of large buildings, or could be if the code requirement were to exist?

○ Yes - Already have capacity
○ Yes - Capacity could easily be met if required
○ Unsure
○ No - No local capacity
○ No - No local interest

Comments:

32. If you feel that there isn't currently local capacity to perform air-tightness testing of large buildings what would be needed to improve this?

☐ Local Testing Agency or Consultants from out of town
☐ Training and Education of local firms
☐ Testing Equipment

Comments

33. Do you have any air-tightness measurements from Multi-Unit Residential Buildings which you have tested and could be included in the research study? Any identifying information about the building is not required and the results will be aggregated with data from other buildings to estimate current air-tightness levels. If you agree we will contact you by email to collect this data.

○ Yes
○ No

Email

Thank you.

Appendix C

Airtightness Database Data Collection Form

Building Airtightness Test Data Submission Form

Please complete as much of the form below as possible. Completed forms and any questions or comments regarding the form or the airtightness database should be sent to Graham Finch at RDH Building Engineering Ltd via gfinch@rdhbe.com. Thank-you.

Test Organization Identification

Organization		E-mail	
Contact Person		Phone	

Building Identification

Name/Number Used to Identify Building	
Associated Report (Please provide copy of report if possible)	

Building Characteristics

Building Type		Number of Stories	
Occupancy Type		Height [m]	
Location		Floor Area [m²]	
Year of Construction		Volume [m³]	
Year of Air Barrier Retrofit			

Construction Type	
Wall Construction	
Roof Construction	
Window Type	

Comments Regarding Building Construction:

Airtightness Testing Information

Description of Test Area	
Reason for Testing	

Test Method Used (standard)		HVAC System Sealed During Test?	
Depresurized/Pressurized/Both?		Test Includes Roof (Yes/No)	
Single or Multi-point test?		Year Tested	
Overall Quality of Data			

Description of Test:

Building Enclosure Area [m²]	
Does enclosure area include below grade area?	
Enclosure Area of Tested Portion of Building [m²]	
Floor Area of Tested Portion of Building [m²]	
Volume of Tested Portion of Building [m³]	

Comments Regarding Testing:

Test Results

Test Result							
Units of Test Result							
Test Pressure [Pa]							

If an airtightness target was set, what was it and was it met?	

n		Calculated from multi-point test or assumed?	
C [L/s·Pa^n]		Calculated from multi-point test or from assumed n value?	

If multi-point test:

R² of Correlation:	
Confidence Interval [%]:	

Comments on Correleation:

Comments Regarding Test Results: