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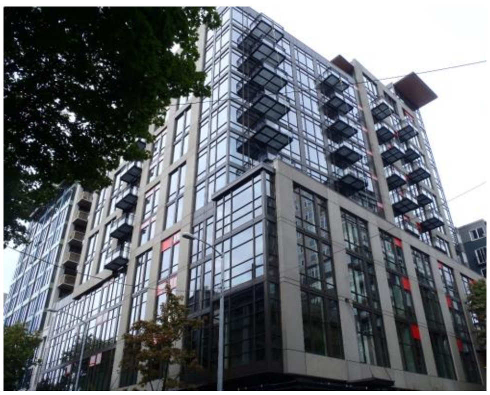
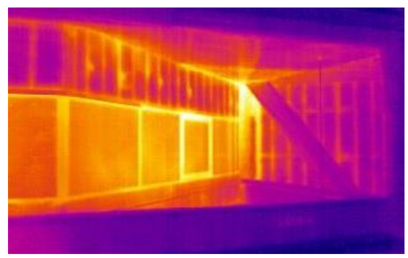
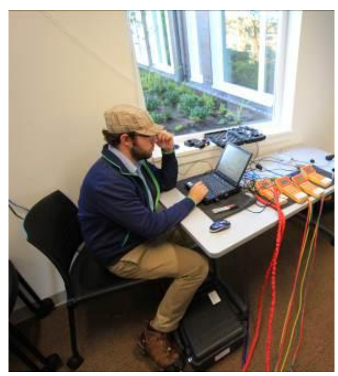
Study of Part 3 Building Airtightness | Project 8980.00







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Executive Summary

Airflow into, out of, and within buildings affects building durability, occupant comfort, and indoor air quality, and, importantly, energy consumption. Modelling results estimate that approximately 16% of heating and cooling energy for office buildings in the United States, and 24% of multi-unit residential building energy consumption, is attributable to infiltration. (VanBronkhorst, Persily, & Emmerich, 1995; CMHC, 2007)

Despite the significant impact of air leakage on building energy consumption, relevant building codes and standards provide limited guidance with respect to the construction of these systems, and also with respect to accurate modelling for energy calculations. The two energy standards referenced by the National Building Code of Canada (NBC) 2010, National Energy Code of Canada for Buildings (NECB) 2011 and ASHRAE-90.1 2010, both indicate that a continuous air barrier is required, but do not provide a quantified performance requirement, nor do they require verification of performance by testing. This study works to provide the necessary technical background to support potential implementation of airtightness performance requirements in the NECB, and also to provide comment on the air leakage rate currently prescribed in Part 8 of the NECB for energy modelling.

To ascertain the state of the industry in Canada with respect to airtightness, a database of airtightness test results for large (i.e. Part 3) buildings was compiled, and surveying was conducted to evaluate the impact of airtightness requirements and the capacity for testing. Jurisdictions where airtightness performance and testing requirements have been implemented, such as the State of Washington, were assessed as part of all phases of the study to learn from their experience.

The compiled database of airtightness testing results indicates that the average airtightness for large buildings in Canada is approximately 2.15 L/(s·m²) at 75 Pa. Jurisdictions in which airtightness performance requirements have been implemented achieve statistically significant differences in airtightness with US Army Corps Buildings and State of Washington buildings achieving average performances of 1.0 and 1.3 L/(s·m²) respectively at 75 Pa. This finding clearly illustrates the potential improvements in airtightness which can be realized as a result of implementation of a performance and testing requirement.

Surveys found that general perceptions towards whole building airtightness are positive in voluntary jurisdictions. In mandatory jurisdictions, airtightness testing has served as a measuring stick for the quality of the installation of the air barrier. However, a pervading theme with respect to the implementation of airtightness performance and testing requirements in the State of Washington was a lack of education. While industry capacity in Canada is currently limited, there is interest in expanding the capacity if a requirement were to be implemented. Education and training to develop the necessary expertise should be a key part of the successful and smooth implementation of an airtightness requirement.

Based on the compiled data, whole building airtightness in Canada is significantly higher than the input assumptions in the NECB. However, measured enclosure airtightness does not correspond directly with in-service air leakage, as in-service infiltration and exfiltration will depend heavily on the pressure differences created by wind, stack effect, and mechanical ventilation systems. As a result of the large number of factors which impact in-service air leakage rates, a single value for infiltration likely will not address the complexity of estimating infiltration and exfiltration in large buildings.

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1 Introduction

Airflow into, out of, and within buildings affects building durability, occupant comfort, and indoor air quality, and, importantly, energy consumption. In Canada, approximately 30% of all secondary energy is consumed by buildings, and approximately 58% of that is used for space heating and cooling (Natural Resources Canada, 2014). Modelling results estimate that approximately 16% of heating and cooling energy for office buildings in the United States is attributed to infiltration, not including the energy associated with conditioning ventilation air. (VanBronkhorst, Persily, & Emmerich, 1995) This percentage would likely be even higher in the relatively colder Canadian climate, and even this study notes that the modeling of airflows was greatly simplified. For multi-unit residential buildings, CMHC (2007) estimates that approximately 24% of building energy consumption is attributable to air leakage. As other components of building energy consumption are improved, such as conductive heat loss through the enclosure, the fraction of building energy consumption attributed to infiltration will increase.

Despite the significant impact of air leakage on building energy consumption, relevant building codes and standards provide limited guidance with respect to the construction of these systems, and also with respect to accurate modelling for energy calculations. The two energy standards referenced by the National Building Code of Canada (NBC) 2010, National Energy Code of Canada for Buildings (NECB) 2011 and ASHRAE-90.1 2010, both indicate that a continuous air barrier is required, but do not provide a quantified performance requirement, nor do they require verification of performance by airtightness testing.

The relevant standards also provide little to no guidance regarding how to model air leakage. Modelling experience has shown that building energy consumption is often sensitive to changes in infiltration; however, the current knowledge of the in-service rates experienced in buildings is limited, and creates a large range of possible inputs, sometimes varying by orders of magnitude. Typically these flow rates are modelled using one number to set a constant infiltration rate, and this method is specified when using NECB 2011; however, air leakage is often a much more complex and dynamic phenomena.

Recently, in response to increasing societal concern regarding the environment and rising energy costs, building enclosure airtightness and reducing air leakage is garnering more attention. Various jurisdictions in North America and worldwide have integrated or are considering integrating quantitative airtightness performance requirements into building regulations.

Whole building airtightness testing of single family houses (i.e. Part 9 buildings) has been common for many years in North America and other parts of the world including Europe. Measurement of the as-built enclosure (i.e. envelope) is a recognized component of achieving a high performance energy efficient building. The technology associated with whole building airtightness measurement in houses is readily available and many practitioners are able to undertake the testing using well established test protocols with testing costs usually being only a few hundred dollars. The challenge for larger buildings is to extend the well-established technology and process for houses to larger buildings in a cost-effective manner so that airtightness testing can be performed, and also to develop accurate and reasonable methods to account for air leakage as part of whole building energy modelling.

Figure 1-1 Example of fan door equipment used for airtightness testing of Part 9 housing.

1.1 Study Approach

This study works to provide the technical background necessary for the future implementation of a whole building airtightness performance and testing requirement for large buildings, and also to provide some of the background information necessary to improve the modelling of air leakage in Part 8 of the NECB. To do this, key information needs to be compiled including:

→ What would be an appropriate airtightness performance metric?

→ What test airtightness methods currently exist and how appropriate are they for the intended testing?

→ What would the impact be of implementing an airtightness performance and testing requirement?

→ What are the airtightness performance and testing requirements currently being implemented in other jurisdictions and what has been their impact?

→ How do current Canadian codes and standards address airtightness and air leakage?

This study develops this key information through six tasks.

→ Task 1: Compilation of available airtightness testing results into a database and subsequent analysis

→ Task 2: Assessment of whole building airtightness performance and testing requirements in various jurisdictions

- → Task 3: Surveying to evaluate the potential impact of implementing whole building airtightness requirements
- → Task 4: Assessment of whole building airtightness test methods and procedures
- → Task 5: Surveying to evaluate the industry capacity for whole building airtightness testing
- → Task 6: Comparison of existing building performance with values currently provided in Canadian codes, and in particular in Part 8 of the 2011 NECB

2 Background

This chapter provides general background information with respect to typical air barrier systems which provide the airtight layer of the building enclosure, and airtightness metrics which are used to quantitatively describe their performance.

2.1 Airflow, Airtightness & Pressure Differences

Airflow in all contexts is caused by pressure differences across a flow path. Both a pressure difference and flow path are necessary for airflow to occur, and the rate is governed by the magnitude of the pressure difference and the resistance to airflow provided by the flow path.

For buildings, pressure differences are created by either the natural causes of wind and stack effect, or by mechanical ventilation systems, which collectively will be referred to as *driving forces* of airflow. These driving forces move air into, out of, and within buildings. This airflow is resisted by various building elements including exterior and interior walls, doors, windows, floors, elevator doors, et cetera. The resistance to airflow provided by these elements, including the building enclosure, is referred to as *airtightness* and is a property of the building element(s). The combination of airtightness of building elements and the pressure differences created across them by the driving forces of airflow result in *air leakage*. Air leakage from inside to outside is referred to as *exfiltration*, while air leakage from outside to inside is referred to as *infiltration.*

Airflow through building materials, components, systems, and enclosures have been found to be well described by Eq. 2.1. (Sherman & Chan, 2004; ASHRAE, 2009; Tamura & Shaw, 1976; Straube & Burnett, 2005; Thorogood, 1979; Proskiw & Phillips, 2008)

$$Q = C \cdot \Delta P^n \qquad \text{Eq. 2.1}$$

Where: Q = Airflow from High to Low Pressure [m^3/s]
C = Flow Coefficient [$m^3/s \cdot Pa^n$]
ΔP = Pressure Difference [Pa]
n = Flow Exponent [dimensionless]

This equation is commonly referred to as the power law airflow relationship and is fundamental to the understanding of building airtightness, infiltration, and exfiltration. In this equation, airtightness is described by the combination of flow coefficient ("C") and the flow exponent ("n"), while the resulting air leakage rate is described by "Q".

The flow exponent ("n") in Eq. 2.1 is bounded by the lower limit of 0.5 provided by turbulent sharp edged orifice flow and by the upper limit of 1.0 provided by laminar flow through diffuse media. When the flow coefficient is measured outside of this range it indicates that the physical characteristics of the pressure boundary changed during the test. For example, higher pressure differences may cause windows to seal more completely, or they may make laps in a membranes open wider, both of which change the physical properties of the associated pressure boundaries. Typically, the flow exponent for a building enclosure is approximately 0.65, and often if multi-point airtightness testing is not performed, this value is assumed. (Straube & Burnett, 2005; Orne, Liddament, & Wilson, 1998)

2.2 Pressure Differences – Driving Forces of Airflow

As discussed airflow into, out of, and within buildings is created by pressure differences which are created by the natural forces of wind and stack effect, as well as by mechanical ventilation systems. These pressure differences may exist between the exterior and the interior of a building, and between internal building spaces.

While each of the driving forces of airflow can be considered in isolation, it is the combination that will determine airflow patterns for a building. The pressure differences created by the driving forces of stack effect, wind, and mechanical ventilation systems can be summed to determine the pressure acting across a building element. This concept is illustrated graphically in Figure 2.1.

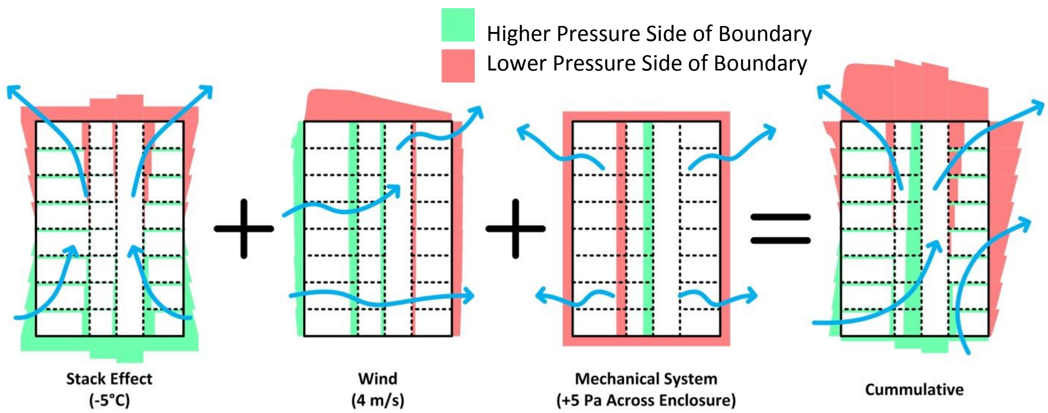

Figure 2.1: Schematic cumulative effect of driving forces of airflow on a tall building. (Ricketts, 2014)

To examine the relative impact of stack effect and wind on buildings of different heights and located in different climates, the magnitudes of stack effect and wind were calculated for building heights of 20 m, 40 m, 60 m, 80 m, and 100 m (66 ft, 131 ft, 197 ft, 262 ft, and 328 ft) using the maximum pressure created by stack effect (assuming NPP at mid-height of building) and the stagnation pressure of the wind (Cp = 1) at the roof of a building. Similar to previous calculations, these calculations use Canadian Weather for Energy Calculations (CWEC) weather data for locations in Canada and typical meteorological year (TMY) data for locations in the United States. (U.S. Department of Energy, 2013) The proportion of the total absolute magnitude of the driving forces attributable to stack effect, wind, and a mechanical pressure of 10 Pa was then determined on an hourly basis for each of these building heights in eight cities in North America. Figure 2.2 shows the annual average proportion of the absolute magnitude of the total pressure differences created by the driving forces for various building heights in Toronto, and Figure 2.3 shows the proportions for a 40 m (131 ft) tall building in each of eight cities with different climates.

Note that Figure 2.2 through Figure 2.3 do not indicate the direction of the pressure differences created nor do they indicate the distribution of the pressure differences but instead are intended only to indicate relative magnitudes. As the mechanical ventilation pressure used for these graphs is always 10 Pa, this value can be used in interpreting the graphs to determine the approximate magnitudes of the driving forces.

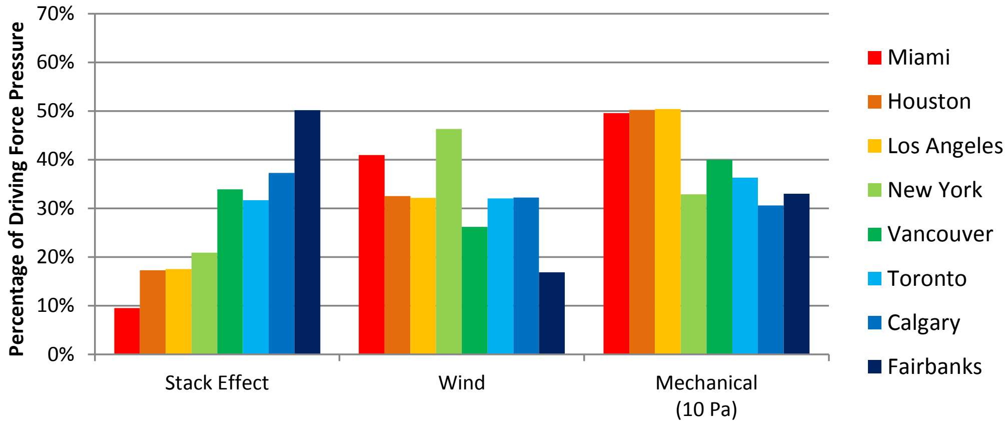

Figure 2.2: Annual average proportion of total absolute pressure difference attributable to each driving forces at the top of a building for various building heights in Toronto

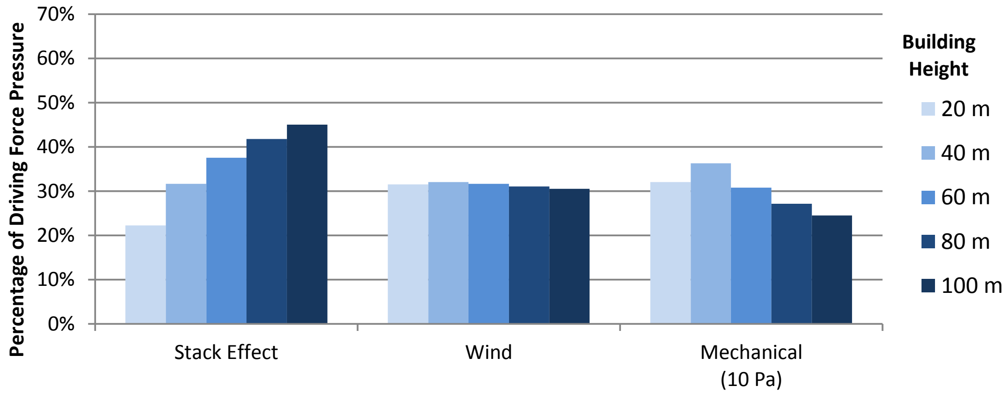

Figure 2.3: Annual average proportion of total absolute pressure difference attributable to each driving forces at the top of a building for various building heights in Toronto

The combination of the preceding graphs illustrates that, as one would expect, stack effect is a dominant driving force in colder climates and during colder periods of the year, but that in warmer climates wind and mechanical pressures are more likely to dominate. Also, the total magnitude of pressure differences created by stack effect and wind increases with building height, and thus the proportion of pressure difference due to the mechanical ventilation system decreases with building height. Overall, it is possible that any one of the driving forces is dominant in both the short and long-term depending on climate and building height.

2.3 Air Barriers

Air barrier systems are used to separate spaces with respect to airflow using air barrier assemblies and components, made up of and connected by air barrier materials and accessories. These systems create a continuous, relatively air impermeable layer that significantly reduces the flow of air through it. Each of these air barrier elements is defined below based on definitions provided by the Air Barrier Association of America (ABAA) (2011).

→ **Air Barrier System:** The combination of air barrier assemblies and air barrier components, connected by air barrier accessories that are designed to provide a continuous barrier to the movement of air through an environmental separator (i.e. the building enclosure).

- → **Air Barrier Assembly:** The combination of air barrier materials and air barrier accessories that are designated and designed within the environmental separator to act as a continuous barrier to the movement of air through the environmental separator.
- → **Air Barrier Component:** Pre-manufactured elements such as windows, doors, and service elements that are installed in the building enclosure that form part of the air barrier system.
- → **Air Barrier Material**: A building material that is designed and constructed to provide the primary resistance to airflow through an air barrier assembly.
- → **Air Barrier Accessory:** Any construction material that is used to join air barrier materials, air barrier assemblies, and air barrier components.

Air barrier systems must comply with a number of design requirements in order to function adequately and remain airtight over the life of the building, or building element. The following list has been generated based on guidance in Straube & Burnett (2005), and RDH Building Engineering Ltd. & FPInnovations (2013).

- → An air barrier system must be completely continuous over the boundary that it defines including at junctions with adjacent air barrier systems. This includes sealing at all penetrations and joints.
- → An air barrier system must comprise elements which are adequately air impermeable. This is discussed further in subsequent sections.
- → An air barrier system must be able to resist the air pressure forces imposed upon it by the driving forces of airflow (primarily wind) without deflection that compromises its performance.
- → The air barrier system should have a service life as long as that of components which would need to be removed to replace it, or alternatively should be easily accessible for repair or replacement.

The continuity requirement for air barrier systems is of particular importance. Many common materials used in the construction of buildings are airtight enough to meet the material requirements of an air barrier; however, it is the interfaces and joints between these materials where significant airflow can occur. For this reason, the performance of an air barrier system is often highly dependent on the design of interface details and the quality of workmanship with which they are installed. To aid in achieving good workmanship, the constructability of an air barrier system is a key consideration. (Steffen, 2012) Additionally, during the selection and design of air barrier assemblies it is important to consider penetrations such as plumbing pipes and electrical outlets as these types of penetration can be difficult to seal and may compromise the continuity of an air barrier system.

2.4 Airflow and Airtightness Metrics

Common metrics used for reporting of airflow and airtightness are described in this section for reference.

2.4.1 Airflow Rate

The total airflow rate can be used to indicate the airtightness characteristics of a pressure boundary. This number can be useful for ventilation and energy calculations, and it is often known since it is directly measured as part of most airtightness testing procedures as discussed in Chapter 6. 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. There is some discrepancy within industry as to which is preferable, and one of the common arguments for using 50 Pa is that it is a more easily achieved test pressure and it is usually possible to include this test pressure within the tested range so that extrapolation is not required to determine the result. However, as buildings become more airtight, 75 Pa is becoming a more easily achievable pressure difference for testing and typically the higher the pressure difference, the more stable and reliable the flow measurement. In either case, it is most useful to provide flow coefficients (or normalized flow coefficient) and flow exponents since these values can be used to calculate the flow rate at any pressure difference to allow for comparison. Flow rates are also often provided at lower pressures to represent in-service conditions. The airflow rate at a given pressure difference ΔP (in Pascals) is denoted $Q_{\Delta P}$ [m³/s].

2.4.2 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 area of the pressure boundary, which in many cases is the total enclosure area of the building. In some cases, only the above-grade area of the building enclosure is used. The equation for calculation of the normalized airflow rate is provided in Eq. 2.2.

$$q_{\Delta P} = \frac{Q_{\Delta P}}{A} \qquad \text{Eq. 2.2}$$

Where: $q_{\Delta P}$ *= Normalized Airflow Rate at ΔP [m/s]*
ΔP = Pressure Difference [Pa]
$Q_{\Delta P}$ *= Airflow Rate [m³/s]*
A = Area of Pressure Boundary [m²]

2.4.3 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. This value is found by dividing the flow rate into a space by the volume of that space as shown in Eq. 2.3. The volume of the space used for this calculation is the entire volume enclosed by compartmentalizing elements or the building enclosure.

$$ACH_{\Delta P} = N_{\Delta P} = \frac{Q_{\Delta P}}{V} \cdot 3{,}600 \qquad \text{Eq. 2.3}$$

Where: $ACH_{\Delta P}$ or $N_{\Delta P}$ = Air Changes Per Hour ΔP [h^{-1}]
ΔP = Pressure Difference [Pa]
$Q_{\Delta P}$ = Airflow Rate [m^3/s]
V = Volume of the Zone [m^3]

ACH is not a fundamental indicator of resistance to airflow as it depends on the zone volume; however, it is commonly used as an indicator of airtightness, especially for houses. It is most useful when considering ventilation rates.

2.4.4 Equivalent Leakage Area

Equivalent leakage area (EqLA) represents the size of a sharp-edged orifice which would produce the same air flow at a given pressure differential as would occur cumulatively through all the leakage paths in a given pressure boundary. While the concept behind this metric is to provide a tool for visualization of the airtightness of a pressure boundary (i.e. size of the hole), the hole size calculated does not actually provide a measurement of the cumulative size of the "holes" in the pressure boundary.

For the calculation of EqLA in accordance with *CGSB 149.10-M86 Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method* (1986), a discharge coefficient of 0.611 is assumed and a reference pressure difference of 10 Pa is used. A rearrangement of the sharp-edged orifice equation is provided in Eq. 2.4 to calculate EqLA according to CGSB 149.10-M86. By substitution, Eq. 2.5 can be developed to calculate EqLA based on only the flow coefficient (C) and the flow exponent (n).

$$EqLA = \frac{Q_{10}}{0.611}\sqrt{\frac{\rho}{2 \cdot 10}} \cdot 10{,}000 \qquad \text{Eq. 2.4}$$

Where: EqLA = Equivalent Leakage Area [cm^2]
Q_{10} = Airflow at 10 Pa [m^3/s]
ρ = Air Density [kg/m^3]

$$EqLA = \frac{C \cdot 10^n}{0.611}\sqrt{\frac{\rho}{2 \cdot 10}} \cdot 10{,}000 \qquad \text{Eq. 2.5}$$

Where: EqLA = Equivalent Leakage Area [cm^2]
C = Flow Coefficient of Pressure Boundary [$m^3/s \cdot m^2 \cdot Pa^n$]
A = Area of Pressure Boundary [m^2]
n = Flow Exponent [dimensionless]
ρ = Air Density [kg/m^3]

The 10 Pa reference pressure used to calculate equivalent leakage area is intended to be representative of typical in-service pressure differences experienced at buildings. It is important to note, however, that in-service pressure differences are often highly variable as they depend on the driving forces of airflow as discussed in Section 2.2.

2.4.5 Effective Leakage Area

Effective leakage area (EfLA) is a term commonly confused with EqLA. (Sometimes both of these are referred to as ELA.) EfLA is the measure used by the American Society for Testing and Materials (ASTM) and the calculation procedure is provided in ASTM E779-10 (2010). EfLA is calculated using the same procedure as EqLA except that the discharge coefficient is assumed to be 1.0 and a reference pressure of 4 Pa is used. Eq. 2.6 is used to calculate effective leakage area and was developed similarly to Eq. 2.5.

$$EfLA = \frac{Q_4}{1.0}\sqrt{\frac{\rho}{2 \cdot 4}} \cdot 10{,}000 = \frac{C \cdot 4^n}{1.0}\sqrt{\frac{\rho}{2 \cdot 4}} \cdot 10{,}000 \qquad \text{Eq. 2.6}$$

Where: *EfLA = Equivalent Leakage Area [cm²]*
Q_4 = Airflow at 4 Pa [m³/s]
C = Flow Coefficient of Pressure Boundary [m³/s·m²·Pa^n]
A = Area of Pressure Boundary [m²]
n = Flow Exponent [dimensionless]
ρ = Air Density [kg/m³]

Similar to equivalent leakage area, the 4 Pa reference pressure used to calculate equivalent leakage area is intended to be representative of typical in-service pressure differences experienced at buildings. Notably, this 4 Pa is different than the 10 Pa used to calculate equivalent leakage area and illustrates the potential difference in in-service pressure differences at buildings. As previously stated, it is important to note that in-service pressure differences are often highly variable as they depend on the driving forces of airflow as discussed in Section 2.2, and it is likely that neither 4 Pa nor 10 Pa adequately addresses the known complexity.

2.4.6 Specific Leakage Area

Specific leakage area (SLA) is either EqLA or EfLA normalized by the area of the pressure boundary. The calculation of SLA is provided in Eq. 2.7.

$$SLA = \frac{EqLA \text{ or } EfLA}{A} \cdot 100 \qquad \text{Eq. 2.7}$$

Where: *SLA = Specific Leakage Area [cm²/100 m²]*
EfLA = Equivalent Leakage Area [cm²]
EqLA = Effective Leakage Area [cm²]
A = Area of Pressure Boundary [m²]

Whether the calculation uses EqLA or EfLA can be specified with a subscript (e.g. SLA_{eq} or SLA_{ef}). In some cases SLA is calculated using the floor area of the zone instead of the enclosure area; however, similar to ACH, this metric does not provide a fundamental indication of the airtightness of a pressure boundary.

2.4.7 Airflow 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. The calculation of this metric is provided in Eq. 2.8.

$$q_{L,\Delta P} = \frac{Q_{\Delta P}}{L} \qquad \text{Eq. 2.8}$$

Where: $q_{L,\Delta P}$ *= Length Normalized Airflow Rate at* ΔP *[m/s]*
ΔP *= Pressure Difference [Pa]*
Q_x *= Airflow Rate [m³/s]*
L = Crack Length [m]

3 Whole Building Airtightness

Building airtightness testing data was collected and compiled in a database to enable assessment of the airtightness performance of the existing building stock, benchmarking of building airtightness performance, and development of appropriate airtightness performance targets for new buildings. The database is populated with data from various sources in literature, from industry members as part of the surveying process, and unpublished data available directly though members of the project team and industry contacts. Data collection efforts focused on test results from Canada and the United States; however, when available, data from other jurisdictions was also included.

For each airtightness testing result that was collected, effort was made to also collect information about the tested building including height, number of storeys, age, building type, and enclosure assembly types. Information was also collected about whether the building was built to meet a specific airtightness performance target and about the motivation for testing. If information about a specific building descriptor was unavailable, those buildings have been removed from the dataset for analysis associated with that descriptor. (i.e. If the building age is unknown then that building was removed for analysis with respect to building age.) This often causes a change in the size of the dataset for different parts of the analysis. The size of the dataset for each part of the analysis is referenced as appropriate.

While airtightness performance results were collected in a variety of metrics, these results were all converted to normalized airflow rates (cfm/ft² or L/(s·m²)) at 75 Pa for ease of comparison. Unlike some other metrics, normalized airflow rates provide a direct measure of the airtightness of the building enclosure, and consequently this metric is used for the analysis in this report. Other metrics such as air changes per hour [h^{-1}], flow rate [cfm or L/s], and equivalent leakage area [in² or cm²] were also determined and are provided in the database for reference. To allow for conversion of the data, a flow exponent value of 0.65 was assumed if insufficient data was available to determine it directly using regression analysis.

This database of buildings is not all encompassing. Certainly, testing data exists that has not been included in the database, and it is intended that the database be continuously developed as additional testing results become available and as new tests are completed.

Also, the database of test results is likely not a representative sample of building airtightness because buildings which are tested for airtightness are likely to be more airtight than the average building. Only in rare cases are buildings tested that are not associated with performance targets or air-sealing work. Testing of buildings prior to air sealing work also provides a non-representative sample as these buildings are likely less airtight than an average building as they have been identified as candidates for air sealing work.

3.1 Overview of Database Population Statistics

The database contains data for 721 different airtightness tests categorized into four different building types (Commercial, Institutional, Military, and MURB). Of these collected results, there are a total of 584 unique buildings and 566 test results which are appropriate for analysis. There are more total test results than buildings because in some cases buildings were tested before and after airtightness retrofits. Unless otherwise noted, the before and after retrofit tests were treated as separate buildings because the air barrier was deemed to have changed significantly between the two tests. The remainder of the data was deemed unusable for analysis due to inconsistencies in the reported results, or test areas which were not deemed comparable (i.e. test includes interior partitions). This data is included in the database for comparison purposes only, but has not been used as part of the analysis in this report. Out of the 566 useable test results, 142 are Commercial, 51 are Institutional, 260 are Military, and 113 are multi-unit residential buildings (MURBs). Figure 3.1 provides a graphical representation of the distribution of building types. Unsurprisingly, military buildings are the most prevalent due to the U.S. Army Corps of Engineers (USACE) requirement for airtightness testing of all new buildings. It should be noted that buildings classified as military actually include buildings of various types, including buildings that would be similar in nature to both multi-unit residential buildings and commercial buildings; however, because these buildings perform substantially differently than buildings in the rest of the sample, it was decided that military buildings would be analysed separately. Commercial and military buildings are sub-categorized and analysed in Sections 3.3.1 and 3.3.4 because these categories make-up such large proportions of the database, and because in many cases the use types can be significantly different.

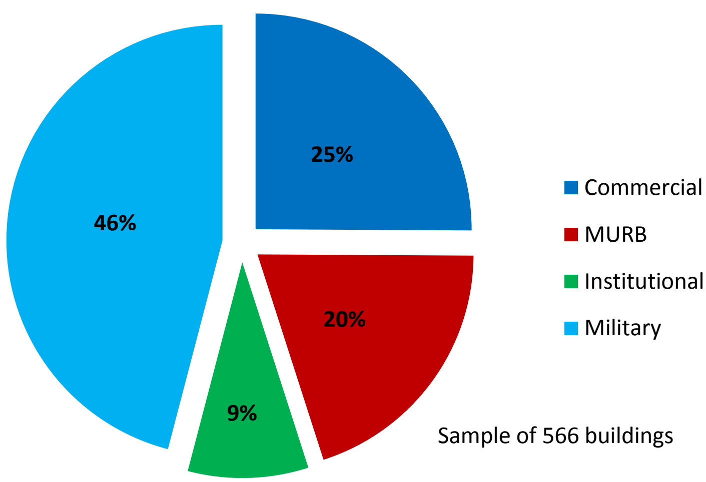

Figure 3.1: Distribution of building types for all of the buildings in the database

The buildings in the database are mostly located in the United States (USA), Canada, and the United Kingdom (UK) as shown in Figure 3.2. Most of the buildings are located in the USA because a large portion of the buildings in the database are from the results of the USACE mandated airtightness testing.

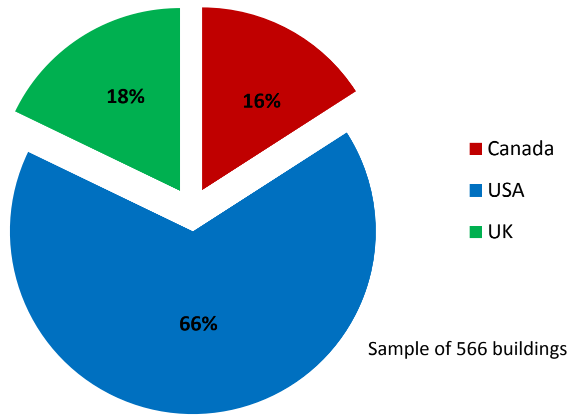

Figure 3.2: Geographic location of all of the buildings in the database

The age of the buildings in the database varies from new to over 130 years in age. The oldest building was constructed in 1880 and the newest in 2014. The distribution of buildings in each age category is shown in Figure 3.3.

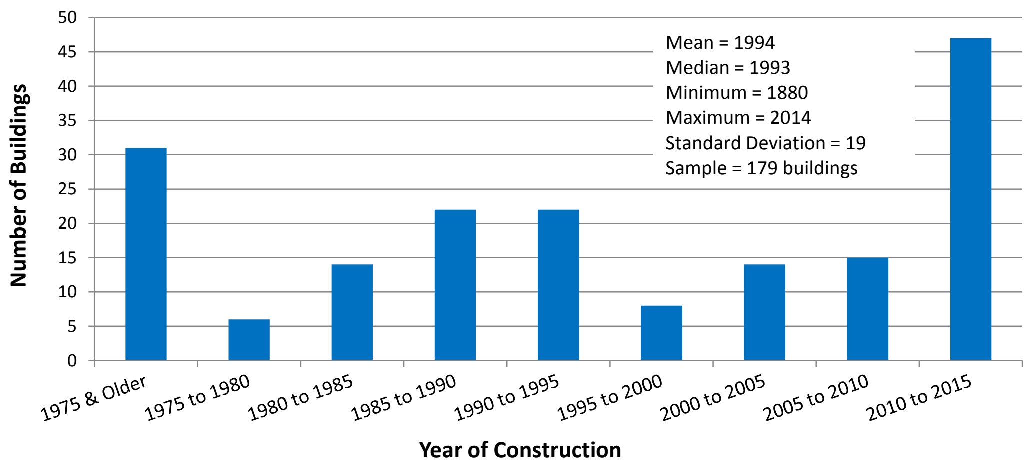

Figure 3.3: Date of construction of all of the buildings in the database

The database contains a variety of building heights as shown in Figure 3.4, with the majority of the buildings in the database being either one or two stories. The tallest building in the database is a 25 storey tall residential building.

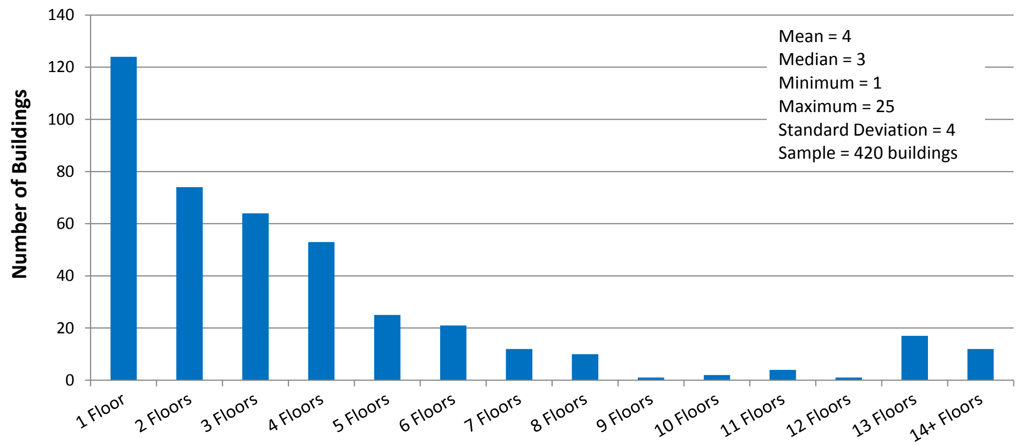

Figure 3.4: Height of all of the buildings in database

3.2 Whole Database Analysis

The data collected and discussed in this section is for all 566 buildings within the database. The data includes all buildings for which sufficient airtightness testing data was available to make valid comparisons. In some cases buildings were not included in the analysis because insufficient information was available. The airtightness performance data of the buildings are shown in Figure 3.5 and the distribution of the airtightness testing performance is shown in Figure 3.6.

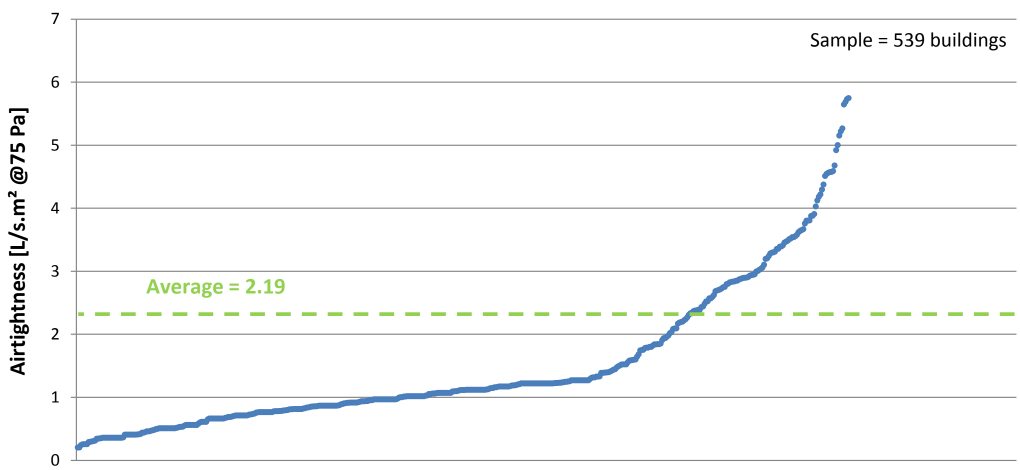

Figure 3.5: Airtightness of all buildings in the database sorted from minimum (most airtight) to maximum (least airtight)

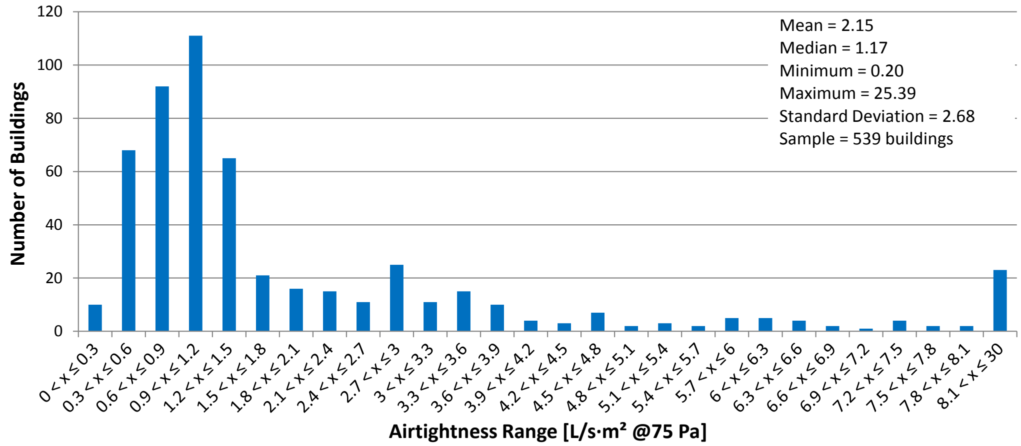

Figure 3.6: Distribution of the airtightness of all of the buildings in the database

As shown above in Figure 3.6, the mean average airtightness for all the buildings in the database is 2.15 L/(s·m²) at 75 Pa. From the distribution it is clear that most of the buildings performed between approximately 0.3 and 1.5 L/(s·m²) at 75 Pa. The median and standard deviation are 1.17 and 2.68 L/(s·m²) at 75 Pa respectively. Overall the airtightness of buildings in the database varies by orders of magnitude from 0.2 to 25.39 L/(s·m²) at 75 Pa.

To evaluate the relationship between building airtightness and the original year of construction and building height, these values were plotted against each other Figure 3.7 and Figure 3.8 respectively.

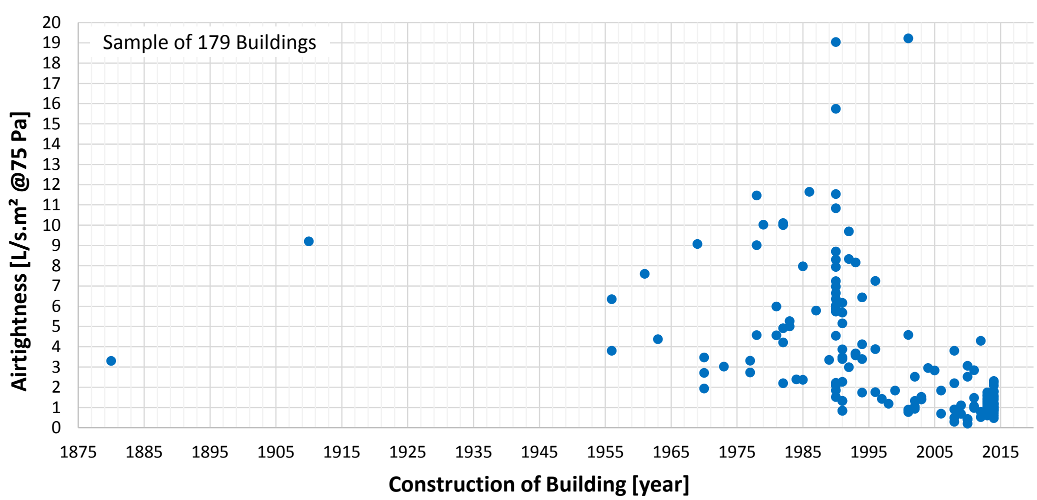

Figure 3.7: Airtightness of all buildings in the database versus original year of construction

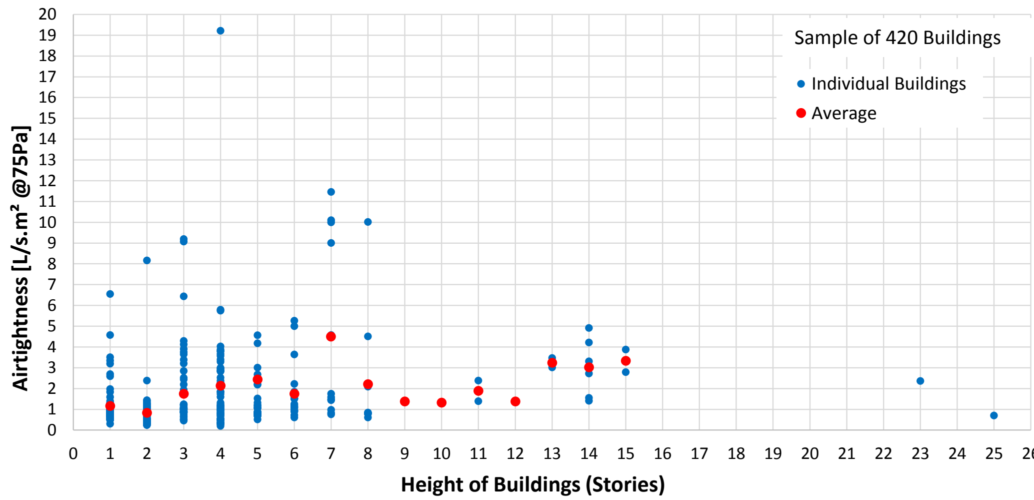

Figure 3.8: Airtightness of all buildings in the database versus building height

The distribution in Figure 3.7 indicates that more recently constructed buildings are generally more airtight and have less variation. Figure 3.8 indicates that there does not appear to be a significant correlation between building height and airtightness.

To assess the relationship between wall construction type and airtightness, concrete, masonry, steel-frame, and wood-frame buildings were analysed separately and are shown in Figure 3.9.

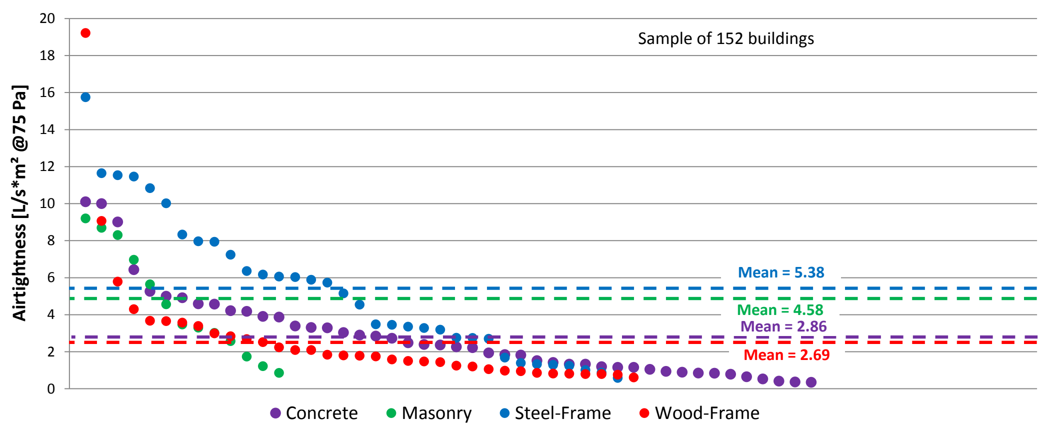

Figure 3.9: Airtightness of all buildings in the database by wall type

The minimum airtightness values for these four wall types are approximately the same, indicating that each type can be built to be quite airtight; however, there is a noticeable difference in the average performance. The data suggest that wood-frame buildings are generally more airtight than masonry and concrete frame, with steel-frame being the least airtight. While this finding may be taken to imply that one type of construction is superior to another, generally it is the opinion of the authors that any of these systems can be made airtight and that the finding presented here may be a result of a limited data set, differences in building complexity and form, and the presence of airtightness performance requirements. For example, wood-frame buildings are nearly always low-rise type buildings, while the other non-combustible building types may be high-rise.

As building airtightness is often expressed in air changes per hour, the air changes per hour at 75 Pa of the buildings in the database are provided in Figure 3.10. In some cases insufficient information was available to convert between metrics, some quite a few buildings have been removed compared to the data set provided for normalised airtightness graphs in Figure 3.5, while in some cases additional buildings have been included. There are 182 buildings in this dataset compared to 539 buildings in the normalized airflow dataset.

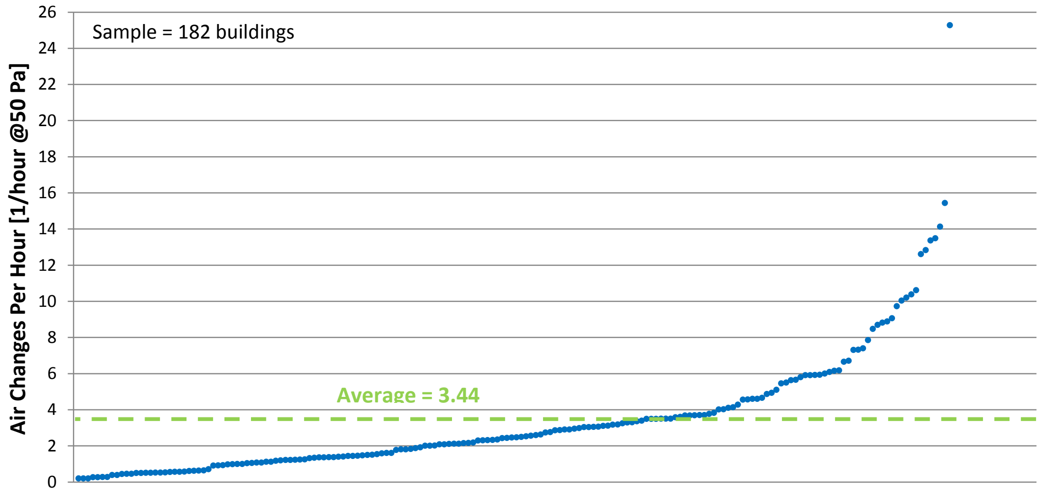

Figure 3.10: Air changes per hour of all buildings in the database sorted from minimum (most airtight) to maximum (least airtight)

Air changes per hour is not generally recommended for use as a measure of building airtightness as it is not a direct indication of building enclosure airtightness due to its dependence on building volume; however, it is frequently used in industry and can be useful when considering ventilation rates.

A flow exponent ("n") value of 0.60 or 0.65 has typically been assumed in industry when multi-point testing was not performed and consequently it is not possible to determine the flow exponent using regression analysis. To assess the appropriateness of these selections, the flow exponents measured for all of the building in the database were analysed and are presented in Figure 3.11 and Figure 3.12.

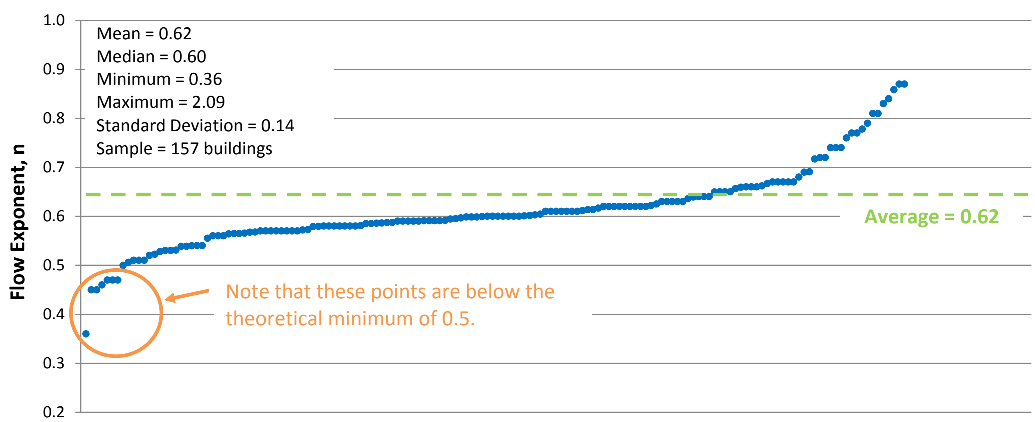

Figure 3.11: Flow exponents of all of the buildings sorted from minimum to maximum

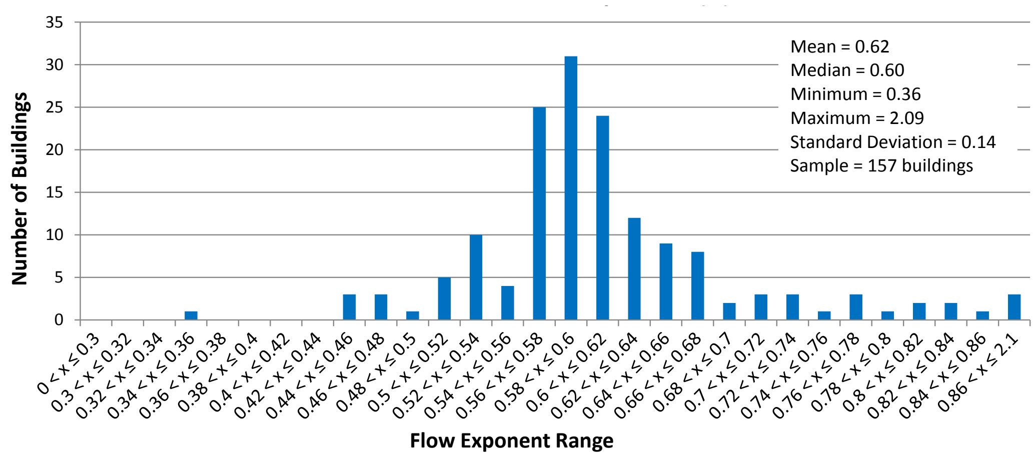

Figure 3.12: Distribution of flow exponent values for all buildings in the database

The average of the flow exponents was found to be 0.62 which corresponds well with the commonly used values of 0.60 and 0.65.

3.3 Analysis by Building Type

This section provides analysis of the whole building airtightness with respect to the different building types. Direct comparisons between the different building types are provided Section 0.

3.3.1 Airtightness of Commercial Buildings

The data collected and discussed in this section is for the 142 commercial buildings in the database. The distribution of the airtightness performance of these buildings is shown in Figure 3.13.

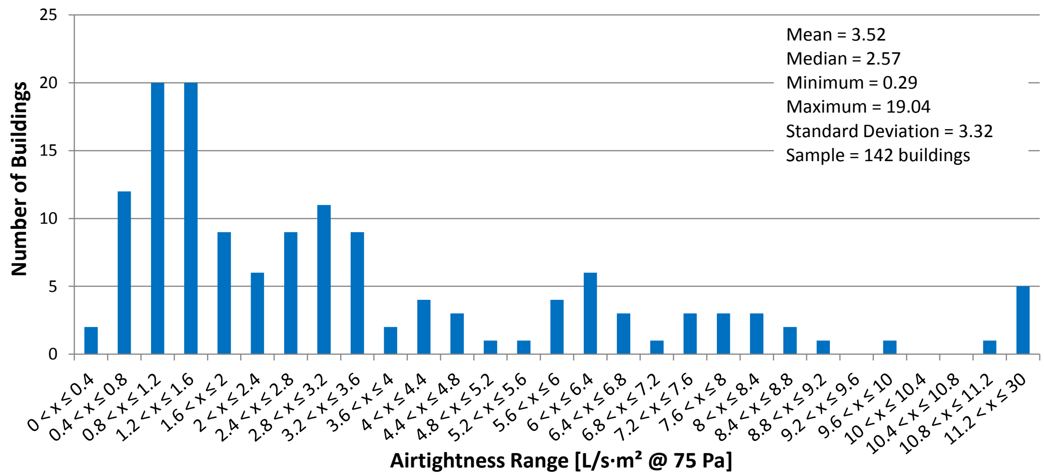

Figure 3.13: Distribution of commercial building airtightness

As shown in Figure 3.13 above, the average (mean) airtightness value for the commercial buildings in the database is 3.52 L/(s · m²) at 75 Pa. The median and standard deviation are 2.57 and 3.32 L/(s · m²) at 75 Pa respectively. Overall the airtightness of buildings in the database varies by orders of magnitude from 0.29 to 19.04 L/(s · m²) at 75 Pa.

Commercials buildings cover a large variety of buildings types so the 142 commercial buildings were further broken down by the type occupancy category. The occupation categories break the building up into five different categories as seen in Figure 3.14. Figure 3.15 shows the airtightness performance of these different occupancy types. Industrial buildings which are used for manufacturing are significantly less airtight then all the other classifications and is skewing the average for commercial buildings.

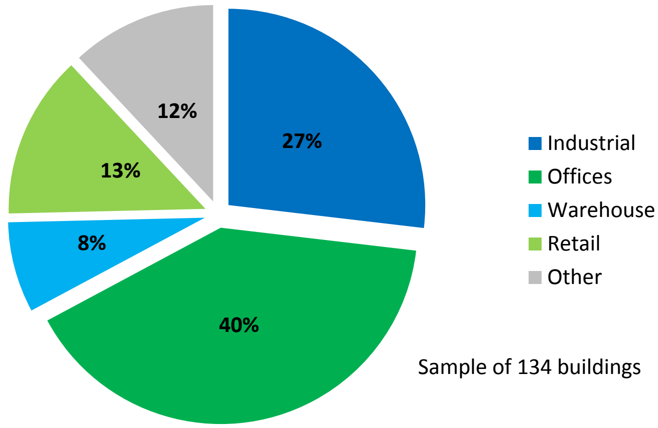

Figure 3.14: Occupancy classification of the commercial buildings

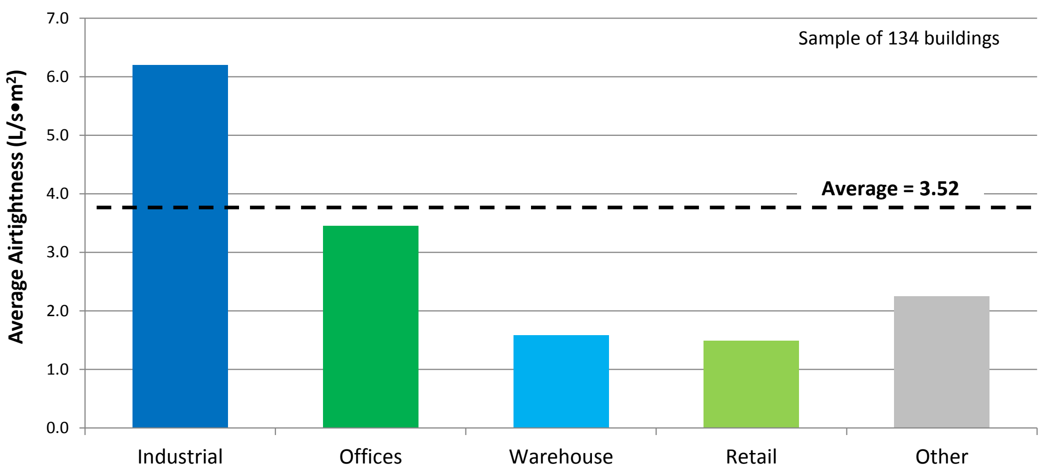

Figure 3.15: Average airtightness of commercial buildings by occupancy classification

The building airtightness data was also graphed versus original year of building construction, and building height as shown in Figure 3.17, and Figure 3.16 respectively.

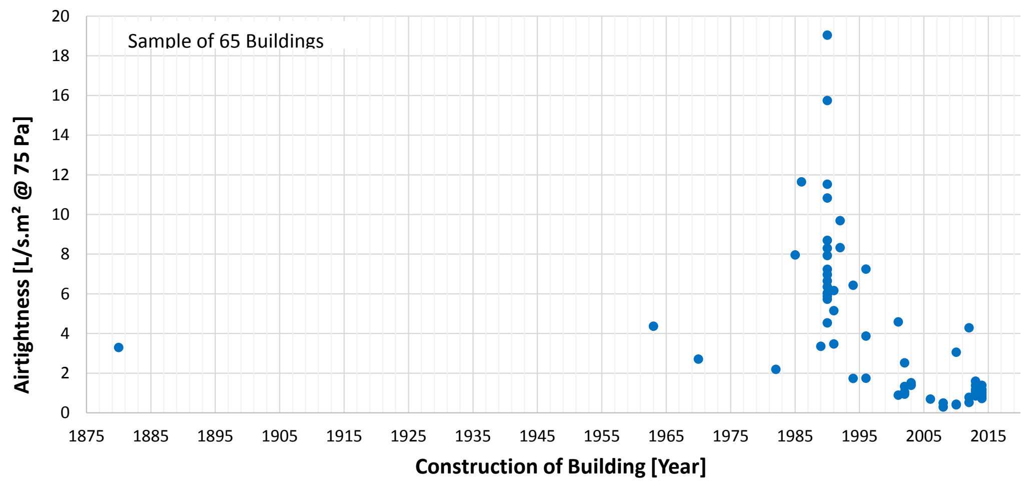

Figure 3.16: Airtightness of commercial buildings versus original year of construction

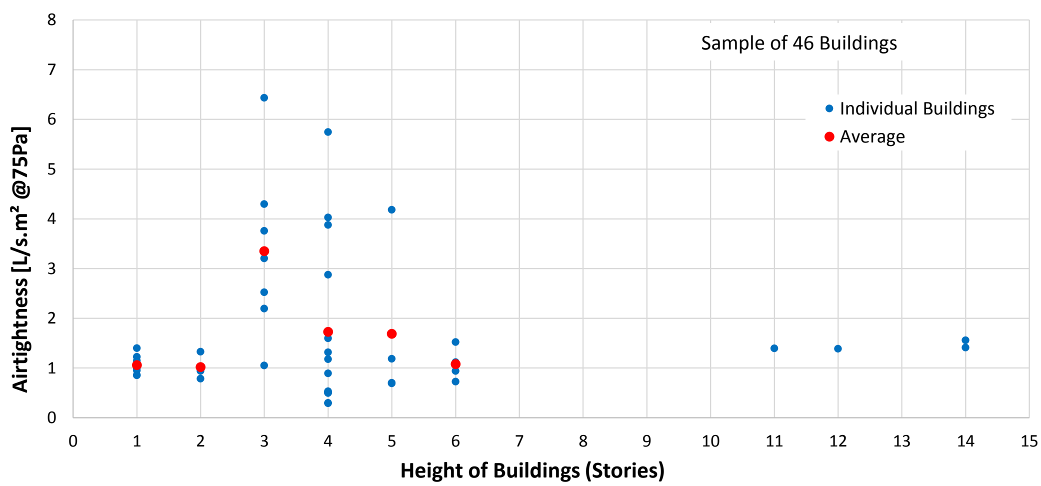

Figure 3.17: Airtightness of commercial buildings versus building height

Similar to the analysis of all of the buildings in the database, more recently constructed commercial buildings are generally more airtight and have less variation. The airtightness of commercial buildings was not found to be strongly correlated with building height.

3.3.2 Airtightness of Institutional Buildings

The data discussed in this section is for the 51 institutional buildings which includes university buildings as well as government office buildings. The distribution of the airtightness testing performance is shown in Figure 3.18.

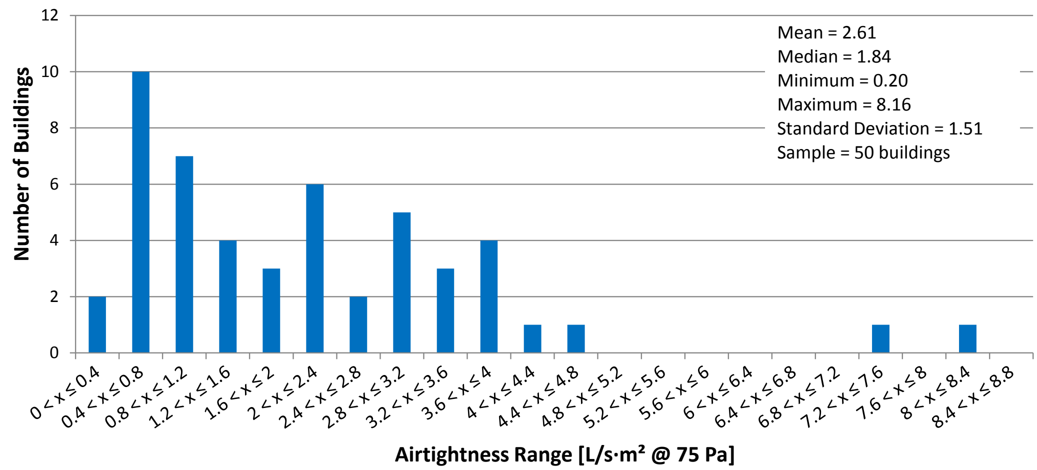

Figure 3.18: Distribution of the airtightness of institutional buildings in the database

As shown above, the average (mean) airtightness value for the institutional buildings in the database is 2.61 L/(s·m²) at 75 Pa. The median and standard deviation are 1.84 and 1.51 L/(s·m²) at 75 Pa respectively. Overall the airtightness of the commercial buildings in the database varies by orders of magnitude from 0.20 to 8.16 L/(s·m²) at 75 Pa.

The building airtightness data was also graphed versus original year of building construction, and building height as shown in Figure 3.19 and Figure 3.20 respectively.

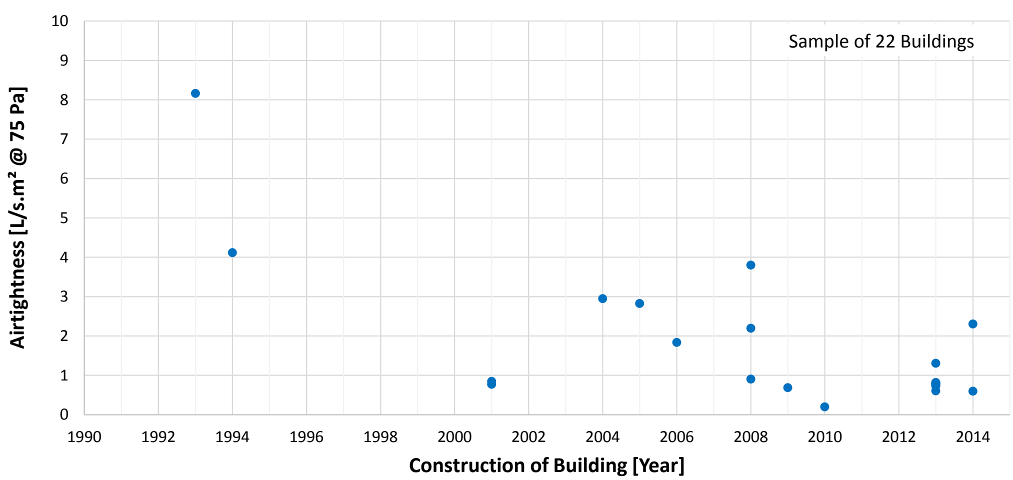

Figure 3.19: Airtightness of institutional buildings vs year of construction

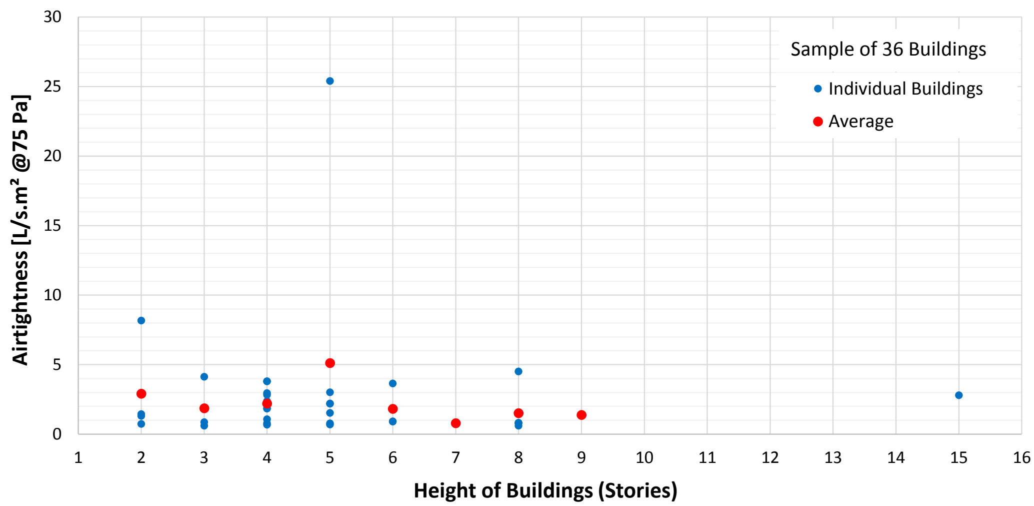

Figure 3.20: Airtightness of institutional buildings vs building height

As the date of construction was only available for 22 of the commercial buildings, it was not possible to determine if a correlation exists. Figure 3.20 shows that the airtightness of the institutional buildings is not strongly correlated with building height.

3.3.3 Airtightness of Multi-Unit Residential Buildings

The data discussed in this section is for the 113 multi-unit residential buildings (MURBs) in the database. The distribution of the airtightness performance of these buildings is shown in *Figure 3.21*.

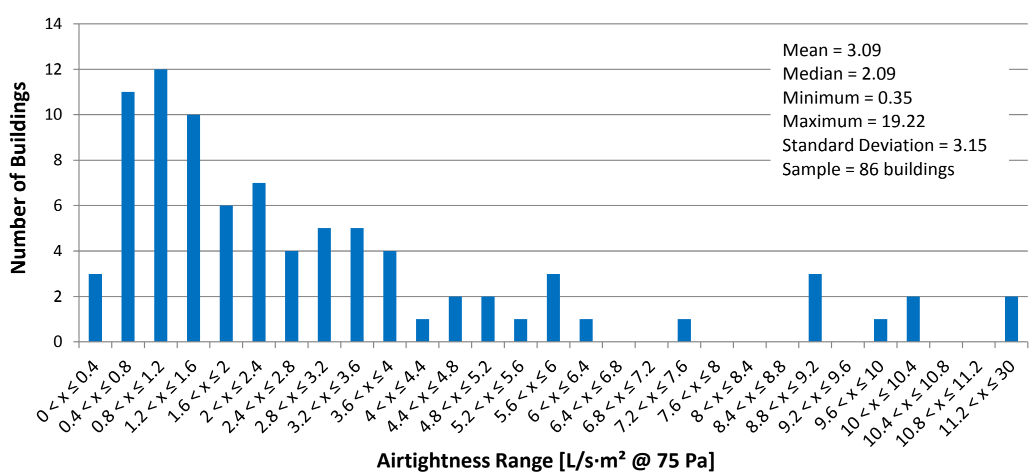

Figure 3.21: Distribution of airtightness of multi-unit residential buildings in the database

As shown above, the average (mean) airtightness value for the MURBs in the database is 3.09 L/(s·m²) at 75 Pa. The median and standard deviation are 2.09 and 3.15 L/(s·m²) at 75 Pa respectively. Overall the airtightness of buildings in the database varies by orders of magnitude from 0.35 to 19.22 L/(s·m²) at 75 Pa.

The MURB airtightness data was also graphed versus original year of building construction, and building height as shown in *Figure 3.22* and *Figure 3.23* respectively.

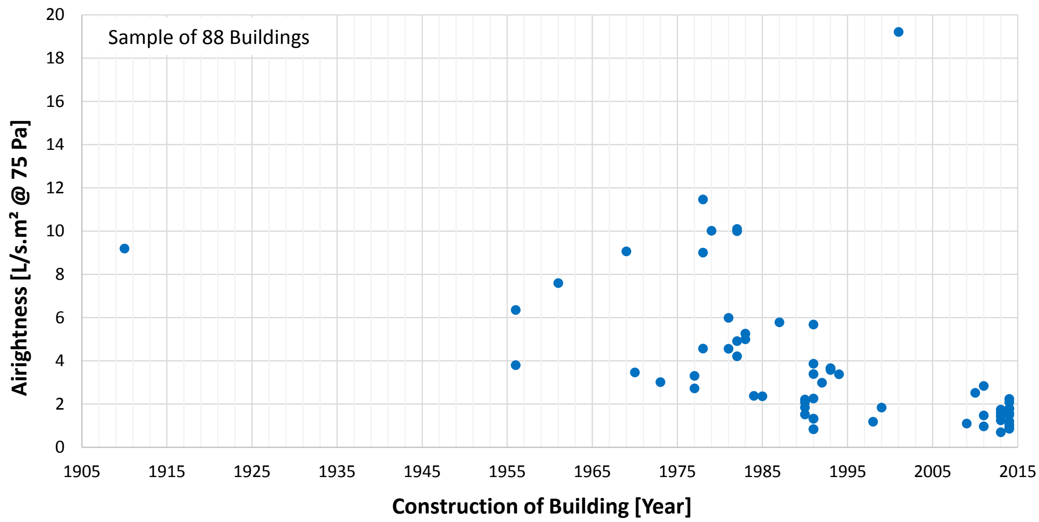

Figure 3.22: Airtightness of multi-unit residential buildings vs year of construction

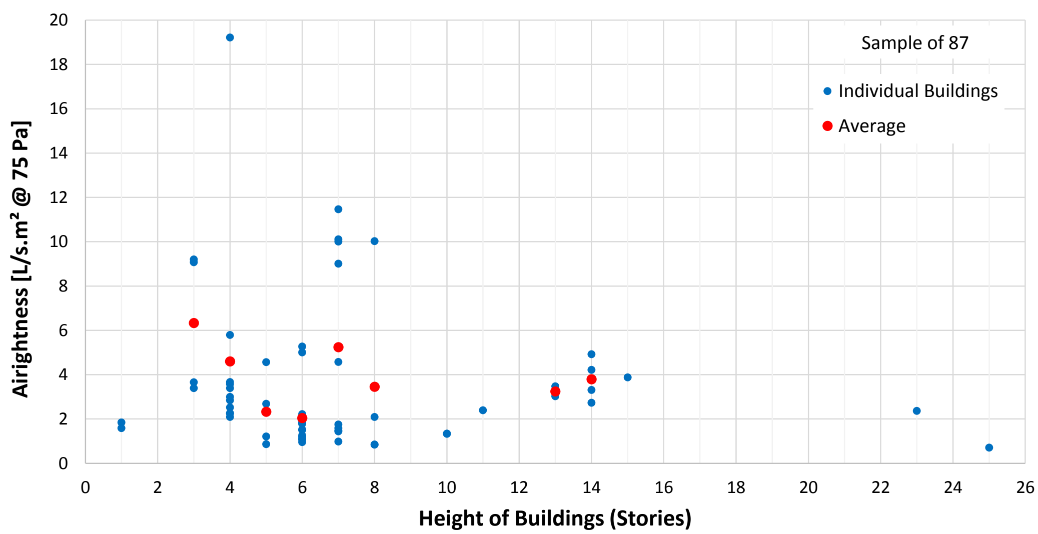

Figure 3.23: Airtightness of multi-unit residential buildings vs height of the building

Similar to the analysis of all of the buildings in the database, more recently constructed MURBs are generally more airtight than older MURBs. Similar to all the other buildings types the airtightness of MURBs seem to have no significant correlation with building height.

3.3.4 Airtightness of Military Buildings

The data discussed in this section is for the 260 military buildings. The distribution of the airtightness of these buildings is shown in Figure 3.24.

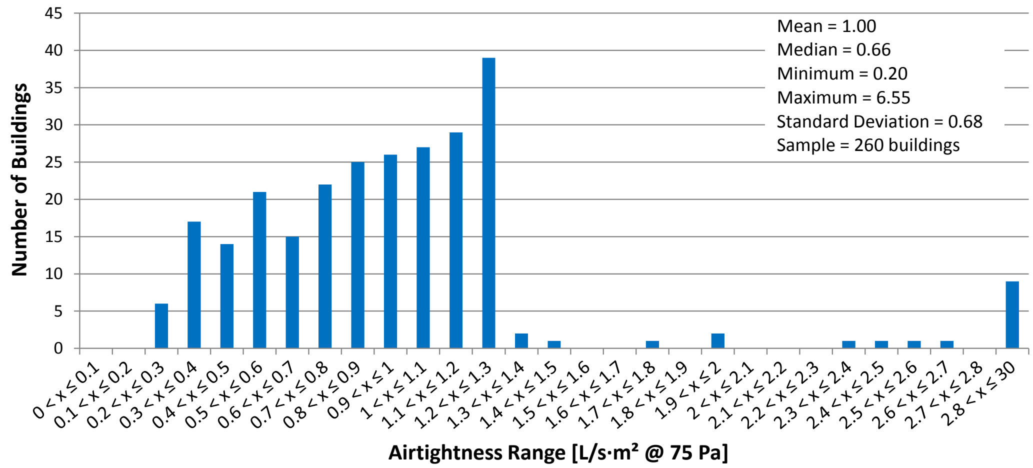

Figure 3.24: Distribution of airtightness of military buildings in the database

As shown Figure 3.24, the average (mean) airtightness value for the military buildings in the database is 1.00 L/(s·m²) at 75 Pa. The median and standard deviation are 0.66 and 0.68 L/(s·m²) at 75 Pa respectively. The vast majority of military buildings are more airtight than 1.27 L/(s·m²) at 75 Pa, which is the USACE performance requirement for new buildings. Buildings which do not initially achieve this requirement must be modified and retested.

The distribution of airtightness performance for these buildings is unusual, and shows and sharp drop in frequency corresponding with the prescribed performance target. While this may occur due to modification and retesting, one would still expect a more normal distribution of results about a mean performance level.

Military buildings cover a large variety of buildings types, so the 260 military buildings were further broken down by the type of service the building offers (i.e. occupation classification). The occupation classification breaks the buildings up into six different categories as shown in Figure 3.25. To assess whether these differences in building types significantly impact the airtightness performance of the buildings, the average airtightness for each occupancy classification is provided in Figure 3.26. This figure shows that the average airtightness for most of the military occupancy classifications are similar, but that service buildings are relatively less airtight.

The armory classification includes any buildings used to store or repair military weapons which includes vehicles. Barracks classification includes large dorm style buildings as well as on base family housing. Facilities include any buildings required for the maintenance of the base such as warehouses or operational buildings. Offices include any administration buildings and team headquarters. Service buildings are the most varied classification and included therapy centres, health centers, day cares, on base family community centres, chapels, etc. Training buildings are any buildings set-up with the purpose of teaching new skills so this includes classrooms, gun ranges, weight rooms, etc.

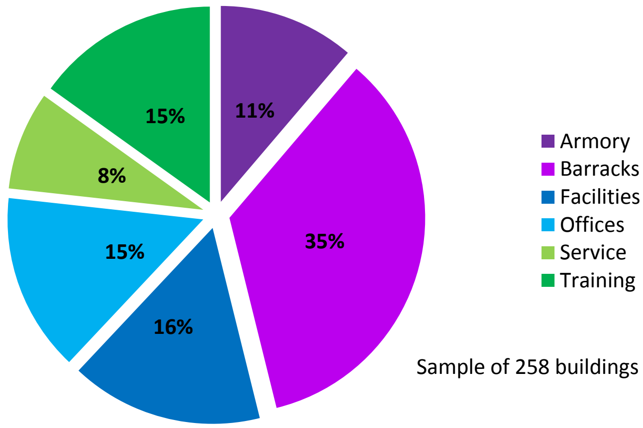

Figure 3.25: Distribution of occupancy classification of military buildings

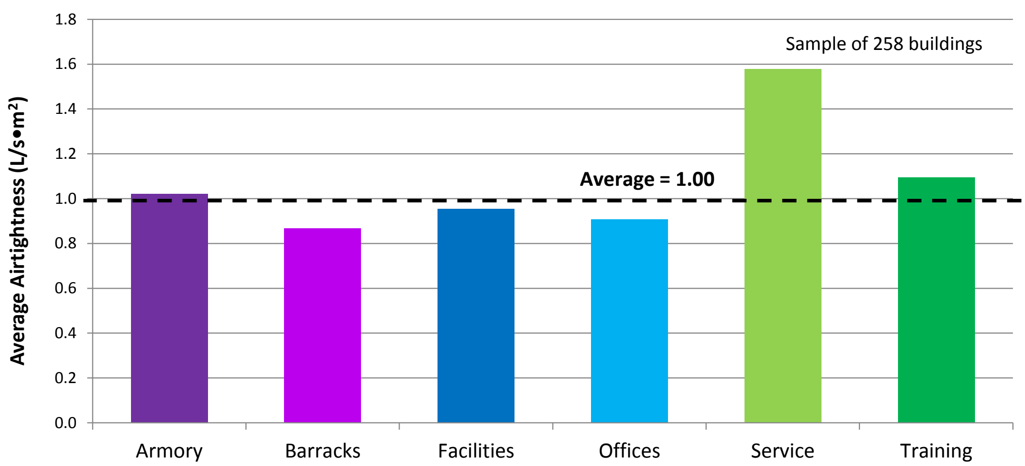

Figure 3.26: Average airtightness by for each military building occupation classification

The military building airtightness data was also graphed versus building height as shown in Figure 3.27. This figure illustrates that the airtightness of military buildings shows no correlation with building height. Insufficient data was available to assess the airtightness of the military buildings based on year of construction.

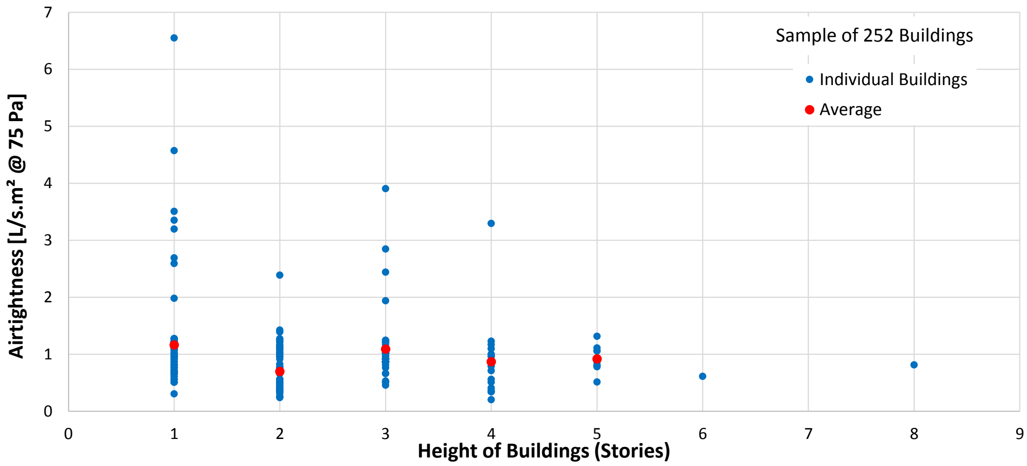

Figure 3.27: Airtightness of military buildings vs building height

It is important to note that while these buildings have been classified as military, it would actually be more accurate to classify them as USACE buildings as their performance is more indicative of that associated with buildings were airtightness testing was required. The performance of these buildings, for example, is unlikely to be representative of the performance of Canadian military buildings.

3.4 Analysis of Canadian Buildings

The data collected and discussed in this section is for the 74 buildings located in Canada. There are 16 buildings located in British Columbia, 29 in the prairies, 14 in Ontario, 10 in Quebec, and 5 in the Atlantic Provinces. The distribution of the geographic locations of the Canadian buildings in the database is shown in Figure 3.28.

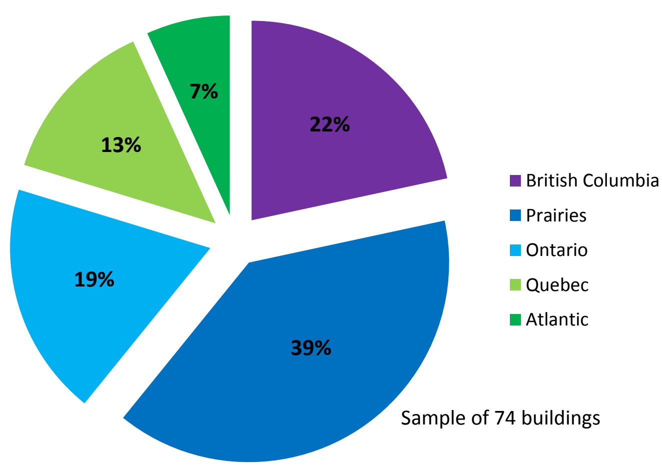

Figure 3.28: Geographical distribution of Canadian buildings

The distribution of the airtightness of the Canadian buildings, as provided in Figure 3.29, indicates that the airtightness of these buildings is highly variable. The average (mean) airtightness value for the Canadian buildings in the database is 2.93 L/(s·m²) at 75 Pa. Airtightness performance of these buildings varies by orders of magnitude with the minimum and maximum being 0.20 L/s·m2 and 19.22 L/s·m2 at 75 Pa respectively.

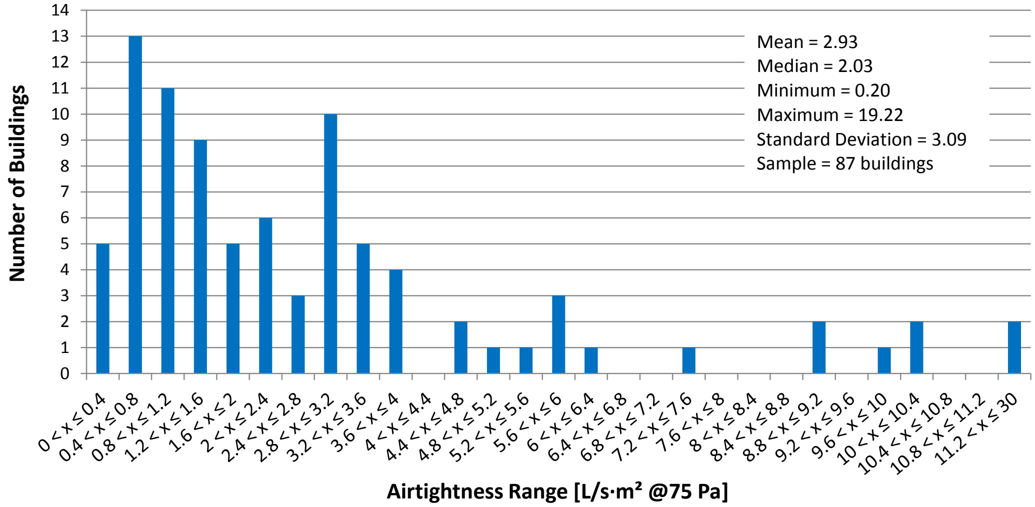

Figure 3.29: Distribution of Canadian building airtightness

Figure 3.30 shows the average airtightness of the buildings in each province. There is a significant difference in the airtightness of buildings in each province with the Prairies generally having significantly more airtight buildings than the other provinces. This may be due to colder climate, or alternatively could be a reflection of many of the prairie buildings having been constructed relatively recently. Buildings in Quebec and the Atlantic provinces are the least airtight with an average of 7.14 L/(s · m²) and 6.61 L/(s · m²). British Columbia and Ontario are close to the Canadian average with an average of 3.57 and 2.77 L/(s · m²) respectively. The observed difference in performance may reflect differences in standard construction practices, climate, etc.

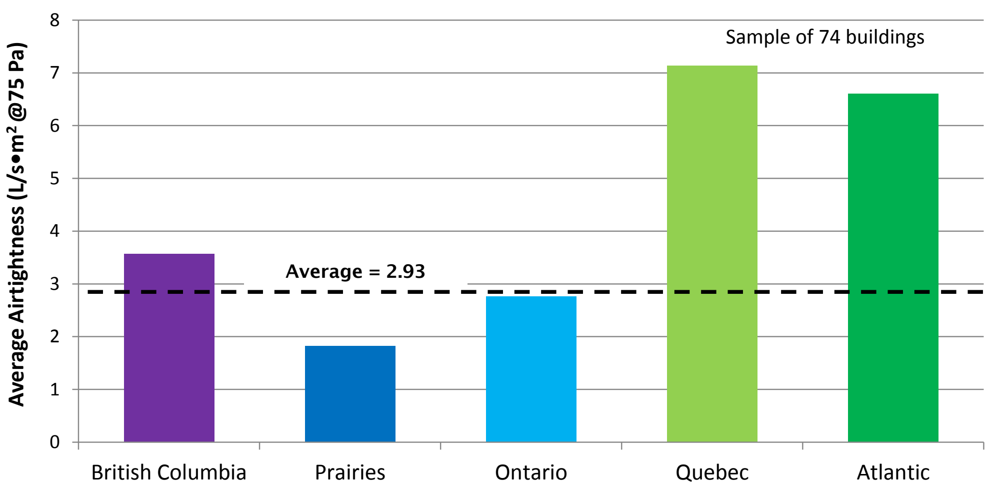

Figure 3.30: Average airtightness of Canadian buildings by location

Figure 3.31 and Figure 3.32 show the airtightness of the Canadian buildings versus year of construction and height.

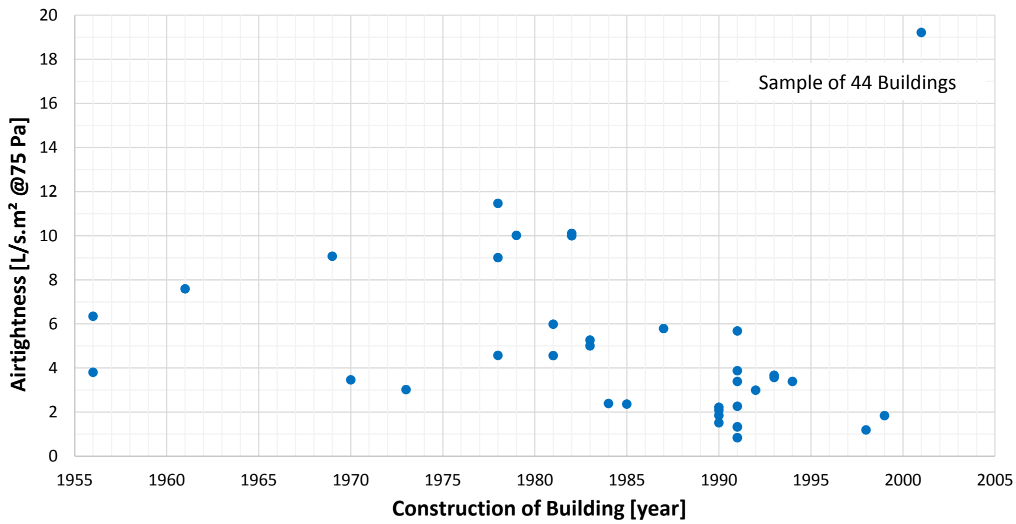

Figure 3.31: Airtightness of Canadian buildings vs year of construction

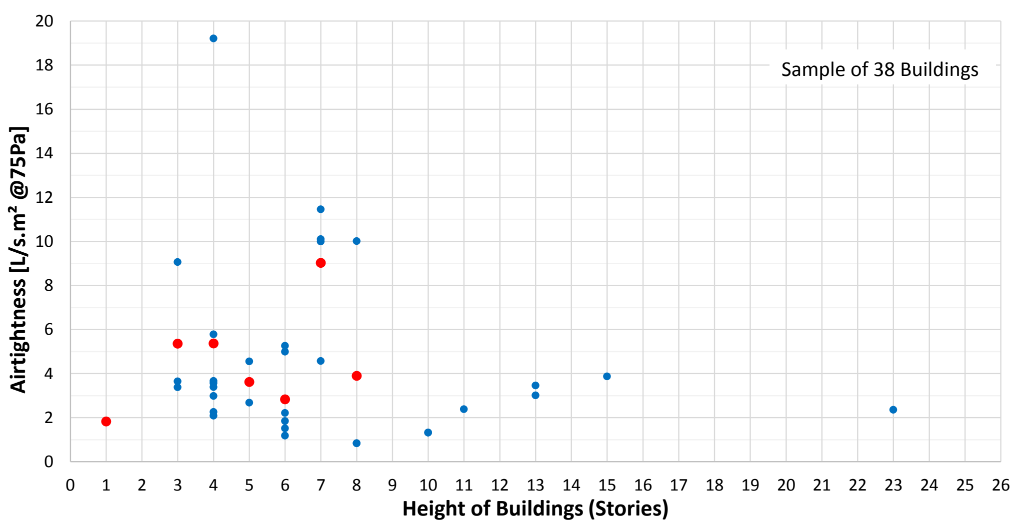

Figure 3.32: Airtightness of Canadian buildings vs building height

Similar to the analysis of all of the buildings in the database, more recently constructed Canadian buildings are generally more airtight and have less variance as shown in Figure 3.31. Also similar to the analysis of all of the buildings in the database, the airtightness of Canadian buildings shows no significant correlation with building height.

3.5 Comparison of Building Types and Location

There is a noticeable difference between the airtightness of the different building types (Commercial, Institutional, Military, and MURB). The differences in the averages for each building type can be seen below in Figure 3.33.

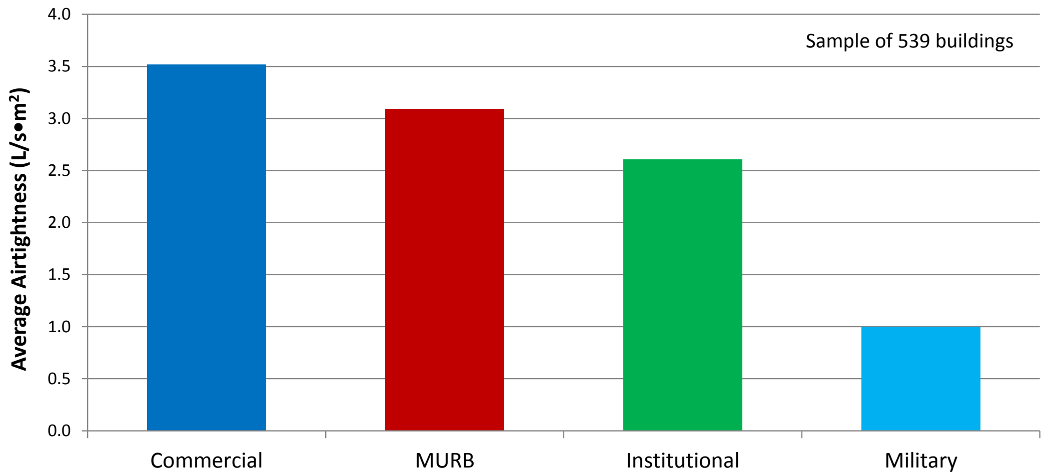

Figure 3.33: Average airtightness of building types

Not only are the averages of the building types different, but the distributions of airtightness are also significantly different. Figure 3.34 shows a statistical summary of each building type. Details included in the statistical summary are the maximum and minimum values for the dataset, median (middle of the dataset) and the first and third quartiles (the value under which 25% and 75% of the values fall). In this graphical representation it is clear that the military buildings are the most airtight, and these buildings also have the smallest variation in performance.

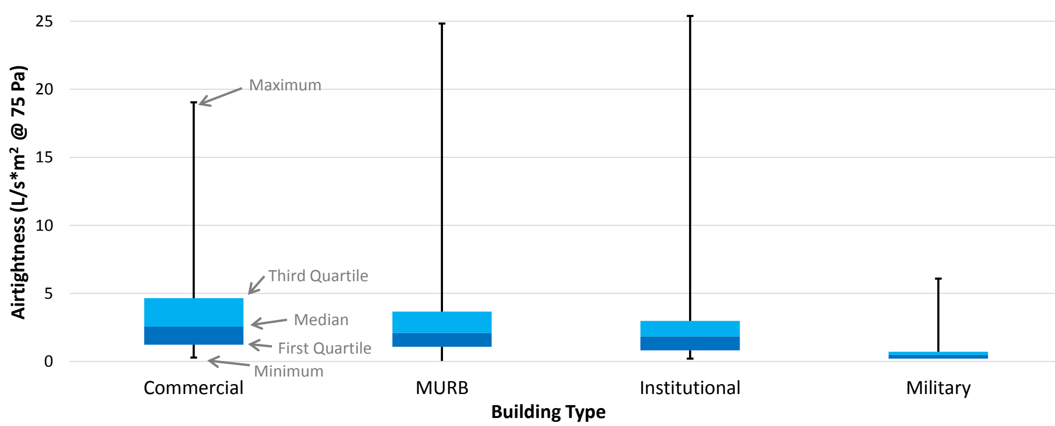

Figure 3.34: Statistical summary of building airtightness by building type

Figure 3.35 is the same statistical graphical representation of airtightness but by location instead of building type. The USA graph is very similar to that of the military graph and that is because most of the data from the USA is the 245 buildings which were tested as part of USACE requirements. The influence of these buildings where mandatory testing is required significantly skews the USA data.

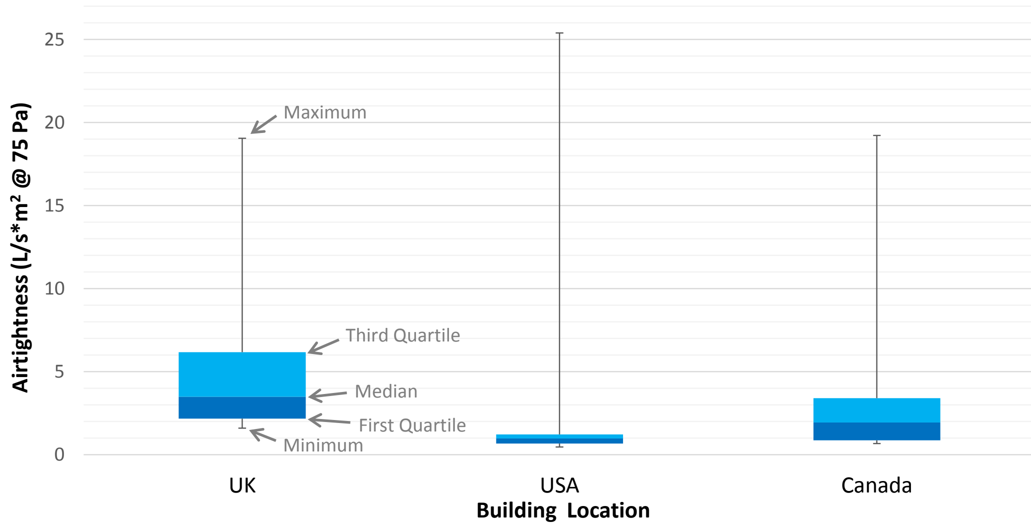

Figure 3.35: Statistical summary of airtightness of buildings by location

3.6 Analysis for Jurisdictions Requiring Testing

The airtightness database contains data from primarily two different sources where an airtightness performance requirement is enforced with mandatory testing.

One of these locations is the state of Washington where airtightness of 2.03 L/(s·m²) (0.4 cfm/ft²) at 75 Pa must be achieved for buildings over five stories. This does not include military buildings since they are covered under the more stringent USACE standard. The distribution of building airtightness for buildings in the State of Washington is provided in Figure 3.36. Importantly, the average airtightness of these buildings is significantly lower than for the dataset as a whole, and the variation in performance is also significantly reduced. Nearly all of the buildings meet the performance requirement, except for four buildings; however, these four buildings are less than five storeys tall, so the requirement does not apply.

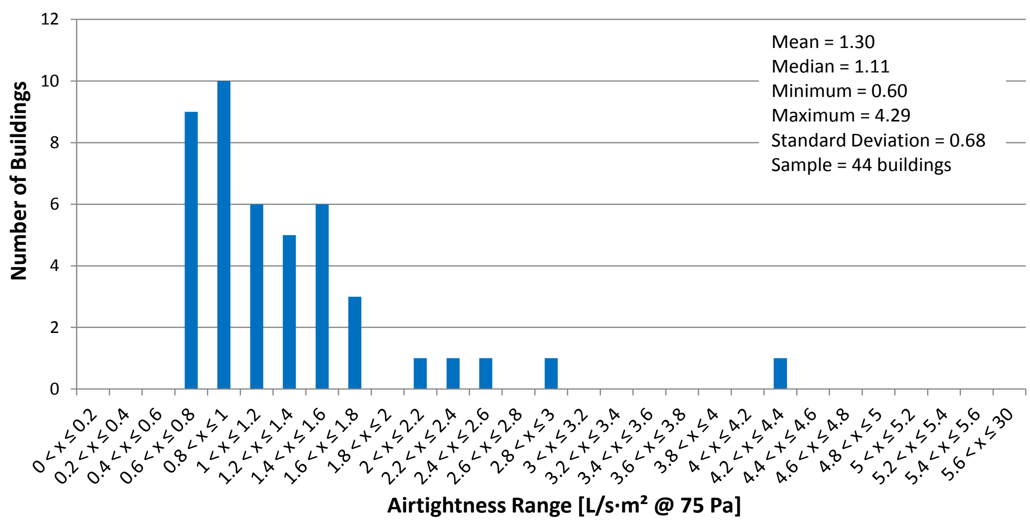

Figure 3.36: Distribution of Washington Buildings' Airtightness

Another jurisdiction which enforces a mandatory airtightness testing and performance requirement is the United States Army Corps of Engineers (USACE). The USACE requires that all new military buildings built after 2012 must be airtightness tested and achieve an airtightness of 1.27 L/(s·m²) (0.25 cfm/ft²) at 75 Pa. The distribution of buildings tested under this requirement can be seen in Figure 3.37. Out of 260 buildings only 19 buildings do not meet the requirement. Similar to the distribution for buildings tested in the State of Washington, the variation in performance is also significantly reduced when compared to the database of buildings as a whole.

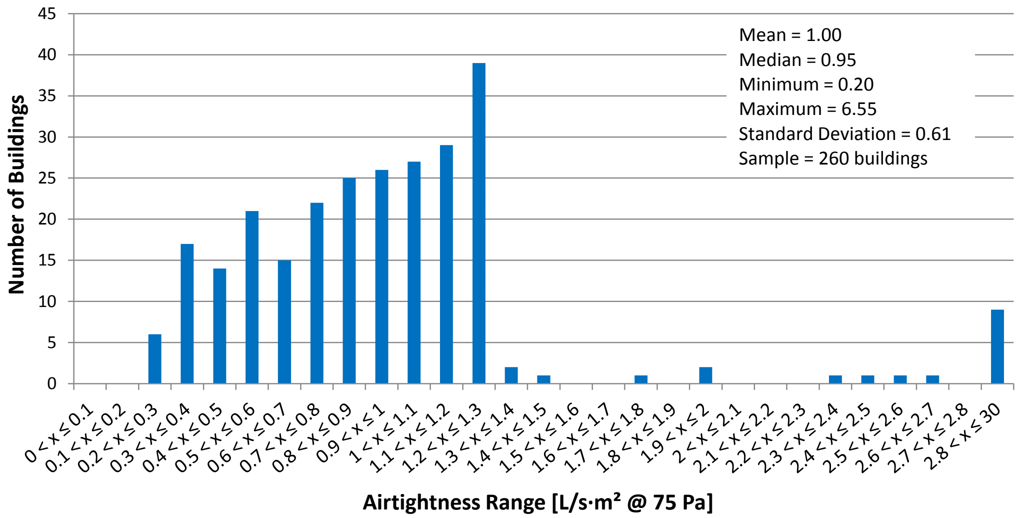

Figure 3.37: Distribution of USACE Buildings' Airtightness

Importantly, the State of Washington and USACE data indicate that when airtightness performance and testing requirements are implemented, significantly more airtight building can be consistently constructed to meet the requirement.

As part of the data collection, the motivation for airtightness testing was recorded. Figure 3.38 provides the airtightness performance results based on whether they were collected for research purposes or as part of compliance with a testing and performance requirement. This figure clearly indicates that buildings which were tested as part of a mandated performance and testing requirement are significantly more airtight than data collected from buildings which were not built to such a requirement. This finding suggests that the implementation of airtightness requirements can lead to the construction of significantly more airtight buildings.

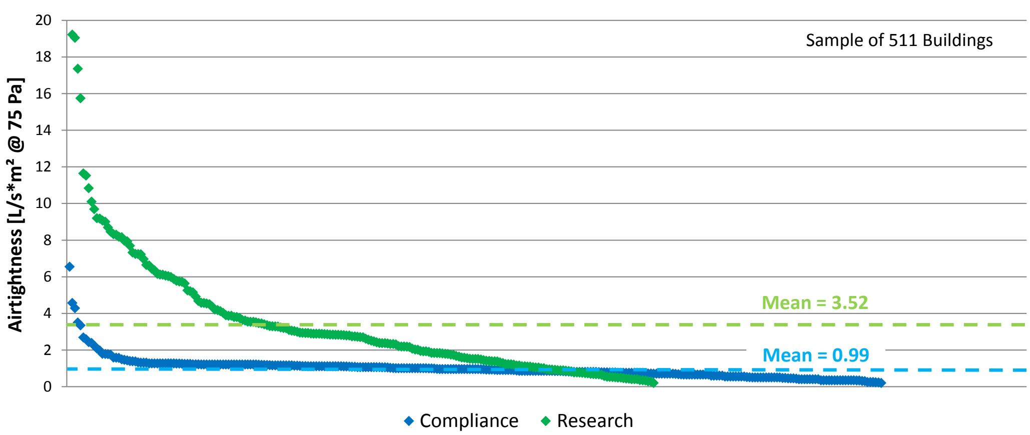

Figure 3.38: Airtightness of buildings by for compliance and research testing

To confirm this finding, the distribution of data for the State of Washington, USACE, and "research" testing are plotted in Figure 3.39 to illustrate the differences in this data. Additionally, a two sided t-test was performed to compare the mean averages of the research and compliance test data, and this analysis confirmed that the average performance of these datasets is statistically different at a 95% confidence interval.

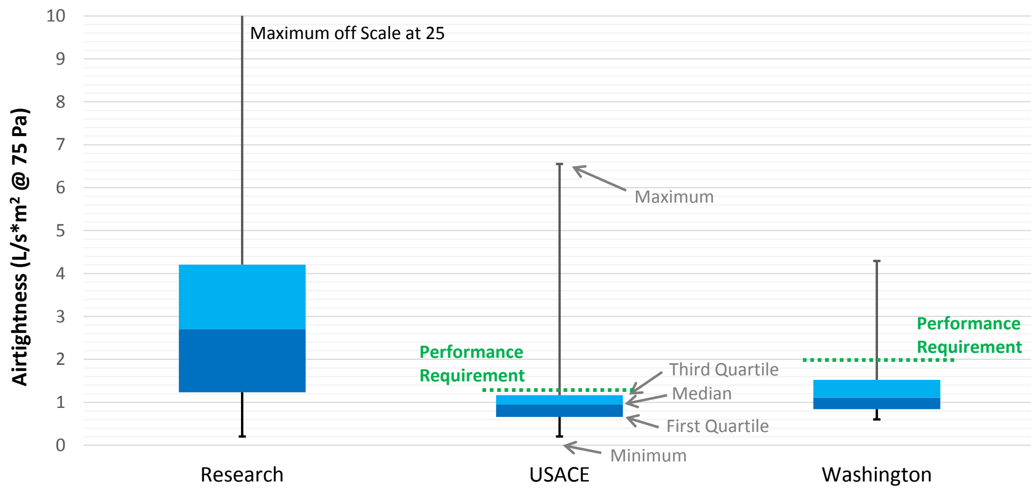

Figure 3.39: Comparison of distribution of airtightness performance for buildings tested for research purposes and buildings tested for compliance with USACE and State of Washington mandatory testing requirements.

Figure 3.40 plots the test results for a sample size of 31 WSEC/SEC buildings by primary wall air barrier type. This data clearly indicates that any one of these systems can be constructed to be highly airtight, and consequently it is primarily the detailing o interfaces and workmanship which have a larger impact on the airtightness of the building. Each of these air barriers provides performance typically well below the code target of 2.0 L/s·m² at 75 Pa. (Jones et al., 2014)

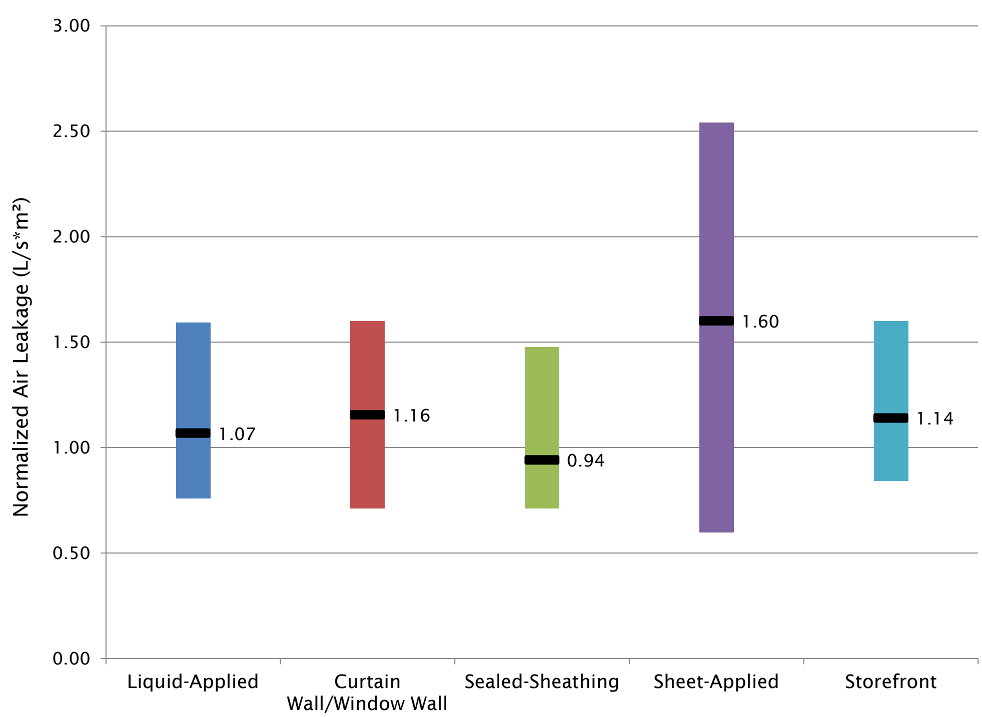

Figure 3.40 Whole building minimum, maximum, and average airtightness results for each air barrier type for WSEC/SEC buildings. Average values shown as black dashes. (Jones et al, 2014)

4 Whole Building Airtightness Performance and Testing Requirements

4.1 Summary of Performance and Testing Requirements

This section provides a summary of whole building airtightness testing and performance requirements with a focus on North America. Many building codes and standards provide guidance regarding the air permeance of materials, accessories, and components which form part of a building's air barrier system; however, these requirements are outside the scope of this study, and are seldom the most important factor with respect to whole building airtightness. Detailing of penetrations and transitions is where most air leakage tends to occurs. This chapter also only describes codes and standards with respect to large (i.e. Part 3) buildings, as single-detached residential buildings (i.e. Part 9) typically have substantially different requirements. A table summarizing North American and international requirements is provided in Section 4.1.11.

4.1.1 Codes & Standards with No Whole Building Requirement

The majority of codes and standards in North America do not include a specific testing or performance requirement with respect to whole building airtightness. Most of these include requirements for the air permeance of materials and components (i.e. windows), and in some cases also include language indicating the enclosure must include an air barrier which must be detailed as continuous. These standards include:

- → National Building Code for Canada (NBC) 2010
- → National Energy Code for Buildings (NECB) 2011
- → ASHRAE 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings
- → ASHRAE 189.1-2014 Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings
- → Leadership in Energy and Environmental Design (LEED) v4 and LEED Canada 2009

It is worth noting that while the NECB does not include a specified airtightness, it does include a recommended air leakage rate of 0.25 L/(s·m²) which Section A-8.4.3.4.(3) of the code indicates corresponds with "a typical infiltration rate at 5 Pa." This recommended rate is discussed in detail in Chapter 0.

4.1.2 International Building & Energy Conservation Codes 2012

The International Building Code (IBC) 2012 does not specifically address whole building airtightness, but does specify that buildings be built in accordance with the International Energy Conservation Code (IECC) 2012.

The IECC 2012 includes airtightness requirements for commercial buildings located in Climate Zones 4 to 8. Commercial buildings under the IECC includes nearly all large buildings, including multi-unit residential buildings. Compliance with respect to airtightness can be achieved through one of three paths: materials, assemblies, or building. The first two compliance options provide requirements for the airtightness of the materials or assemblies which are used. These requirements are 0.004 cfm/ft² (0.02 L/(s·m²)) or 0.04 cfm/ft² (0.2 L/(s·m²)) respectively when tested at 0.3 inches of water gauge (75 Pa). The building compliance option allows instead for testing of the completed building. The code specifies that these buildings are to achieve an airtightness of 0.40 cfm/ft² (2.0 L/(s·m²)) at 0.3 inches of water gauge (75 Pa). The test is to be in accordance with ASTM E 779 or an equivalent which can be approved by the code official. In Climate Zones 1 to 3, air barriers are not required in buildings following the commercial requirements of the IECC. Figure 4.1 provides a map of the ASHRAE/IECC Climate Zones for reference.

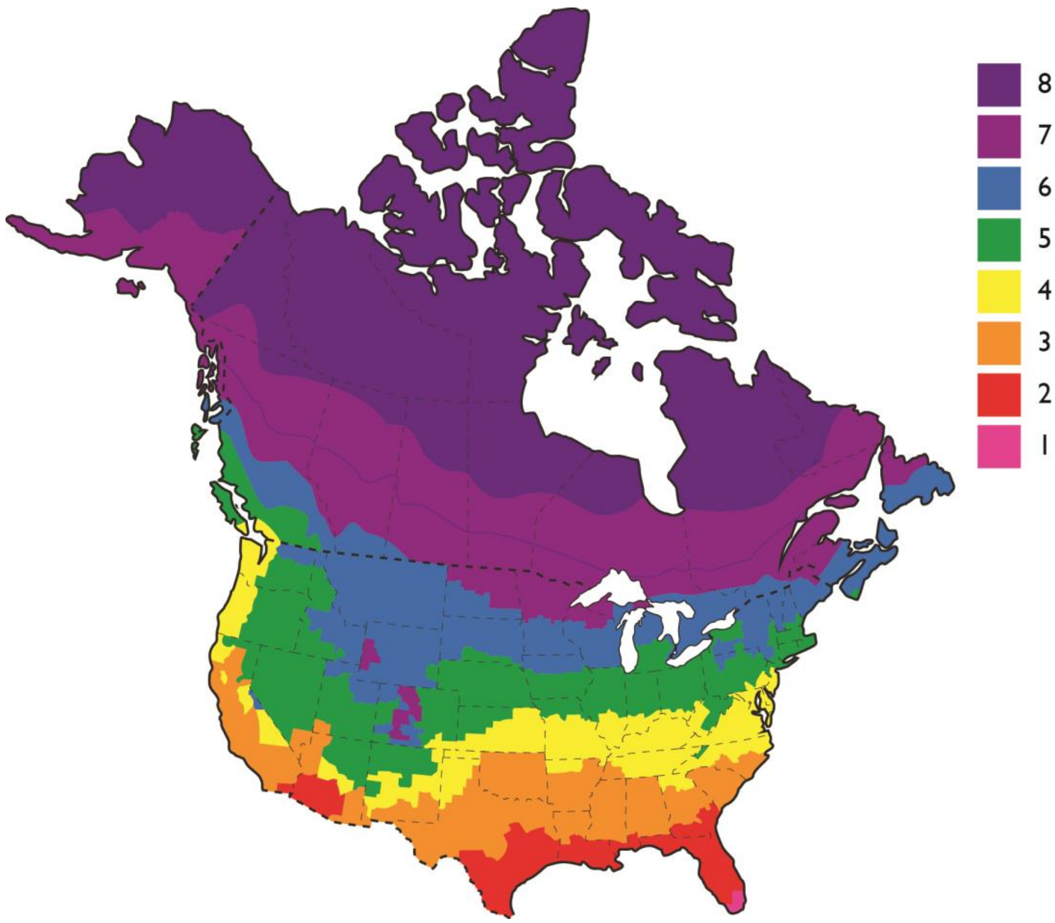

Figure 4.1: ASHRAE/IECC Climate Zone Map – Based on Current DOE US and Canadian Climate Zones 1 through 8

The IECC 2012 also includes airtightness testing and performance requirements for residential buildings; however, these requirements do not typically apply to the type of buildings addressed in this study. For residential buildings, a whole house or dwelling unit fan-door test must achieve a maximum air leakage rate of 5 ACH50 (air changes per hour at 50 Pa) or less in Climate Zones 1-3 and 3 ACH50 or less in Climate Zones 4-8 is required.

4.1.3 International Green Construction Code (IGCC) 2012

The International Green Construction Code (IGCC) 2012 requires that building achieve the same airtightness requirement as the IECC 2012 except that the requirement is specified to apply to all climate zones (i.e. 1 to 8) and the requirement is 0.25 cfm/ft² (1.25 L/(s·m²)) at 0.3 inches of water gauge (75 Pa). Under the IGCC, whole building airtightness performance and testing is the only compliance path.

4.1.4 Washington State & Seattle

The first versions of the Washington State and Seattle Energy Codes to include a whole building airtightness testing requirement were dated 2009, and were effective July 1, 2010 and January 1, 2011 respectively. The 2009 SEC required testing of all new commercial buildings, while the 2009 WSEC required testing of all new commercial buildings over 5 stories in height. (Commercial buildings are defined in the same manner as for the IBC 2012.) In the 2009 version of these codes, only testing of the buildings was required, and the result had to be reported, but a performance target did not have to be achieved.

The new 2012 WSEC and SEC also require whole building airtightness testing, and both are applicable to all new commercial buildings. Both codes specify a minimum airtightness of 0.40 cfm/ft² (2.0 L/(s·m²)) at 0.3 inches of water gauge (75 Pa) when tested in accordance with ASTM E 779. Some relatively minor modifications to the ASTM E 779 test standard are specified when using the SEC. Under both codes, if the building fails to meet the airtightness performance target, measures must be taken to inspect and seal the air barrier "to the extent practicable." Once a report documenting this sealing work has been submitted to the code official, there is no need to retest the building to ensure compliance with the performance target.

The WSEC and SEC also require testing of residential buildings; however, this requirement is not of particular relevance to this study.

4.1.5 City of Fort Collins, Colorado

The city of Fort Collins, Colorado also mandates whole building airtightness testing under its Ordinance No. 031, 2011. For commercial buildings covered by the IBC, Fort Collins has specified that an airtightness testing of the completed building must be performed and that the building must achieve 0.25 cfm/ft² (1.25 L/(s·m²)) at 0.3 inches of water gauge (75 Pa) when tested in accordance with ASTM E 779 or an equivalent approved method. This requirement is similar to that provided by the IGCC. The commercial building airtightness provisions of the ordinance came in to effect on January 1, 2012.

4.1.6 United States Army Corps of Engineers

The United States Army Corps of Engineers (USACE) has developed its own airtightness testing procedure in partnership with the Air Barrier Association of America (ABAA0. The specific of the test procedure are discussed in a later section of this report; however, of importance is that the standard also include a performance requirement. All new buildings and renovations worth 25% or more of the building replacement cost that are under the jurisdiction of the USACE must be tested in accordance with the standard and achieve a whole building airtightness of 0.25 cfm/ft² (1.25 L/(s·m²)) at 0.3 inches of water gauge (75 Pa). The USACE test standard is based on ASTM E 779. The USACE standard came in to effect in 2012.

4.1.7 General Services Administration (PBS-P100)

The United States General Services Administration (GSA) PBS-P100 *Facilities Standards for the Public Buildings Service* includes requirements with respect to airtightness performance and testing. The standard requires that all new buildings and major repairs or alterations under the jurisdiction of the GSA achieve airtightness performance of 2.0 L/(s·m²) at 75 Pa (0.4 cfm/ft² at 0.3 inches of water gauge) when tested in accordance with ASTM E 779 or ASTM E 1827.

The GSA standard also requires that these buildings achieve a minimum gold rating through the Leadership in Energy and Environmental Design (LEED) Green Building Rating System of the U.S. Green Building council. As discussed in Section 4.1.10, this requirement carries with it additional airtightness testing requirements.

4.1.8 United Kingdom

The Airtightness Testing & Measurement Association in the United Kingdom produces *Technical Standard L2 – Measuring Air Permeability of Building Envelopes (Non-Dwellings).* The most recent version (October 2010) of this standard requires that all building with floor area greater than 500 m² must be tested and achieve a minimum airtightness of 10 m³/(h·m²) (2.8 L/(s·m²) or 0.55 cfm/ft²) at 50 Pa. Assuming a flow exponent ("n") of 0.65, this corresponds with 3.6 L/(s·m²) (0.72 cfm/ft²) at 75 Pa.

4.1.9 Passive House

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 Passive House 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 Passive House.

4.1.10 LEED Green Building Rating System

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System 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 airtightness requirements with respect to energy consumption or durability purposes. Instead, LEED's airtightness requirements are included for containment of indoor pollutants – primarily tobacco smoke.

LEED Canada for New Construction and Major Renovations 2009 and LEED v4 for Building Design and Construction (US Green Building Council) include one compliance path which includes airtightness testing of multi-unit residential buildings, hotels, motels and dormitories. Individual suites in these buildings must be tested in accordance with ASTM E779-03 and achieve an Equivalent Normalized Leakage Area (Normalized EqLA) of 1.65 cm²/m² (1.52 L/(s·m²) or 0.56 cfm/ft²) of enclosure when calculated using the CGSB 149.10 method. In this case, the "enclosure" includes both the exterior enclosure and interior separating elements. (CaGBC, 2009)

In the American version of LEED, if smoking is to be permitted within a multi-unit residential building, one of the mandatory requirements of the standard which is necessary to obtain any LEED certification, is that individual suites achieve an 1.17 L/(s·m²) (0.23 cfm/ft²) at 50 Pa. (USGBC, 2014)

There is no airtightness requirement for other building types under either the Canadian or American versions of the LEED rating system.

4.1.11 Summary of North American and International Requirements

For reference, a summary of North American and international airtightness testing and performance requirements is provided in Table 4.1 and Table 4.2 respectively. These tables have been adapted with permission from the tables provided in the Residential Pressure and Air Leakage Testing Manual produced by Retrotec (2012). Note that in some cases the test requirements referenced here are only one of the potential compliance paths for meeting the airtightness requirement, and consequently, testing may not actually be required. When possible, all performance metrics have been converted to L/(s·m²) at 75 Pa using an assumed flow exponent of 0.65.

TABLE 4.1 WHOLE BUILDING AIRTIGHTNESS PERFORMANCE REQUIREMENTS FOR CANADA AND THE UNITED STATES (RETROTEC, 2012)

Standard	Region	Comments	Requirements
USACE	USA	Large Buildings	1.27 L/(s·m²) @ 75 Pa
		Large Buildings (Proposed)	0.76 L/(s·m²) @ 75 Pa
GSA	USA	All Buildings	2.03 L/(s·m²) @ 75 Pa
2012 Washington State Energy Code	Washington State	Commercial Buildings	2.03 L/(s·m²) @ 75 Pa
2012 Seattle Energy Code	Seattle	Commercial Buildings	2.03 L/(s·m²) @ 75 Pa
IBC/IECC	Model Code	Commercial Buildings in Climate Zone 4 – 8	2.03 L/(s·m²) @ 75 Pa
IGCC	Model Code	Commercial Buildings	1.27 L/(s·m²) @ 75 Pa
LEED	USA	All 6 surfaces enclosing an apartment.	1.17 L/(s·m²) @ 75 Pa
LEED Canada	Canada	All 6 surfaces enclosing an apartment.	1.52 L/(s·m²) @ 75 Pa
Passive House (Canada	Canada	All buildings	0.6 ACH_{50}

TABLE 4.2 INTERNATIONAL WHOLE BUILDING AIRTIGHTNESS PERFORMANCE REQUIREMENTS (RETROTEC, 2012)

Region	Standard/ Code	Applies To	Requirements
Austria		Naturally Ventilated	3.0 ACH_{50}
		Mechanically Ventilated	1.5 ACH_{50}
Belgium			4.3 L/(s·m²) @ 75 Pa

TABLE 4.2 INTERNATIONAL WHOLE BUILDING AIRTIGHTNESS PERFORMANCE REQUIREMENTS (RETROTEC, 2012)

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		2.2	L/(s·m²) @ 75 Pa
		Small buildings, existing		3.3	L/(s·m²) @ 75 Pa
		Large buildings, new		1.1	L/(s·m²) @ 75 Pa
		Large buildings, existing		2.2	L/(s·m²) @ 75 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		2.2	L/(s·m²) @ 75 Pa
		Other buildings		4.7	L/(s·m²) @ 75 Pa
Germany	DN 4108-7	Naturally ventilated		3	ACH_{50}
		Mechanically ventilated		1.5	ACH_{50}
India	Energy Conservation Code			2.0	L/(s·m²) @ 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		1.1	L/(s·m²) @ 75 Pa
		Medium		2.1	L/(s·m²) @ 75 Pa

TABLE 4.2 INTERNATIONAL WHOLE BUILDING AIRTIGHTNESS PERFORMANCE REQUIREMENTS (RETROTEC, 2012)

		High		4.1	$L/(s \cdot m^2)$ @ 75 Pa
Slovenia		Naturally ventilated		3.0	ACH_{50}
		Mechanically ventilated		2.0	ACH_{50}
Scotland		Current Regulation		1.8	$m^3/hr \cdot m^2$ @ 50 Pa
		New Regulation		0.4	$m^3/hr \cdot m^2$ @ 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			3.6	$m^3/hr \cdot m^2$ @ 50 Pa
United Kingdom	ATTMA TS-L2	Best Practice	Office – Natural Ventilation	1.1	$L/s \cdot m^2$ @ 75 Pa
			Office – Mixed Ventilation	0.9	$L/s \cdot m^2$ @ 75 Pa
			Office – AC/low energy	0.7	$L/s \cdot m^2$ @ 75 Pa
			Factories/Warehouses	0.7	$L/s \cdot m^2$ @ 75 Pa
			Supermarkets	0.4	$L/s \cdot m^2$ @ 75 Pa
			Schools	1.1	$L/s \cdot m^2$ @ 75 Pa
			Hospitals	1.8	$L/s \cdot m^2$ @ 75 Pa
			Museums/archives	0.4	$L/s \cdot m^2$ @ 75 Pa
			Cold stores	0.1	$L/s \cdot m^2$ @ 75 Pa
		Normal Practice	Office – Natural Ventilation	2.5	$L/s \cdot m^2$ @ 75 Pa
			Office – Mixed Ventilation	1.8	$L/s \cdot m^2$ @ 75 Pa
			Office – AC/low energy	1.8	$L/s \cdot m^2$ @ 75 Pa
			Factories/Warehouses	2.2	$L/s \cdot m^2$ @ 75 Pa
			Supermarkets	1.8	$L/s \cdot m^2$ @ 75 Pa
			Schools	3.3	$L/s \cdot m^2$ @ 75 Pa
			Hospitals	3.3	$L/s \cdot m^2$ @ 75 Pa
			Museums/archives	0.5	$L/s \cdot m^2$ @ 75 Pa
			Cold stores	0.1	$L/s \cdot m^2$ @ 75 Pa
	Current Regulations	New Building		3.6	$L/s \cdot m^2$ @ 75 Pa
		Small Building (less than 500 m^3)		5.4	$L/s \cdot m^2$ @ 75 Pa
		Large Building		1.8	$L/s \cdot m^2$ @ 75 Pa
	New Regulations	With cooling requirement		1.1	$L/s \cdot m^2$ @ 75 Pa
		Without cooling requirement		1.8	$L/s \cdot m^2$ @ 75 Pa

5 Impact of Implementing Whole Building Airtightness Requirements

This chapter discusses the impact on the industry of implementing whole building airtightness requirements both on a voluntary and mandatory basis. This impact is evaluated using interviews and surveys that asked various members of industry including designers, constructors, and regulators about changes in construction practice as a result of the implementation of airtightness requirements. Both jurisdictions with mandatory airtightness testing and jurisdictions with voluntary testing are included.

A data collection challenge for this task was sample selection. Due to time and resource limitations, convenience sampling was used as the primary sampling method. This approach required the team to gather contextual data as part of the survey so that patterns could be accurately interpreted (for example, the level of knowledge of and support for airtightness testing may be skewed if the final sample includes a high percentage of building enclosure specialists who are likely to understand the process but may not be representative of the local industry).

To meet these challenges, a three-part data collection process was developed:

1. Identify industry associations and understand the association's perspective on the topic
2. Circulate a general survey to members within the association
3. Conduct interviews to gather more detailed information from selected individuals within that group

Not all stages produced data for both voluntary and mandatory jurisdictions. Because the goals and data for voluntary and mandatory jurisdictions are somewhat different, their results are discussed separately. Results are then discussed together in the analysis section.

5.1 Voluntary Jurisdictions

For voluntary jurisdictions, the primary goal was to provide a review of market acceptance along with benefits and challenges of incorporating whole building airtightness requirements.

5.1.1 Association-Level Feedback

An initial list was created of 79 organizations and/or regional branches with a potential interest in airtightness testing requirements. These included associations/organizations for architects, contractors, construction educators, building envelope specialists, building owners, HVAC specialists, engineers, building officials, and certified energy advisors. The organizations range in size from 30 or 40 members for regional professional groups to thousands of members for large provincial and national organizations. All regions of Canada were included as shown in Table 5.1.

TABLE 5.1 PROVINCES/TERRITORIES REPRESENTED IN ORGANIZATIONS SURVEYED		
Province/Territory	**Number of Organizations Contacted**	**Number of Organizations Participating**
Alberta	9	2
British Columbia	7	1
Manitoba	9	0
New Brunswick	1	0
Northwest Territories	1	0
Newfoundland/Labrador	0	0
Nova Scotia	5	1
Nunavut	0	0
Ontario	23	5
Quebec	8	0
Saskatchewan	3	0
Yukon	1	0
National	12	4
TOTAL	**79**	**13**

Contact information was obtained for each of these organizations and a brief email was sent explaining the project and requesting participation. Representatives from 13 of the 79 organizations expressed interest in participating. All of these received a link to an online survey to be distributed to their membership. Organizational representatives were also invited to fill out a shorter email survey themselves. Specifically, association representatives were asked:

1. If airtightness targets and testing were added to the national building code, how would your association describe the impact of these code changes on the industry generally?
2. If airtightness targets and testing were added to the national building code, do you think that construction practices would change for your members specifically? If so, in what way?
3. Do members of your association see a benefit to increasing the airtightness of large buildings through changes to the national energy code?
4. List specific concerns that you think your members might have about these code changes.
5. As we continue this study, are there issues you think we should be asking about?
6. We would like to gather input from as many people as possible. Could we have your assistance in distributing a short but more detailed survey to your membership?

The main goal of these questions was to get a sense of issues that association members may be more aware of, or perspectives that might influence their responses to the longer, more widely circulated general survey. However, the six email surveys that were received also yielded qualitative data that is interesting in itself. Overall, the feedback was positive regarding the possibility of mandatory requirements. For example, one respondent stated:

> *It is the same building science that applies to residential housing, where air tightness targets are specified, and Blower door testing as well (NBC 9.36). Other jurisdictions are ahead of Canada – Europe, US Army Core of Engineers etc.*

Other comments included "A move towards an overall measure of whole building airtightness is essential to achieve true energy reduction goals" and "Durability, HVAC system balancing and energy efficiency are among the benefits that would be realized through increased airtightness".

Even where less value was seen or concerns were raised, these do not seem to be perceived as significant barriers. For example, another respondent commented that members of his association would "probably not" see a benefit to increasing the airtightness of large buildings through code changes, but also noted that "like everything else we will adapt. Ontario is already close to this space now with the various energy programs used." Another respondent stated that "Initially, there would be a shortage of qualified field testing personnel and prices would be higher…Within a year or two there would be a levelling off".

Several respondents noted that building practices and processes would need to change significantly to accommodate mandatory testing. This predicted change was seen as positive but some concerns were raised about timelines. For example, a building code official from Ontario noted that "In projects where testing is part of the final building commissioning, the trades seem to take more pride and ownership in the work they do and they tend to work more co-operatively", but "the industry needs sufficient advance notice of an implementation date to ensure there is capacity to deliver", including capacity for municipal inspections. There was also a need expressed for specific protocols to ensure that testing happens when there is still an opportunity to correct problems and improve test results.

Some respondents also noted that acceptance of new requirements would likely be different across different sectors of the building industry. For example, one respondent noted that "single and multiple residential, light industrial and commercial developers" are "primarily motivated by profit objectives and to maximize returns for their investors" and often use products and systems that might pass individual component leakage tests but would fail if evaluated using whole building airtightness testing. Another respondent suggested there would be resistance from the HVAC industry in response to down-sizing of HVAC systems (example given: "HRAI's response to adopting the new CSA F280 revision").

Other concerns about whole building airtightness testing requirements from all of the initial email responses include:

- → Whole building airtightness versus discrete air tightness of compartments. (Example given: "in a tall building, the individual tenants on higher floors will not want to pay for the air losses of ground floor tenants who may be retail, with many doors being often used, and maybe in the case of eating businesses left open.")
- → Cost to construction companies/building owners
- → Availability of qualified trades to do the work

- → Adequate time for all affected parties to adapt (e.g. "Building Officials have restricted budgets and unlike the industry, we often need significant lead time to ramp up with staffing and provide training")
- → Ensuring that related systems and issues are considered simultaneously and that mandatory airtightness is matched with mandatory measures to address e.g. ventilation and IAQ, vapour diffusion, etc.
- → Liability and consumer education issues – what recourse will building owners have if a building does not meet mandatory levels of airtightness? How will consumers be educated about airtightness expectations and whether/how to modify their buildings without compromising airtightness?
- → Inexperience of some architects related to designing a continuous air barrier
- → Obstacles related to the numerous building products and systems available on the market that do not achieve a whole building airtightness

A full list of the associations contacted for this phase of the survey is provided in Appendix A.

5.1.2 General Survey Results

From the organizations contacted, 13 expressed interest in distributing the online survey to their members, and were sent a link and brief introductory text. These organizations are noted in the appendix. They include two from Alberta, five from Ontario, one from British Columbia, one from Nova Scotia, and four that are national in scope.

A separate web copy of the general survey was prepared for each organization to facilitate tracking of results by organization. This online survey included questions about respondents' background, their experience with different building types, and their role in the construction of new buildings. It then asked a series of questions designed to gather information about perceived benefits and challenges of incorporating whole building airtightness requirements into the building code, as well as overall resistance to or acceptance of existing voluntary requirements.

141 survey responses were received. Because the survey was distributed indirectly through industry organization representatives, an exact response rate cannot be calculated. However, to provide some context we can estimate that the 13 organizations that received a survey link might represent about 1300-3000 members. In other words, although a sample of 141 is small relative to the large, nation-wide audience that could potentially have been reached if all organizations had participated, it is likely about 5-10% of the smaller subset who actually received the survey responded. This response rate is a reasonable for surveys of this type.

As seen in Table 5.2 and Figure 5.1, respondents represent a range of professional backgrounds and experiences within the building industry. Geographically, respondents were concentrated in British Columbia (20% of respondents) and Ontario (59%). Additional follow-up was conducted with organizations in areas with a low response rate; however, these efforts to obtain a wider distribution met with limited success. Anecdotal feedback from contacts suggests that the issues in the survey may not have been perceived as urgent due to the lack of current or imminent whole building airtightness testing requirements in most Canadian jurisdictions. The low response rate may also indicate disinterest or a lack of understanding.

TABLE 5.2 PROFESSIONAL QUALIFICATIONS OF PHASE II SURVEY RESPONDENTS	
Professional Background	**Number of Respondents with this Background**
Engineer	43
Architect	6
Technologist	38
Skilled Trade Contractor	12
Energy Advisor or Energy Auditor	24
Other	48

Note: Total number of reported backgrounds exceeds total survey responses due to individuals who identified more than one professional background. Responses under "other" included researchers, specifiers, builders, building inspectors, product distributors.

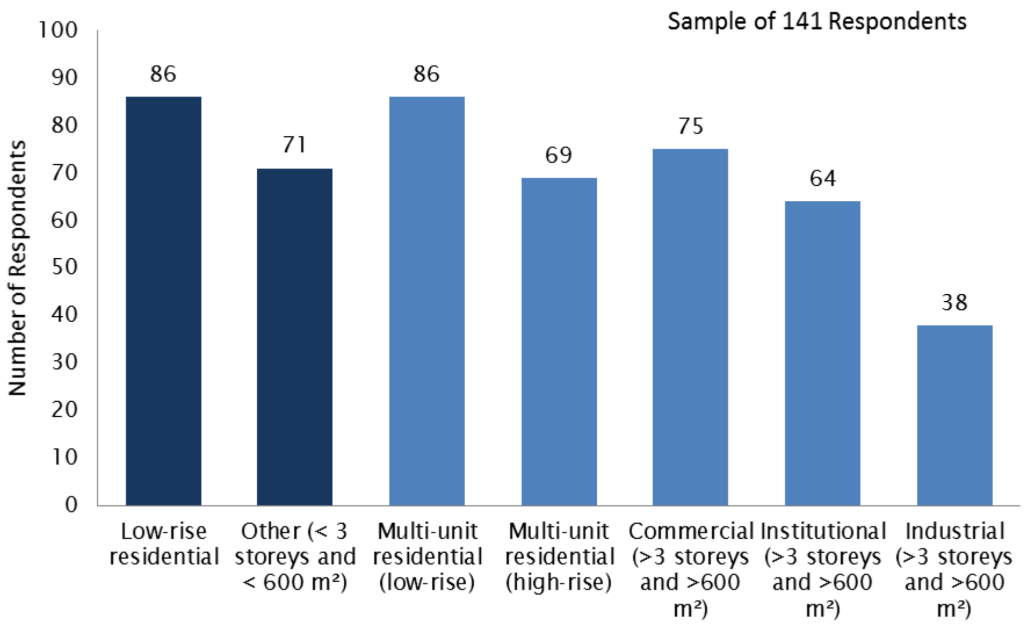

Figure 5.1: Number of respondents from Canadian jurisdictions involved with different types and sizes of buildings. Note that most respondents reported involvement with more than one building type.

Acceptance and Current Use of Whole Building Airtightness Testing

Most respondents work in areas where there are only voluntary airtightness testing standards as shown in Figure 5.2. This result is not unexpected, since most areas in Canada have only voluntary standards[1]. However, based on RDH experience, some Canadian

[1] The National Air Barrier Association identifies Vancouver as the only Canadian jurisdiction with a code requirement for blower door testing (specifically, Vancouver requires this test for one or two family homes). See "Whole Building Airtightness Testing", www.naba.ca/technical_library/whole_building_air_tightness_testing.php.

companies do work in the United States and have experience in U.S. jurisdictions where airtightness testing is mandatory (i.e. Washington State, Seattle, California). As well, a few respondents identified Canadian jurisdictions as requiring mandatory testing (Vancouver, York Region, Centre Wellington), and some stated that they complete "mandatory" testing for e.g. LEED buildings or R2000 buildings.

About a third of respondents indicated that their companies use airtightness testing on at least some of their projects where testing is voluntary, as shown in Figure 5.2[2]. However, high perceived benefits and relatively low perceived barriers and costs suggest a general acceptance of airtightness testing (see next section).

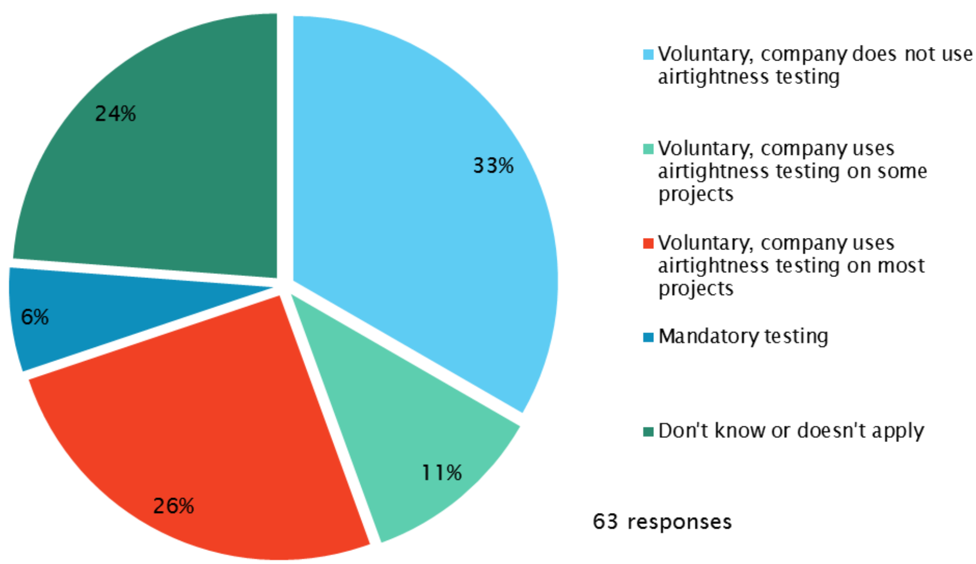

Figure 5.2: Percentage of respondents whose companies meet airtightness standards, and type of standard met.

Perceived Benefits and Challenges

Survey responses suggest a high level of appreciation for the importance of airtightness testing and its benefits. Approximately half of respondents answered "Yes, whole building airtightness requirements are definitely worthwhile" to the question "In general, do you feel that whole building airtightness requirements are worthwhile in terms of increased building performance and quality of design/workmanship?" Another 13% felt that such requirements were "somewhat worthwhile, but not enough to offset the costs involved". Although response rates were too low to do an in-depth analysis, there was some variation associated with professional background. For example, two out of eight responses from building owners indicated that testing was not worthwhile (a 25% rate, compared to the 7% rate for all respondents). Building officials were also more likely to respond "no", at 24%. This may be due to their greater knowledge of building codes and awareness of the difficulties

However, this information appears to be outdated, as Whitehorse bylaws also require blower door testing for new homes. See "New Green Building Standards", http://www.city.whitehorse.yk.ca/index.aspx?page=216.

[2]Note that this figure excludes a portion of data from respondents for whom the question was not relevant (i.e. building code officials are not normally part of a company that might use airtightness testing).

involved in implementing them. It may also reflect a concern about additional workload and complication for inspections.

Table 5.3 shows specific reasons for doing airtightness testing, with most reasons being rated above 3 on a scale where 1="not important" and 5="very important". Energy efficiency and moisture control were seen as the most important reasons for testing.

TABLE 5.3 AVERAGE RATING OF IMPORTANCE OF REASONS FOR DOING WHOLE BUILDING AIRTIGHTNESS TESTING (SAMPLE OF 109 RESPONDENTS)

Reason	Average Rating (1 = Not Important, 5 = Very important)
Energy	4.2
Moisture Control	4.2
Indoor Air Quality	3.6
Acoustics	2.9

In terms of barriers to adopting airtightness testing as part of regular practice, approximately 2 out of every 3 respondents felt that there are "moderate" or "significant" costs involved in whole building testing aside from the cost of the test itself. When asked to rank a list of factors that might add to cost, respondents gave the highest average ranking to increased labour cost and cost of remedial work Table 5.4.

TABLE 5.4 AVERAGE RANKING OF COSTS ASSOCIATED WITH AIRTIGHTNESS TESTING IN TERMS OF IMPACT ON TOTAL COST (SAMPLE OF 77 RESPONDENTS)

Reason	Average Ranking (1=low, 5=high)
Cost of remedial work (in case of a failed test)	3.5
Increased labour cost	3.4
Changes in construction schedule/sequencing	2.9
Increased design effort	2.8

Interestingly, many respondents answered "neutral/no opinion" when asked their opinion about the qualifications, cost, and availability of services that provide whole building airtightness testing in Canada. The most negative responses were regarding qualifications, with 29% of respondents indicating that qualifications need improvement and 11% describing it as "unacceptable".

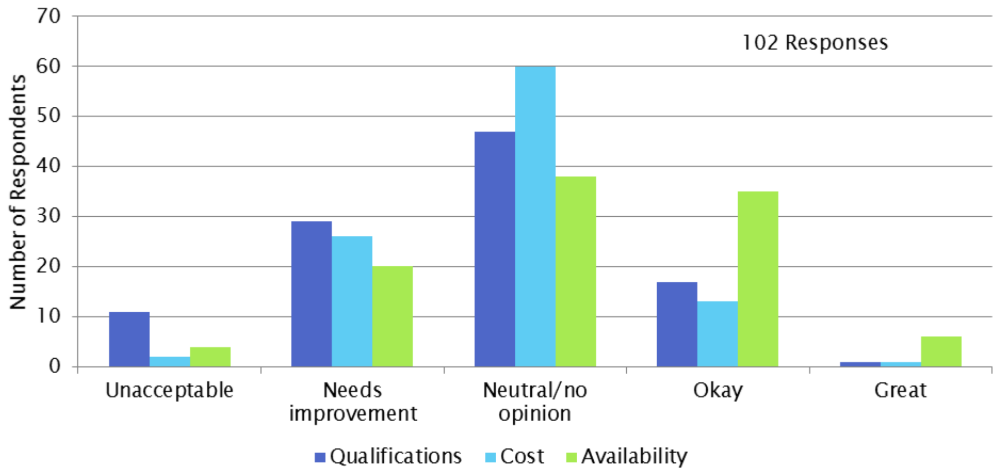

Figure 5.3: Ratings of qualifications, cost and availability of whole building airtightness testing services in Canada

5.2 Mandatory Jurisdictions

For mandatory jurisdictions, the primary goal of the survey was to obtain responses from designers, constructors, and regulators with respect to changes in construction practices resulting from whole building airtightness requirements. This includes training, cost implications, and resistance or acceptance of the requirements. A second goal was to report on the percentage of compliance with whole building airtightness requirements and the experience of jurisdictions in dealing with buildings which do not meet the requirements.

In choosing contacts for surveys, the State of Washington was chosen for the following reasons:

- → Washington is currently the only jurisdiction in North America that requires whole building airtightness testing of large buildings on a state/provincial level
- → The authors have numerous contacts in Washington State

5.2.1 Testing Metadata

The survey respondents were asked to select what types of buildings they are typically involved with and the results are provided in Figure 5.4. This figure shows that respondents are primarily involved with testing of multi-unit residential buildings and commercial buildings.

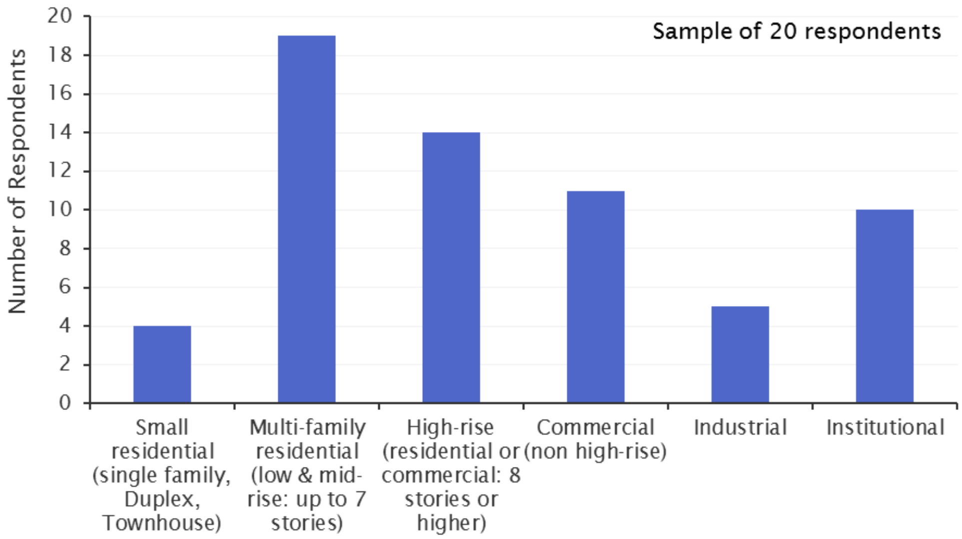

Figure 5.4: Types and sizes of buildings that respondents from mandatory jurisdictions are involved with. Note that most respondents reported involvement with more than one building type.

Under the current Washington State Energy Code all of these building types would require some kind of airtightness test. Refer to Chapter 4 for further details about the testing requirements.

Respondents were divided by their role in the construction industry. Most respondents were involved directly in the design/construction side as opposed to the development side as shown in Figure 5.5.

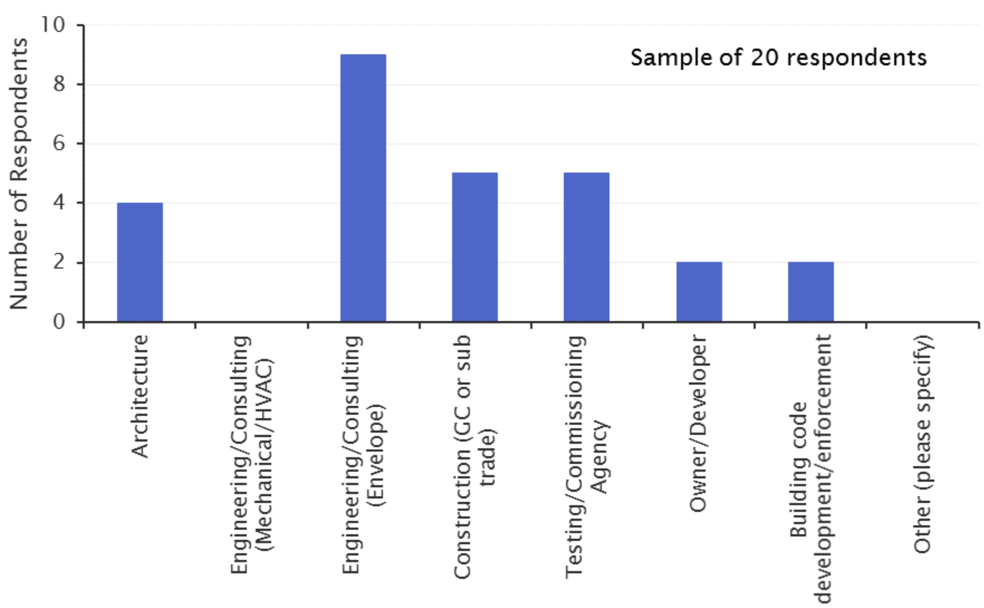

Figure 5.5: Respondents' involvement with new construction in mandatory jurisdictions. Note that the total number of reported backgrounds exceeds total survey responses due to individuals who identified more than one professional background.

Among all respondents, most had taken part in less than 10 whole building airtightness tests, as displayed in Figure 5.6. Those who were more involved were typically consultants & testing agencies who frequently work on numerous buildings at once. Contractors, architects, and developers at the individual employee level tend to work on only one or two buildings at a time.

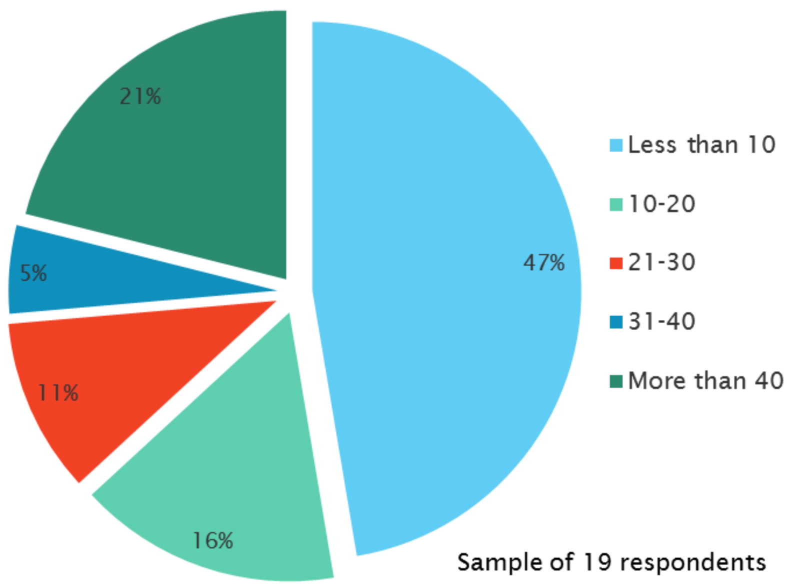

Figure 5.6: Number of tests respondents have been involved with which had mandatory airtightness performance requirements

5.2.2 Attitudes toward Airtightness Requirements

Respondents were asked if they felt airtightness testing was worthwhile and beneficial. Overall, most respondents agreed that the testing was beneficial, but some did not see testing as worthwhile. Figure 5.7 below summarizes the survey responses for this particular question. It should be noted that of those who did not see testing as worthwhile and/or beneficial, all were either in property development or construction. All respondents involved with the design or testing felt that the requirements were both beneficial and worthwhile.

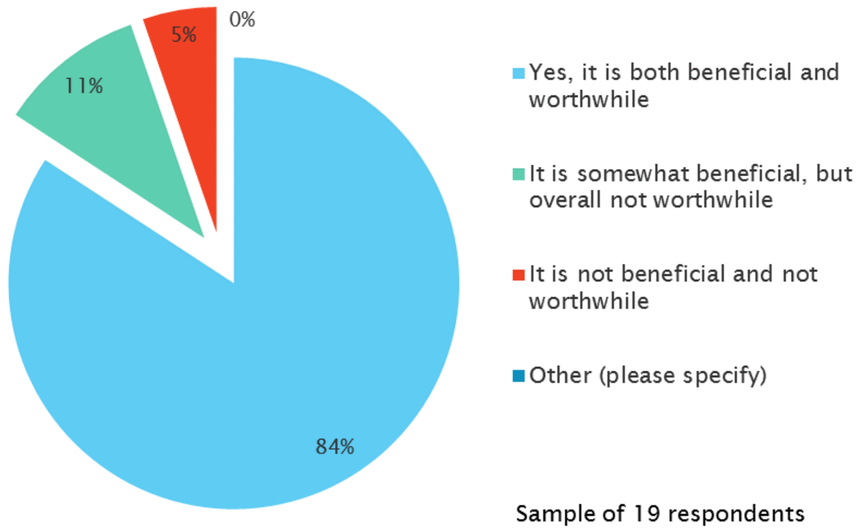

Figure 5.7: Respondents' response when asked if airtightness testing was worthwhile and beneficial

The respondents were also asked of their opinions about the current airtightness target for buildings, as shown in Figure 5.8. Most agreed that the current target of 2.0 L/(s·m²) at 75 Pa (0.4 cfm/ft²) is appropriate. Many respondents in the consulting/testing side view the requirements as too lenient. No respondents indicated that the current target is too stringent.

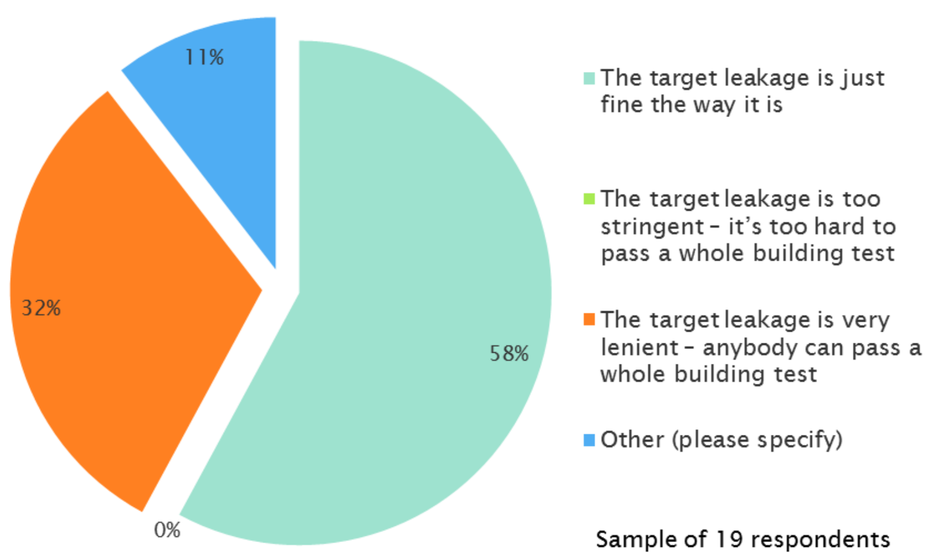

Figure 5.8: Respondents' opinions of the current airtightness target of 2.0 L/(s·m²) at 75 Pa (0.4 cfm/ft²) in mandatory jurisdictions

The fact that most respondents felt the current standard is acceptable is derived from their experiences. When asked to report the percentage of buildings tested which did not meet the airtightness target, the majority of respondents indicated that all buildings tested were acceptable, as shown in Figure 5.9. It should be noted that the respondents who indicated 31-40% of buildings did not meet the airtightness target are testing agencies. These agencies often test USACE buildings which have much more stringent airtightness requirements (1.26 L/(s·m²) at 75 Pa).

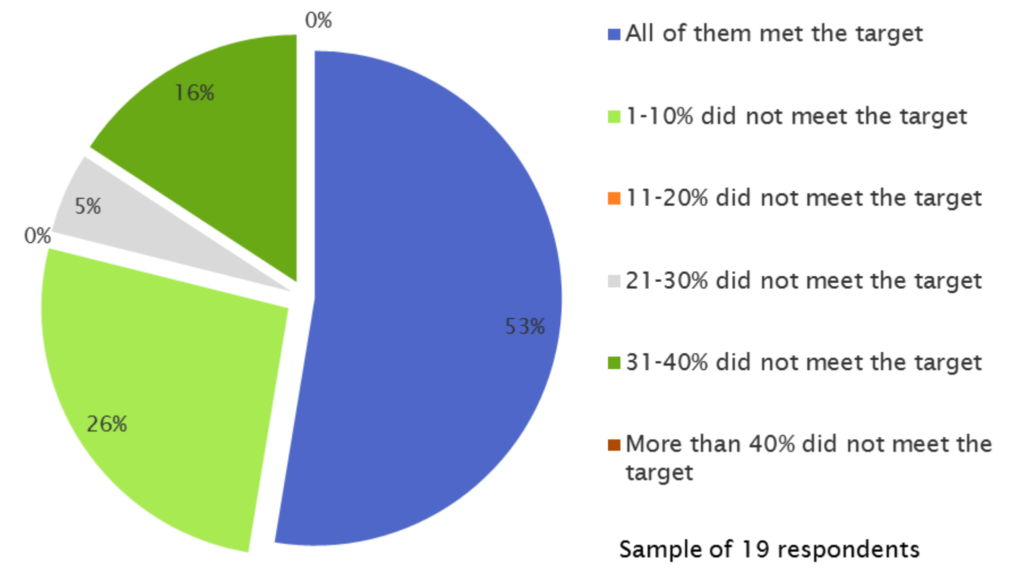

Figure 5.9: Percentage of buildings respondents were involved with that did not meet the target in mandatory jurisdictions

5.2.3 Impact of Airtightness Requirements

The impact of mandatory testing is difficult to quantify at this stage. It is still too early to have any reliable data about energy savings. Anecdotal survey responses from contractors indicate that the testing is somewhat costly, but most thought the testing was a worthwhile quality control measure. Respondents to the survey were asked if they felt the airtightness testing requirements significantly increase the cost of construction, not including the cost of the test itself. Most respondents agreed that there is low or moderate cost involved, as indicated in Figure 5.10.

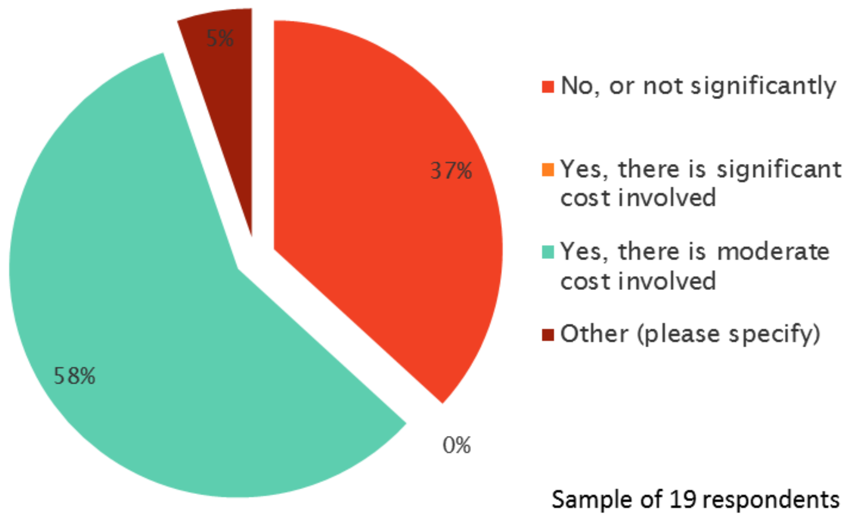

Figure 5.10: Respondents' opinions about the cost of mandatory testing requirements – aside from the cost of testing

Respondents were subsequently asked to rank a variety of factors with respect to their impact on the cost associated with airtightness testing, as shown in Table 5.5. The factors were evaluated on the following scale:

1. Cost savings
2. No cost increase
3. Low cost increase
4. Moderate cost increase
5. High cost increase

TABLE 5.5 AVERAGE RATING OF FACTORS ASSOCIATED WITH AIRTIGHTNESS TESTING IN TERMS OF IMPACT ON TOTAL COST (19 RESPONDENTS)

Factor	**Average Rating**
Increased Design Effort	3.1
Changes in Construction Schedule/ Sequencing	3.2
Increased Labour Cost	3.2
Increased Material Cost	2.9
Cost of Remedial Work (in Case of a Failed Test)	3.6

The cost of the test itself can vary widely – anecdotal reports of test budgets ranged from $4,000 to $40,000. The cost of the test is related to the size and complexity of the building; A 20 story residential tower is significantly more costly to test than a 5 story apartment building.

The survey also asked respondents to reflect on common problem areas associated with airtightness. Figure 5.11 summarizes these results, and clearly identifies roof to wall transitions, mechanical penetrations, and dampers as being particularly common sources of air leakage. It should be noted that there were several comments relating to leaking temporary seals at mechanical penetrations, meaning that the preparation work was having a significant impact on the test results.

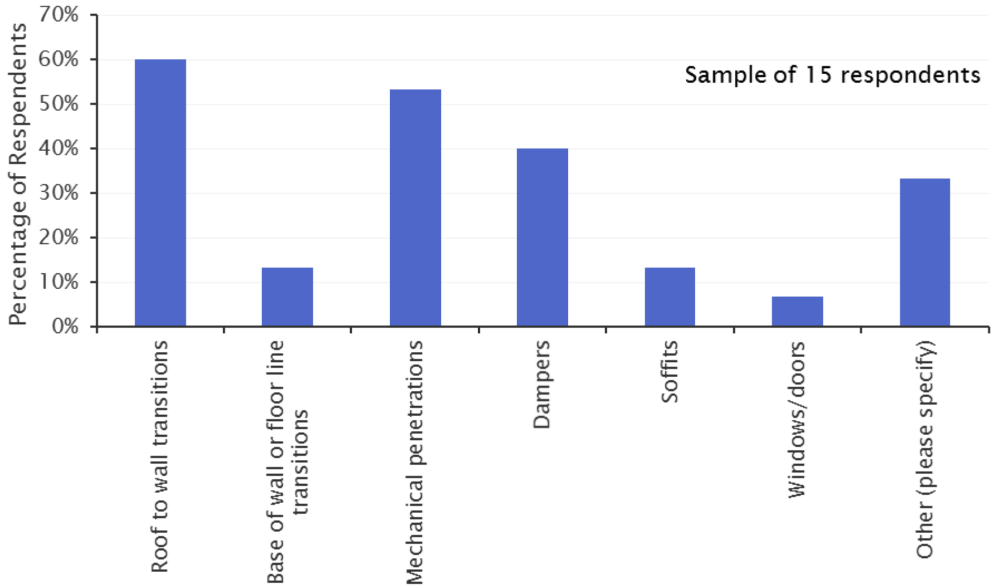

Figure 5.11: Common locations of air leaks identified by respondents in mandatory jurisdictions

Airtightness testing is slowly becoming more accepted in Washington State as a valuable part of the commissioning process. The Seattle building industry has been for the most part successful in meeting the challenge of building relatively airtight buildings.

5.2.4 One-on-One Interviews

Interviews were conducted over the phone with four people:

- → Energy Code and Energy Conservation Advisor at the City of Seattle
- → Field Operations & Quality Control Manager at a General Contractor
- → Building Envelope Specialist at a General Contractor
- → Quality Assurance Manager at a General Contractor

Notes taken during these phone interviews were typed and sent to each interviewee to be reviewed for correctness and completeness. The following sections do not offer direct quotes from the interviewees, but the authors feel that these sections accurately reflect the opinions of each interviewee.

It became clear after several interviews with general contractors that the attitude toward testing is similar among contractors in the greater Seattle area.

Energy Code and Energy Conservation Advisor (City of Seattle)

It is well known in the building community that unintended air leakage does not result from improper materials or assemblies, but rather from the interfaces of all these different building components. Simply knowing that there will be a test provides motivation to contractors and trades to perform better quality work.

Initial reactions from the building industry were mostly negative. Nobody wanted to pay for the testing, and very few people on the development/construction side understood the value of having an airtight building. This attitude appears to be changing slowly as more contractors get better at coordinating and preparing for tests. However the majority of developers still remain opposed to testing, making it clear that if testing were voluntary virtually nobody would do it.

There was a significant learning curve among the entire industry – testing agencies, architects, contractors, developers, and consultants all had to learn how to coordinate and execute these tests successfully. On larger and more complex buildings, a great deal of coordination is involved to prepare the building for testing. In some cases one building may require multiple tests at different stages for split occupancies. Adding more informative notes into the code language about these considerations would have saved a lot of headaches initially.

Although testing has been mandatory since the 2009 code cycle, reporting the test results to code officials was not required until the 2012 code cycle. In many cases the time between permitting and airtightness testing is 2 years or more. This means the state and local jurisdictions are just beginning to collect test data in 2015. However, even though no central database is available, the general consensus among Seattle code officials is that almost all buildings are meeting the airtightness target.

To date there has been very little oversight from code officials on the quality of test data. There is no required training or certification for testing agencies, and until recently no data was being collected by code officials. Going forward this may be an issue that would need to be addressed.

Field Operations & Quality Control Manager (General Contractor)

The most expensive part of testing a building is the preparation. The process of taping off exhaust fans and other intentional openings in large multi-unit apartment buildings takes a significant amount of labor, and often happens at a critical stage near the end of the project where resources are already stretched thin. This is often subcontracted out to painters or drywallers.

After the test, all temporary seals must be taken off in each unit. This is also a time consuming process which can also result in additional remedial work if paint is damaged or additional cleaning is needed in units that are already finished. The entire process of preparing the building for testing and cleaning up after the test can cost $120 or more per unit, which is passed on to the owner. Also the amount of tape and plastic that gets thrown away from removing temporary seals is not insignificant, and contributes to the overall waste of the project.

Testing does not have any significant effect on the construction sequence, and any delays in schedule caused by testing are at most 1-2 days. Contractors are getting better at test coordination, scheduling, and managing building preparation, but as with anything else in the construction industry, when people get busy it becomes harder to stay proactive and mistakes do happen.

The long term value of continued testing is not clear – initially there were lessons learned about where problem areas are and how to address them, but after testing and passing many buildings it seems unnecessary to continue proving what we already know; however, not all contractors are equal. Some have sophisticated QA/QC programs and know what to look for to ensure a tight building, while others may not place as high a value on achieving a good test result.

All buildings tested thus far by this contractor have met or exceeded the airtightness target.

Building Envelope Specialist (General Contractor)

Author's note: the responses from this interviewee are largely the same as the Field Operations & Quality Control Manager above. For simplicity, only new/different information will be provided in this section.

The testing requirements serve as a valuable motivational tool for subcontractors who know their work will be tested. These requirements have improved the overall quality of buildings.

In addition to improving the quality of work, testing has provided improved detailing. Two examples that come to mind are parapets and vented roof assemblies.

Only one building tested thus far by this contractor did not meet the airtightness target. This was a new addition to an existing building, and most of the leakage was identified as between the new and existing portions.

Quality Assurance Manager (General Contractor)

Author's note: the responses from this interviewee are largely the same as the Field Operations & Quality Control Manager and Building Envelope Specialist above. For simplicity, only new/different information will be provided in this section.

At this stage many superintendents have only been through 1 or 2 tests, but overall knowledge of test procedures is growing company wide and tests are running smoothly. In general the testing requirements have raised the bar for quality of workmanship, and results can be used as a marketing tool by contractors.

5.3 Analysis

For voluntary jurisdictions, some themes or issues are suggested that will be further explored in the final report:

→ **Overall acceptance of whole building airtightness testing**. To date, overall perceptions of whole building airtightness testing seem positive. There are perceived benefits for many, and anecdotal evidence suggests a sense that increased airtightness requirements are a manageable change.

→ **Complications of larger building types**. For example, mixed-use buildings present challenges that are not normally seen in airtightness testing for single-family dwellings.

→ **Possible gaps in knowledge about airtightness testing services**. Although respondents were able to foresee potential costs associated with testing, a high number did not have an opinion on the actual costs of the tests themselves. Many respondents also had no opinion on testing services' staff qualifications and availability of services.

→ **Disengagement with the issue**. Although a large number of organizations and regional branches were contacted, relatively few distributed the online survey to their membership. Similarly, when the survey was distributed by an organization, relatively few members completed it. Anecdotal feedback suggests a lack of perceived urgency from many stakeholders. This may be due in part to the knowledge gaps noted above; it may also impact efforts to address those gaps.

→ **Concerns about availability and qualifications**. A recurrent theme was the need to ensure adequate availability of qualified personnel to meet demand for testing services if code changes made testing mandatory for Part 3 Buildings.

For mandatory jurisdictions, or at least in the State of Washington, testing has served as a measuring stick for the quality of the installation of the air barrier. While air barrier design and detailing has improved slightly as a result of feedback from testing, the biggest determining factor in airtightness test results is the quality of workmanship and the level of QC throughout the project.

The requirements are set in such a way that most buildings are passing, and those that do not are rarely repaired in any significant way. The knowledge that a building will be tested provides motivation to contractors and trades to do higher quality work.

A pervading theme of the interviews is a lack of education. Many lessons about coordination and preparation for testing were learned the hard way. More information within the codes regarding how to plan and coordinate testing in large complex buildings would have made a big difference. There were significant growing pains when the testing requirements were first implemented, and the reaction from the building industry was largely negative.

Most survey respondents agreed that there are moderate cost implications associated with the test aside from the cost of the test itself, though the total economic impact of mandatory testing does not appear to have stunted development in any noticeable way.

When considered together, data from voluntary and mandatory jurisdictions strongly suggests that mandatory testing is feasible but that education and outreach to different sectors will be key to successfully implementing mandatory airtightness testing requirements.

6 Whole Building Airtightness Test Methods and Procedures

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. This study focuses on quantitative airtightness testing which provides measureable performance metrics to facilitate benchmarking comparisons to typical performance for similar buildings, as well as comparison with specified performance targets. Qualitative testing techniques such as infrared thermography and smoke tracer testing can also be useful forensic tools for visually determining the location, direction, and magnitude of air leaks; however, these techniques are outside the scope of this study.

This chapter provides an overview of the various airtightness testing standards which are available, and also provides general commentary regarding approaches to airtightness testing including discussion of the general approach, appropriate test conditions and test pressures, single-point versus multi-point testing, and testing of compartmentalized buildings.

6.1 General Approach to Airtightness Testing

The most common airtightness testing methods are based on similar fundamental principles and measure airtightness by using fans to create a pressure difference across the building enclosure. The airflow through these fans is measured at a pressure difference, and by conservation of mass it is known that the flow in or out of the building through the fans must be equal to the flow in the opposite direction through the building enclosure. All airtightness measurements must be provided with reference to the test pressure difference or else the measurement is meaningless. Airtightness testing reporting metrics were discussed in Chapter 2.

Typically calibrated fan-doors (i.e. blower doors) apparatus are used to pressurize or depressurize the building while measuring the airflow rate into or out of the building. These systems are designed to be temporarily installed in exterior doorways and a single fan can be appropriate for a small building such as a single family house, but the system can also be scaled up for larger buildings by simply adding additional fans either within the same exterior door or in other exterior doors around the building.

Figure 6.1 presents a representative schematic illustrating a pressure equalized airtightness test of one suite in a tall multi-unit residential building.

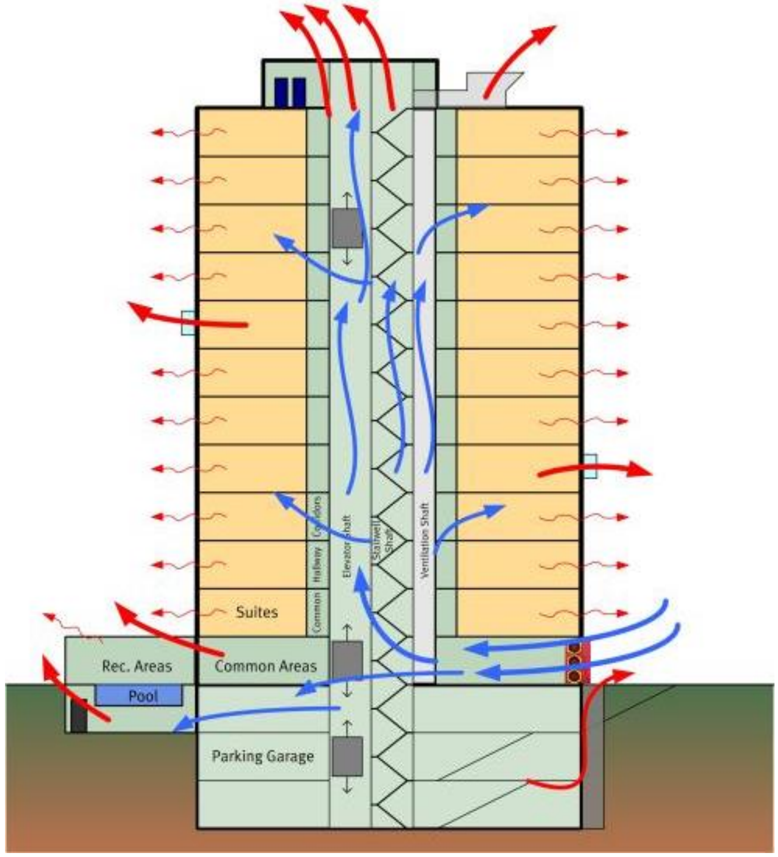

Figure 6.1: Schematic illustration of whole building airtightness test using fans to pressurize the whole building and once while measuring the air flow rate. The results of this test can be used to determine the airtightness of the whole building enclosure.

6.2 Appropriate Test Conditions and Test Pressures

Airtightness testing uses fans to create pressure differences across the building enclosure; however, the naturally occurring forces of wind and stack effect also create pressure differences across the building enclosure. Specified test pressure differences are typically designed to be sufficiently large such that naturally occurring pressure differences are negligible in comparison. While this is quite feasible for shorter buildings which have less height to develop pressure due to stack effect and are usually less exposed to wind, when testing taller buildings or building in exposed locations, the naturally created pressure difference can be a significant impediment to testing.

Both the variability and magnitude of these naturally occurring pressure differences impacts the ability to perform airtightness testing. Variability in these pressures during testing creates unstable test pressure differentials and can impact the accuracy of the test results, and in some cases even make simply conducting the test difficult. Consistent but high magnitude naturally occurring pressure differences can also be problematic. These pressure differences are nearly always not evenly distributed across the building enclosure and consequently means that the test pressure measured for one part of the building enclosure will not necessarily be the same as that measured for other parts of the enclosure. This difference in the test pressures mean that some elements are being tested at higher or lower pressure differences than others and will affect the airtightness measurement.

Figure 6.2 provides a graphical representation of how naturally occurring pressure differences due to stack effect can create an uneven distribution of pressure differences when add to the pressure difference created by the test fans. For taller buildings, more extreme exterior temperatures, or lower test pressures, the relative impact of stack effect on the cumulative enclosure pressure difference would be larger, as would its impact on the airtightness measurement.

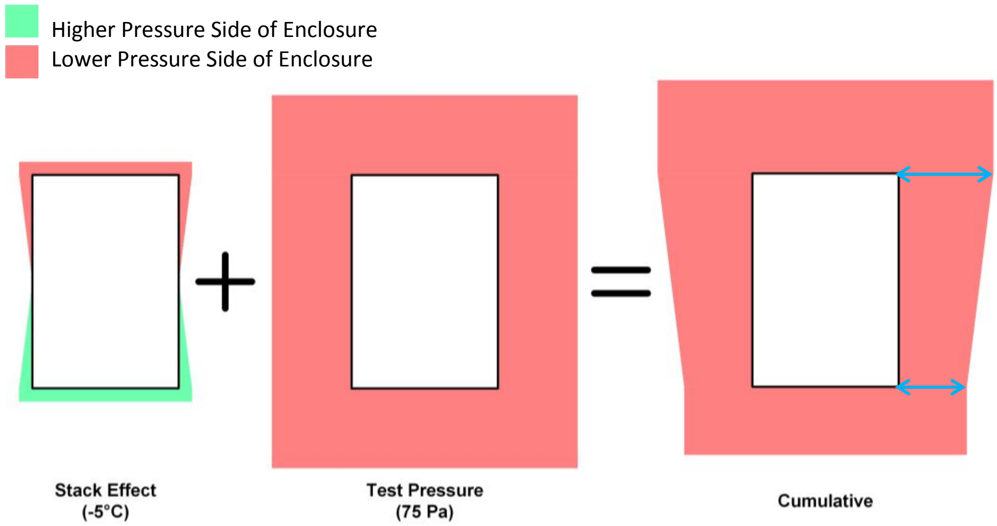

Figure 6.2: Cumulative pressure difference across building enclosure of an 8 storey building due to combination of stack effect (at -5°C) and at 75 Pa test pressure. Note the different pressure difference at the top of the building than at the bottom.

The pressures created by stack effect and wind create practical limits on acceptable test pressure differences and weather conditions for testing.

In light of the potentially substantial impact that baseline pressures created by stack effect and wind have on the accuracy of airtightness testing, it is useful to examine the specific environmental conditions during which accurate testing is feasible. Several test standards identify specific environmental conditions under which airtightness testing should be carried out. Of these, the requirements of CGSB 149.15-96 and ASTM E 779-10 were selected for analysis. The requirements of acceptable environmental conditions provided by these standards are summarized in Table 6.1. While it is desirable to also perform this analysis for other commonly used test standards such as the USACE, many of these other standards either do not specify environmental limitations, or specify the limitations in the form of a limit on the baseline pressure. When the appropriate conditions for airtightness testing are specific as a limit on baseline pressure it is not possible to assess during what times it would be possible to test because the measured baseline pressure is highly dependent on placement of the pressure taps, number of pressure taps, pressure averaging method, building geometry, etc.

TABLE 6.1 SUMMARY OF APPROPRIATE ENVIRONMENTAL CONDITIONS FOR AIRTIGHTNESS TESTING	
CGSB 149.15-96	ASTM E 779-10
< 20 km/h wind, and 1-10 Storeys: Exterior Temperature ≥ 5 °C 11-20 Storeys: Exterior Temperature ≥ 8 °C 21-30 Storeys: Exterior Temperature ≥ 10 °C 31+ Storeys: Exterior Temperature ≥ 15 °C	Building Height x ΔT < 200 m°C

In order to determine the amount of time each year during which testing may be performed, relevant weather parameters were analyzed using CWEC hourly climate data for nine Canadian locations. These parameters were compared to the requirements listed in Figure 6.1 and the percentage of time each year during which airtightness testing can occur was determined for each city. The results of this analysis are provided in Figure 6.3.

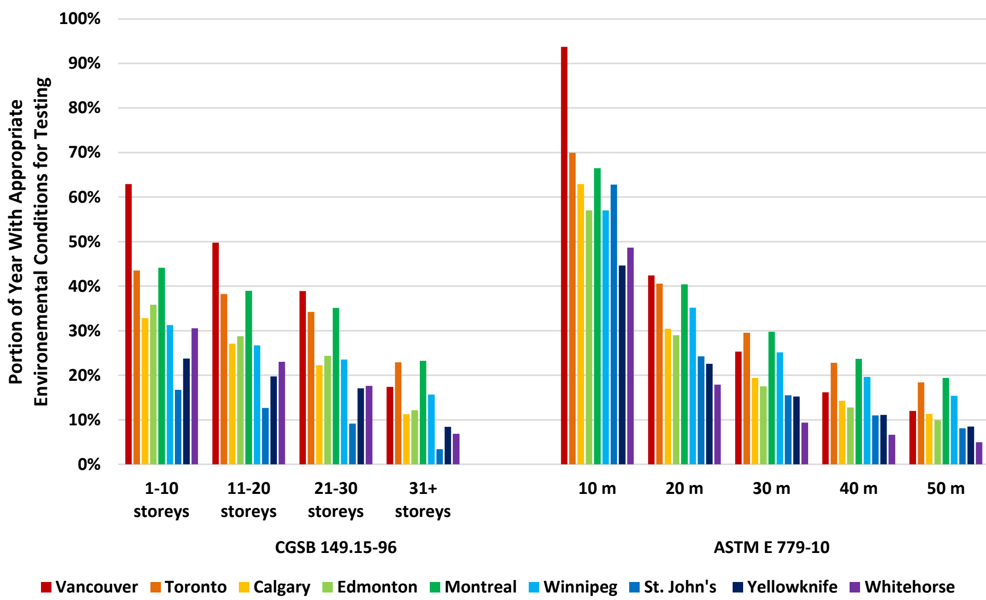

Figure 6.3: Percentage of time during which environmental conditions are appropriate for airtightness testing of various heights iof buildings in different Canadian cities based on guidance provided by CGSB 149.15-96 and ASTM E 779-10.

As shown in Figure 6.3, a substantial range in availability of appropriate test conditions exists across Canada, according to both the CGSB149.15-96 ASTM E 779-10 standards, with even short buildings only being able to be tested between 20 and 40% of the time in most Canadian climates. Appropriate conditions for testing taller buildings are significantly more limited. Some of the major climate variables that influence this are wind speed, average temperature, and timing of high winds (e.g. if high winds tend to occur at nighttime when temperatures are lower, testability will be less influenced under CGSB standards than if high winds were to occur during the day, when outdoor temperatures tend to be warmer).

In order to show a more practical estimate of testability, a similar analysis is presented in Figure 6.4, but late-night hours (e.g. hours between 10 pm and 6 am) are also excluded. This analysis shows that when these hours are removed, suitable conditions for airtightness testing only occur for a limited time, even in relatively mild climates.

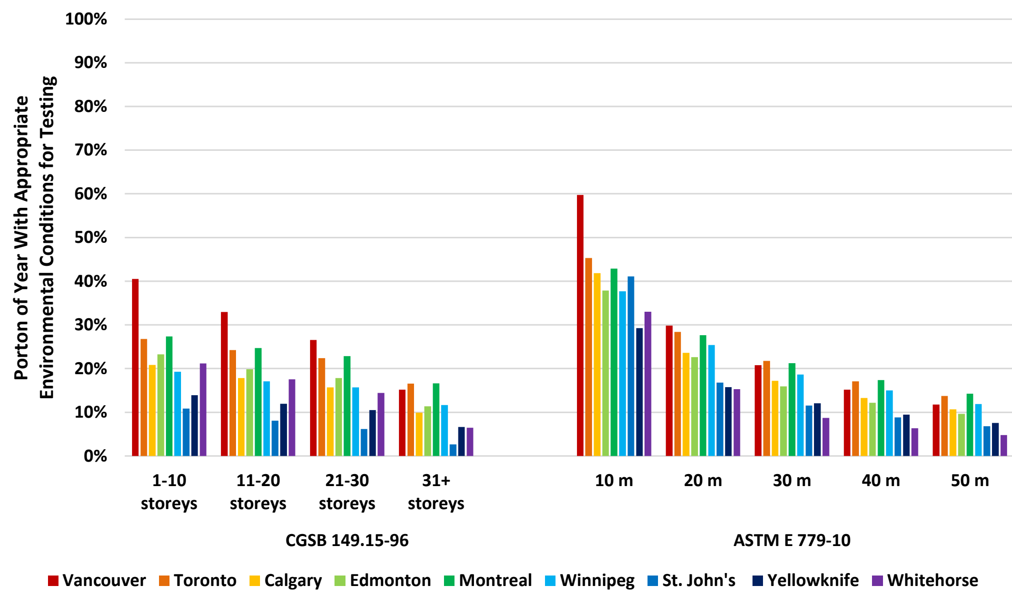

Figure 6.4: Percentage of time during which airtightness testing is feasible, excluding late-night hours (e.g. between 10pm and 6am).

This analysis of how often environmental conditions are suitable for airtightness testing in various Canadian cities clearly illustrates a potential challenge with implementing airtightness testing requirements, especially for tall buildings. Importantly this analysis is not intended to negate the possibility of implementation of airtightness testing requirements, instead it is simply intended to identify a technical challenge associated with conducting these tests in the relatively colder Canadian climate. Potential mitigation strategies for these requirements include testing buildings for longer periods of time to account for fluctuating pressures due to wind, or testing buildings while unconditioned so that interior temperatures are the same as exterior temperatures and stack effect pressures are reduced or eliminated.

6.3 Preparation of Openings

While whole building airtightness testing can potentially test the airtightness of a building in various different conditions depending on how the building is prepared for testing. In this case, preparation of the building primarily refers to which (if any) openings in the building enclosure will be sealed as for the test, and which will be left open. Various test standards provide schedules of recommended conditions for various openings such a grilles, louvres, chimneys, etc. Based on these different schedules, there are primarily three different arrangements in which a building can be tested, each with advantages and disadvantages: as is, sealed intentional openings, and enclosure only. Variations of these are also possible.

6.3.1 As Is Testing

As is airtightness testing measures the airtightness of the whole building including any mechanical penetrations such as ducts. These penetrations are left unsealed for the test, and any air leakage which occurs through them during testing would be reflected in the resulting airtightness. This type of test is intended to provide an indication of the airtightness of the building in-service; however, there are numerous challenges with this type of testing.

Firstly, the pressure differences created during airtightness testing are significantly higher than during in-service operation of the building. Consequently, building elements may be overwhelmed by the test pressures but no by in-service pressure and consequently the measured airtightness will not actually reflect in-service conditions. For example a fan may be rated to create a pressure rise of 50 Pa, which in service would reliably overcome other pressures, but during an airtightness test this pressure rise could be overwhelmed causing a reversal in flow direction that would not likely be experienced in service.

Furthermore, as is testing is highly dependent on the type of mechanical systems etc., and does typically provide easily comparable results.

6.3.2 Testing with Intentional Openings Sealed

Testing with intentional openings sealed means that mechanical openings which in-service would have exhaust or supply air flow through them are sealed such that no air will flow through them during testing. This is sealing is intended to compensate for the noted issue with as is testing that sometimes mechanical ventilation systems could be overwhelmed by test pressures, but not by in-service pressures. Mechanical systems that are intended to be sealed with dampers would only be sealed by closing the damper, with no additional sealing provided. This means that any leakage through the damper would be included in the measured airtightness.

6.3.3 Enclosure Only Testing

Enclosure only testing is intended to reflect only the airtightness of the building enclosure by sealing any potential air leakage paths through mechanical systems. In this type of test all mechanical system penetrations, including those sealed with dampers, would be intentionally sealed to prevent air leakage. This type of test has the advantage of only measuring the airtightness of the enclosure, and consequently is independent of mechanical system design. Furthermore, the results of this type of testing are easily comparable for different buildings.

6.4 Testing of Compartmentalized Buildings

Creating homogeneous pressure differences across the building enclosure to perform airtightness testing is relatively straightforward for small, short, single-zone buildings; however, for large, tall, air-leaky, and compartmentalized buildings, it may not be practically possible to create these homogeneous pressure differences across the entire building enclosure. This is due to difficulty distributing air within the buildings and with overwhelming naturally occurring pressure differences as discussed in Section 6.2.

To overcome some of these issues, test methods have been developed specifically for more complicated buildings such that they can be tested in smaller sections (i.e. floor-by-floor or suite-by-suite) using zones of the building that are more manageable. When testing only a portion of a building, air flow through interior compartmentalizing elements (i.e. suite demising walls, corridor walls, floors, and ceilings) is significant and will alter the test results, but these airflows can be eliminated by using additional fans to pressure equalize zones adjacent to the test zone. By eliminating the pressure differences across the compartmentalizing elements, the airflow through these elements is eliminated. Because the test focuses on a small section of the building, the impact of stack effect and wind is significantly reduced and makes for more even, consistent, and reliable pressure differences.

This type of testing can also be conducted such that each adjacent zone to the test zone is sequentially pressure equalized. By sequentially pressure equalizing the adjacent zones it is possible to determine the airtightness of the interior compartmentalizing elements in addition to the airtightness of the exterior building enclosure. The airtightness of these compartmentalizing elements is important for ventilation system design including control of contaminate transfer within buildings.

Figure 6.5 presents a representative schematic illustrating a pressure equalized airtightness test of one suite in a tall multi-unit residential building.

Figure 6.5: Balanced Fan Pressurization/Depressurization Method Schematic (Finch, 2007)

Pressure equalizing test methods 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 buildings.

6.5 Summary of Airtightness Testing Standards

This section provides a summary of the most relevant airtightness testing standards which are commonly used for testing in North America, and specifically in Canada. A table summarizing these standards is provided Section 6.5.12.

6.5.1 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. There is also an allowance to include an additional test point at 10 Pa, and baseline pressure differences are measured before and after conducting the test.

The standard provides guidance regarding sealing of 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 the flow rate and pressure differences to determine values for the flow coefficient (C) and flow exponent (n) flow exponent. The test results are reported using the flow coefficient, flow exponent, equivalent leakage area, and normalized leakage area.

6.5.2 CGSB 149.15 – 96

CGSB 149.15-96 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 create the pressure differences across the building enclosure. 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 devices 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 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 the flow coefficient (C) and flow exponent (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 6.2.

TABLE 6.2 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 & Phillips, 2001).

6.5.3 ASTM E 779 - 10

ASTM E 779-10 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. Results are reported using the flow coefficient, flow exponent, and effective leakage area for each of the pressurization, depressurization, 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)

ASTM E 779-10 also indicates that single zone conditions should be confirmed by measuring the pressure differences between interior spaces. While this method will help to locate potential restrictions to flow within the building that could be creating uneven pressure distribution within the space, so that an equal change in pressure is applied to all zones of the building.

6.5.4 ASTM E 1827 - 11

ASTM E 1827-11 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, and is one of the most recently updated testing standards. The standard describes two methods of airtightness testing.

The first method is a single-point test whereby flow rates are measured at a pressure difference of 50 Pa, and a flow exponent (n) of 0.65 is assumed for calculation purposes. The second method is a two-point test whereby flow rates are measured at pressure differences of 50 Pa and approximately 12.5 Pa (maximum of 1/3 of first test pressure) to allow for the determination of the flow coefficient and the flow exponent. If 50 Pa cannot be achieved, the highest sustainable pressure difference can be used.

This standard provides a detailed schedule for the preparation of intentional openings including three different options depending on the test type.

This standard also provide a check that the single zone criteria is met. In this case, no greater than a 5% difference in interior pressure may be measured at the maximum test pressure and 2.5 Pa at a 50 Pa test pressure.

Consistent with previously discussed standards, this standard provides a correction of airflow rates and pressure measurements.

It is important to note that single-point and two-point test methods such as those described by this standard provide less ability to detect potential errors in performing the test, and also provide less data for error analysis.

6.5.5 ISO 9972:2012

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 greater than 50 Pa, with the recommended range being from 2 time the baseline pressure measure up to 100 Pa.

This standard also provides brief discussion of testing zones within buildings, but does not provide discussion of pressure equalized testing. Instead this standard simply notes that air will also move through interior walls and affect the test result.

6.5.6 US Army Corps of Engineers (2012)

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.

This testing standard also provides an interesting limit on the flow exponent. While values of the flow exponent theoretically can range from 0.5 to 1.0, this standard indicates that the test must be repeated if the exponent is outside the range of 0.45 to 0.80.

Unlike the other testing standards identified, this standard also include a performance requirement. The standard specifies that the tested buildings should meet 0.25 cfm/ft^2 (1.27 L/(s·m^2)).

6.5.7 ATTMA Technical Standard L1-2010 & L2-2010

British Airtightness Testing and Measurement Association (ATTMA) *Technical Standard L1: Measuring Air Permeability of Building Enclosures (Dwellings)* and *Technical Standard L2: Measuring Air Permeability of Building Enclosure (Non-Dwellings)* are two airtightness testing standards developed based on similar principles to the airtightness testing standards previously noted. The two tests are essentially the same with the second having some additional allowances for the testing of larger, taller, and more complex buildings.

These tests require that 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 10 Pa or 5 times the baseline pressure measurement and reaching a pressure of at least 50 Pa. The range of the pressure measurements must span at least 25 Pa. The standards allows for either pressurization or depressurization testing.

The L2 standard for non-dwelling buildings also provides an allowance for pressure equalized testing of large, tall, or complex buildings which would be difficult to evenly pressurize all at once. Guidance includes comment on how the buildings could be segmented and how representative testing of a sample of spaces could be used to estimate the airtightness of the whole building. For example in a tall building the ground floor, a sample of intermediate floors, and the top floor could be tested.

6.5.8 NEBB Procedural Standards for Building Enclosure Testing (2013)

The National Environmental Balancing Bureau (NEBB) developed a set of procedural standards for building enclosure testing (BET), which are broken down into airtightness testing and infrared thermography. Within airtightness testing, two approaches are defined:

blower door test method procedures and building air moving equipment system test method procedures. The former refers to both *ASTM E 779-10 Standard test method for Determining Air Leakage Rate by Fan Pressurization* as well as *ASTM E 1827-11 Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door*. The latter is a standard developed by NEBB which, while not as accurate as the ASTM tests, offers an alternative approach.

The NEBB building air moving equipment test method involves using the installed HVAC equipment to pressurize the building, and thus is only viable if the installed equipment is sufficiently powerful to achieve the required test pressure differences. The main procedure consists of setting up pressure taps around the enclosure and then conducting 10 tests – 5 tests at a higher test pressure differential (P_1) of 35-75 Pa, and 5 additional tests at a lower pressure differential (P_2) equal to 1/3rd of P_1. In either case, the induced enclosure pressure differential can be determined by subtracting the baseline measurements from the average test values of P_1 and P_2. The measured air flow rate through the fan can be used to determine the air leakage coefficient, *C*, and pressure exponent, *n*. Note that similar to the USACE test standard, if the pressure exponent is less than 0.45 or greater than 0.8 then the procedure declares the test is invalid and must be repeated.

6.5.9 ABAA Airtightness Testing Procedure (unreleased)

The Air Barrier Association of America is currently working to develop its *Standard Method for Building Enclosure Airtightness Compliance Testing*. This standard is not yet released, but versions released for review indicate that it will generally be aligned with the airtightness testing principles noted for the other testing standards which have been discussed. Of important difference is that this standard provides options for the testing of buildings either using a single-point, two-point, or multi-point testing procedure.

6.5.10 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 pressure equalized testing procedures, except that it does not require that adjacent zone be completely pressure equalized with the test zone. Instead this procedure requires that the pressure difference to adjacent zones 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 zones can be determined. The relationships between pressure difference and flow rate can then theoretically be used to determine the airtightness characteristics of the zone. 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.

6.5.11 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 zone can be determined with only one fan by first pressurizing the test zone, and then each of the neighbouring zones 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 & 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 airtightness properties. (Colliver & 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)

6.5.12 Summary of Standardized Test Procedures

For convenience, a summary of the various system quantitative tests, including some in addition to those discussed above, is provided here for reference.

	CGSB 149.10 - M86	CGSB 149.15 - 96	ASTM E 779 - 10	ASTM E 1827 - 11	ISO 9972:2012	USACE	ATTMA Technical Standard L2	ABAA (unreleased)
Origin of Standard	Canada	Canada	USA	USA	International	USA	United Kingdom	USA
Intended Building Type	Small detached but adaptable for larger buildings	Buildings with air handling systems	Single zone buildings	Single zone buildings	Single zone buildings	All buildings	Non-Dwellings	All buildings
Recommended Test Conditions	Wind < 20 km/hr (5.6 m/s)	Wind < 20 km/hr (5.6 m/s) Temperature limit depending on building height	ΔT x Height < 200 m°C	Wind < 2 m/s 5°C ≤ T ≤ 35°C	Wind at Ground < 3 m/s Wind at Station < 6 m/s Wind < 3 on Beaufort Scale ΔT x Height < 250 m·K	Max. Baseline Pressure < 30% of minimum induced pressure difference	ΔT x Height < 250 m·K Baseline < ± 5 Pa	None, but minimum pressure determined based on baseline or stack presures.
Baseline Pressure Measurement	Before and After (no duration provided)	Before and After (no duration provided)	Before and After for min. 10 s	Before and After (no duration provided)	Before and After	Before and After (12 measurements each time for min. 10 sec each)	Before and after for min. 30 sec	Before and after for 120 sec
Range of Test Pressure Differences	15 Pa to 50 Pa	Not provided	10 to 60 Pa	Single-Point: 50 Pa Two-Point: 50 Pa & ≈12.5 Pa	At least one > 50 Pa, with allowance for 25 Pa in large buildings (Recommend 10 Pa (or 2 x baseline) to 100 Pa at maximum 10 Pa increments)	Min. Range of 25 Pa One-Sided: > 50 Pa to > 75 Pa Two-Sided: > 40 Pa to > 75 Pa Max ≤ 85 Pa	Min. is greatest of 10 Pa or 5 x Baseline Max. is > 50 Pa Range > 25 Pa	Min is greatest of "Baseline + 10 x baseline std. dev.", "Stack pressure / 2", and 10 Pa. Max. is < 100 Pa Range > 25 Pa
Number of Test Points & Duration	8 (duration not provided)	4 (duration not provided)	> 5 for min. 10 sec	Single-Point: 5 at 50 Pa Two-Point: 5 at each of 50 Pa & 12.5 Pa (no duration provided)	> 5 (duration not provided)	10 for min. 10 sec	7 at < 10 Pa intervals (no duration provided)	> 10
Preferred Test Direction	Depressurize	Either	Both	Either	Both	Both	Either	Either
Acceptable Test Direction	Depressurize	Either	Both Required	Either	Either	Both (either for very large	Either	Either
Reporting Metric(s)	C, n, EqLa, NLA	C, n, Q_5, Q_{50}, Q_{75}	C, n, EfLA (or other) for both pressurization, depressurization, and average	Single-Point: Q_{50} Two-Point: C, n, EfLA, Q_{50}	C, n for both pressurization and depressurization	Q_{75} & EqLA	C, n, Q_{50}	
Preparation of Intentional Openings	Schedule provided	Limited guidance	Close operable dampers	Schedule provided, with options	Schedule provided, with options	Description provided	Description provided	Schedule provided, with options
Acceptable Ranges	0.50 ≤ n ≤ 1.00 R > 0.990 $(Q_{regression} - Q_{measured}) / Q_{measured}$ < 0.06 L/s for all pressures Standard Error at 10 Pa < 0.07 L/s	0.50 ≤ n ≤ 1.00 R > 0.990 $(Q_{regression} - Q_{measured}) / Q_{measured}$ < 0.06 L/s for all pressures	0.50 ≤ n ≤ 1.00	None provided. (Single and Two-Point tests do not provided sufficient information for detailed precision analysis)	0.50 ≤ n ≤ 1.00 $R^2 > 0.98$	0.45 ≤ n ≤ 0.80 95% CI + Q_{75} < Requirement or Q_{75} < Requirement & 95% CI < 0.02 cfm/ft² at 75 Pa. $R^2 > 0.98$	0.50 ≤ n ≤ 1.00 $R^2 > 0.98$	0.45 ≤ n ≤ 1.05 $R^2 > 0.98$ Max test pressure > 0.9 specified target pressure Various 95% CI requirements for determination of pass or fail.
Other	Includes allowance for pressure equalizing adjacent zones which is intended for attached buildings, but could be adapted for zones within a building	Because calibrated fans are not used in this method, flow rate must be measured using alternative methods.	Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 5% of the test pressure.	Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 5% at the maximum test pressure and 2.5 Pa at 50 Pa.	Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 10% of the measured test pressure.	Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 10% at test pressure of 30 Pa. Contains allowance for testing zone within a building, but does not pressure equalize.	Indicates that a check of single zone conditions should be performed for buildings > 20 m tall to ensure that the interior pressure differs by no greater than 10% at test pressure of 50 Pa. Allowance for equalized testing of tall or complex buildings.	Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 10% of the measured test pressure.

7 Capacity for Whole Building Airtightness Testing

This chapter will discuss industry capacity in relation to whole building airtightness testing. Specifically, it will address the primary objective for Task 5: to determine the capacity of the Canadian industry (all regions from coast to coast and the north) to undertake whole building airtightness testing of Part 3 buildings.

7.1 Method

The goal of this task is to develop detailed information regarding the capacity of the industry to perform airtightness testing in preparation for the potential implementation of regulated testing and/or performance requirements. To develop this information, a survey was developed and distributed to targeted industry members who were expected to have knowledge about industry capacity. This strategy was considered preferable to a general survey of the building industry, both because of the time required for a general survey and because the idea of airtightness testing for large buildings is relatively new, meaning that knowledge in this area is specialized and a targeted sample would be more likely to provide useful information.

A challenge for this survey was to collect information from all jurisdictions. The data collection plan addresses this challenge through direct contact with the industry members that are most likely to be able to judge capacity to conduct testing and the cost of the testing in their area. In developing this list, RDH leveraged existing industry connections to identify businesses and individuals to contact.

To supplement survey data with more detailed qualitative information, several telephone and in-person interviews were conducted with a sub-sample of survey respondents who offered to provide more information.

7.1.1 Survey Design and Key Questions

The survey was designed to answer the following key questions:

- → Is Part 3 whole building airtightness testing currently being provided in different regions of Canada?
- → How much experience do companies and individuals have?
- → Is there an interest in expanding these services, e.g. among companies that do not currently provide such testing?
- → What costs are involved in providing such testing and what variables affect these costs?

The survey was designed for ease of completion, so that only relevant questions would be asked of each respondent. For example, respondents who indicated they do not provide airtightness testing services were not asked about the cost of their services.

Initial questions gathered general information to establish the respondent's knowledge and role in the building industry. Subsequent questions gathered information about current services offered, interest in providing services, and costs involved in airtightness testing.

The full survey is attached (note that question logic, i.e. the paths between question subsets, does not show on the pdf version of the survey). The final question requested contact information so that interested respondents could be contacted for one-to-one interviews.

7.1.2 Data Collection

A list was created of major testing and consulting firms in each Canadian jurisdiction, using industry contacts and an internet search for service providers in major centres and remote locations. Specifically, companies were located in Vancouver, Calgary, Edmonton, Winnipeg, Toronto, Ottawa, Montreal, and Halifax. Additional companies that might have capacity related to airtightness testing were then sought out for more remote locations. The completed list was used in two ways. First, it was used as a contact list for distributing an anonymous online survey regarding perceptions of capacity and costs involved in offering whole building airtightness testing for Part 3 buildings. Invitations to complete the online survey were extended to one or more representatives of each listed company. To speed up the response time and increase the response rate, initial contact emails were followed by direct phone calls. Survey results are discussed in section 7.3.

Second, the compiled list was used as a basis for producing a snapshot of existing capacity to undertake Part 3 whole building airtightness tests, or to develop this service in future. The creation of this more focused list was an important sub-task in itself and further discussion of the information contained in it is provided below in section 7.2.

7.2 Current and Potential Capacity

One goal of the current project was to prepare a listing of existing companies that are capable of undertaking Part 3 whole building airtightness tests, or have the potential to develop this service. Initial information gathering through RDH contacts, as well as through online searches, yielded a list of 73 testing laboratories and consulting firms that were likely to provide airtightness testing. As research progressed, additional companies were added, with a focus on less central locations.

Companies on the list were then investigated to further characterize their capacity. Companies were removed that did not have skills and experience related to whole building airtightness testing or that did not have enough information available to determine their capacity. The remaining list included 49 companies with a combined total of 127 locations across Canada. Thirty-six of these locations were confirmed as having current capacity to complete whole building airtightness testing for Part 3 buildings. An additional 91 locations had some availability of related expertise that could be developed if airtightness requirements came into effect. Indicators of potential future capacity included: company offers Part 9 airtightness testing; company offers Part 3 airtightness testing at a different location; company has documented extensive experience in evaluating enclosure airtightness; company representative reported past experience with whole building airtightness testing; etc. The listing is available in Appendix B.

Although there are many areas where Part 3 whole building airtightness testing is not currently offered, there are companies in all regions of Canada that can provide this testing. Companies with potential capacity to develop these services are more numerous and more evenly distributed across the provinces and territories as shown in Figure 7.1 and Table 7.1

One significant gap in terms of equitable access to services is a relative lack of agencies in Nunavut, the Yukon and the Northwest Territories. However, based on anecdotal evidence and survey results, many companies provide airtightness testing services significantly outside their immediate geographic area. As well, there is significant potential capacity in many remote areas that could be developed to meet new requirements. For example, as mentioned in Chapter 5, Whitehorse has local bylaws enforcing blower door tests for new home construction[3]. As a result, there is a local labour force trained to conduct these tests. Additional capacity could be built on this base.

Other areas in Canada also have an apparent lack of currently available services. However, potential capacity is also notable in several of these areas (e.g. New Brunswick and Quebec). Furthermore, there is a significant network of energy auditors and others across Canada whose skills in testing Part 9 buildings could be adapted to meet new needs for Part 3 testing.

In general, the existence of a variety of airtightness experts across the country speaks to the likelihood that most regions have people who understand the work and are potential candidates for offering services for Part 3 buildings. However, to make use of these resources the industry would need adequate lead time to complete additional hiring, training, equipment purchasing, etc.

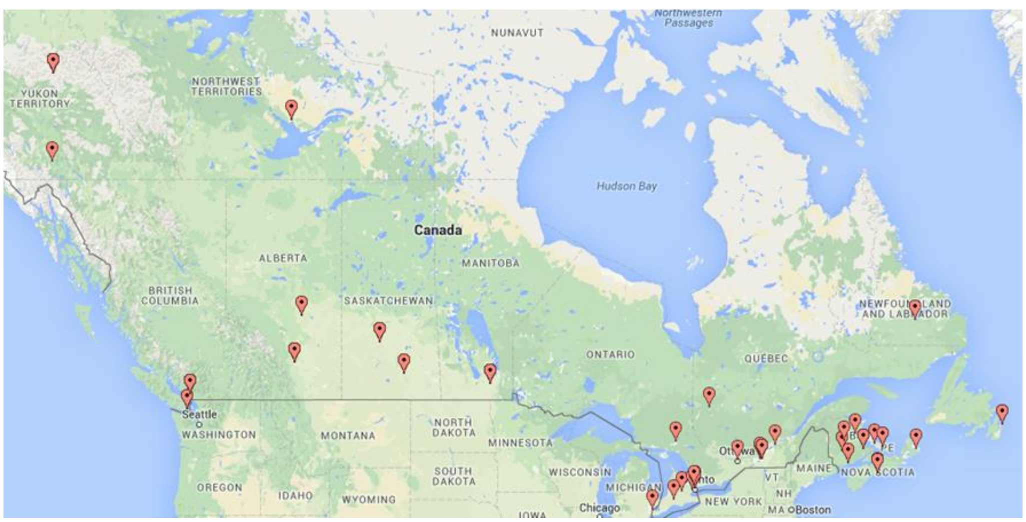

Figure 7.1: Locations of Companies Contacted to Complete Survey (note some locations include multiple companies)

[3]See “New Green Building Standards”, http://www.city.whitehorse.yk.ca/index.aspx?page=216.

TABLE 7.1 PROVINCES/TERRITORIES WITH CAPACITY FOR WHOLE BUILDING AIRTIGHTNESS TESTING OF PART 3 BUILDINGS		
Province/Territory	**Companies/Branches with Current Capacity**	**Companies/Branches with Potential Future Capacity**
Alberta	6	7
British Columbia	12	8
Manitoba	2	5
New Brunswick	0	10
Newfoundland/ Labrador	1	3
Northwest Territories	0	2
Nova Scotia	3	5
Nunavut	1	0
Ontario	9	18
PEI	0	3
Quebec	1	11
Saskatchewan	0	8
Yukon	1	11
TOTAL	**36**	**91**

7.3 Survey Results

One hundred and forty-six companies or company branches from across Canada were identified and contacted about completing an online survey related to industry capacity for whole building airtightness testing. This survey also asked for more detailed information about the costs involved in airtightness testing. It was made anonymous to encourage respondents to share information and opinions more freely.

A total of 33 respondents completed the survey; because not all questions applied to all respondents, response rates for individual questions ranged from 3 to 33 responses. Although the overall response rate was quite good (33/146 or 23%), the low response rate for specific questions presents a challenge in terms of analysis and results should be considered tentative. The geographic distribution of completed surveys is shown in Table 7.2. A cross-section of professionals was captured, as shown in Figure 7.2.

In addition to the main survey sample, an effort was made to arrange distribution through a provincial home-energy-rating association. It was expected that the additional data specifically from those involved in airtightness testing for Part 9 buildings would provide a useful supplement to the initial dataset. However, the survey was not sent out before the completion of this report. Data may be made available as an addendum if requested.

A cross-section of professionals was captured by this survey, as shown in Figure 7.2. It should be noted that most respondents identified with more than one professional category.

TABLE 7.2 PROVINCES/TERRITORIES REPRESENTED IN COMPLETED SURVEYS		
Province/Territory	**Number of Organizations/Branches Contacted**	**Number of Surveys Completed**
Alberta	15	3
British Columbia	23	3
Manitoba	7	1
New Brunswick	13	1
Newfoundland / Labrador	4	0
Northwest Territories	3	0
Nova Scotia	9	1
Nunavut	1	0
Ontario	35	8
P.E.I.	4	0
Quebec	12	0
Saskatchewan	9	0
Yukon	11	0
Other/multiple	0	1
TOTAL	**146**	**18**

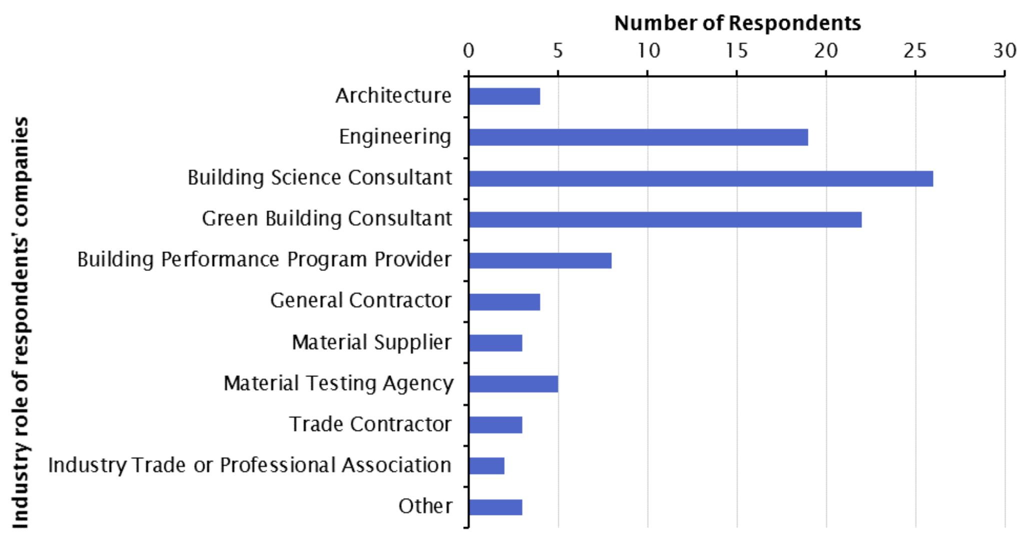

Figure 7.2: Responses to "Please identify the role that your company plays in the industry". Note that most respondents identified with more than one professional category.

7.3.1 Capacity to Provide Airtightness Testing Services

Of the respondents, 70% (23/33) provide whole building airtightness testing services as shown in Figure 7.3. Of those that did not, 40% (4/10) hired or contracted other companies to provide this service. This result is expected based on the sample; companies that were identified as likely to provide airtightness testing services (themselves or through subcontractors) were deliberately targeted to increase respondent knowledge about costs and testing availability.

Of more interest is the result that the location where companies provide services is not necessarily the same as the location of their main offices. In at least one case, the primary location of testing services was identified as the US. Within Canada, respondents tend to provide services over a wide geographic area as shown in Figure 7.4. The transportation of equipment and skilled people to the job site can be an obstacle to testing buildings in remote locations. However, the survey results suggest that whether respondents currently provide Part 3 testing or not, those that provide any whole building airtightness testing typically service a larger region and so it can be assumed that they would also be prepared to address the transportation issue as they consider the introduction of new testing services as part of their operations.

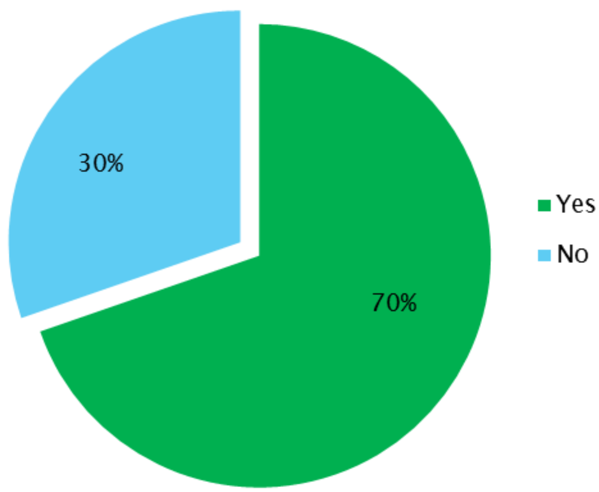

Figure 7.3: Responses to "does your company currently provide whole building airtightness testing?"

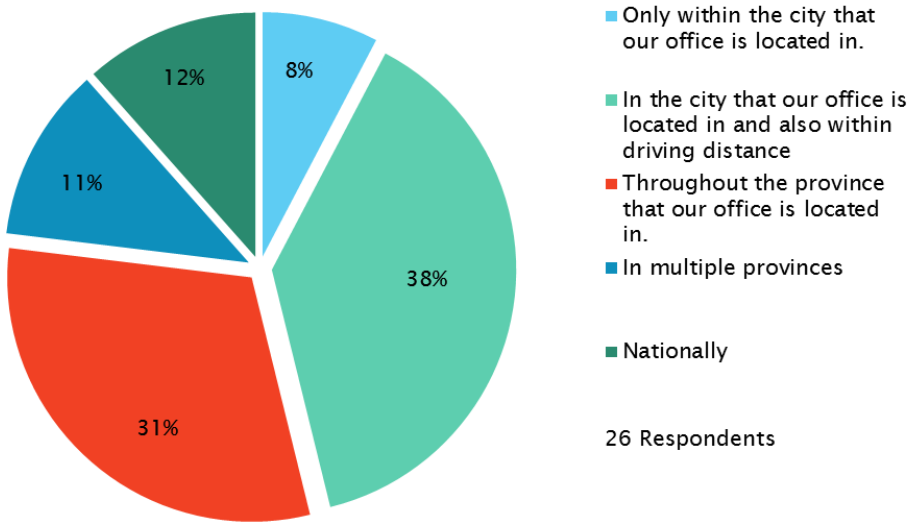

Figure 7.4: Geographic ranges within Canada where respondents provide airtightness testing services

Similarly, respondents have identified that their companies provide services for a range of building types. Of the 16 companies that provided data about the types of buildings they test, 11 said that they test both new and existing buildings and 6 provide testing for both Part 9 and Part 3 buildings.

Of the 15 respondents who rated their company's overall experience, approximately half stated that their companies have "none" or "some" experience as shown in . Interestingly, however, most (9/14 respondents) said that they had been providing services for more than 5 years. The small number of data points for this question makes responses difficult to interpret, but it is possible that at least some companies offer testing but do relatively few tests (i.e. have untapped capacity).

TABLE 7.3 NUMBER OF COMPANIES WITH DIFFERENT LEVELS OF EXPERIENCE IN CONDUCTING WHOLE BUILDING AIRTIGHTNESS TESTS

Experience level	**No. Companies**
None or almost none (we have done no more than a few tests)	2
Some (we have done 10-15 tests since we began offering this service)	6
A significant amount (we have done 15-100 tests since we began offering this service)	1
A high amount (we have done over 100 tests since we began offering this service)	6

Consistent with that possibility, results show an overall interest in expanding the services currently offered. When asked "How would you rate your firm's interest in developing whole building airtightness testing services for Part 3 buildings (e.g. larger non-residential buildings) if building codes change to require this type of testing in the future?" 8/22 responses indicated high interest, and 11/22 indicated some or moderate interest.

7.3.2 Perception of Costs Involved in Airtightness Testing

Information on perceived and actual costs has proven difficult to obtain relative to other data. Again, this is not unexpected as some respondents may lack enough knowledge to feel comfortable providing detailed answers, and others may wish for this information to remain confidential.

To encourage respondents to share general information about costs, respondents were asked about the cost of their companies' testing using several broad ranges:

- Less than $3,000
- Between $3,000 and $10,000
- Between $10,000 and $25,000
- More than $25,000

Most of the tests fell into the lower range: 12/14 responses stated that their tests were less than $10,000, with half less than $3,000. This may be due to the relative rareness of Part 3 testing (i.e. respondents who usually do Part 9 testing might think of a lower average cost). In comparison, the test budgets reported for US testers in Chapter 5 ranged from $4,000 to $40,000.

Fifteen respondents provided their opinion regarding the general cost impacts of a range of possible factors. Responses are given in the matrix below (Table 7.4). Some preliminary patterns can be seen: building size, for example, seems to be an important factor in cost. Number of penetrations and phased construction delivery are also selected by the majority of respondents as major or significant cost factors.

To supplement survey results and provide context, additional data was obtained through semi-structured interviews. It was found that participants were willing to share rich, detailed information in this format, and it is recommended that this research method be strongly considered for future research, in spite of the increased cost involved in conducting interviews on a large scale

TABLE 7.4 EXAMPLE OF COST DATA MATRIX

	Major factor (25% or more of the total cost)	Significant factor (10-24% of total cost)	Minor factor (5-9% of the cost)	Negligible factor (less than 5% of the total cost)
Building area greater than 1,000 square meters	**20.00%** 3	**46.67%** 7	**20.00%** 3	**13.33%** 2
Building height greater than three stories	**35.71%** 5	**35.71%** 5	**21.43%** 3	**7.14%** 1
Phased construction delivery	**40.00%** 6	**26.67%** 4	**26.67%** 4	**6.67%** 1
Testing agency involved only in test (not in early project phases)	**0.00%** 0	**26.67%** 4	**40.00%** 6	**33.33%** 5
Certification of testing through a third party	**0.00%** 0	**50.00%** 7	**35.71%** 5	**14.29%** 2
Experience of testing agency	**6.67%** 1	**33.33%** 5	**53.33%** 8	**6.67%** 1
Existing building	**14.29%** 2	**7.14%** 1	**57.14%** 8	**21.43%** 3
Type of air barrier system installed	**0.00%** 0	**13.33%** 2	**33.33%** 5	**53.33%** 8
Cost of equipment	**6.67%** 1	**46.67%** 7	**26.67%** 4	**20.00%** 3
Interference with other activities on site	**20.00%** 3	**40.00%** 6	**33.33%** 5	**6.67%** 1
Number of penetrations	**26.67%** 4	**46.67%** 7	**13.33%** 2	**13.33%** 2
Requirements for staff training	**13.33%** 2	**26.67%** 4	**53.33%** 8	**6.67%** 1
Administrative costs (e.g. maintaining records of certifications)	**6.67%** 1	**20.00%** 3	**46.67%** 7	**26.67%** 4

Note: Grey-shaded areas indicate 1/3 or more of respondents selecting a given response

7.4 Interview Results

In addition to the survey, two telephone interviews and one in-person interview were conducted to gather qualitative and anecdotal data from survey respondents who offered to provide more information. A fourth interview was conducted with a U.S.-based airtightness testing consultant.

Interviews were conducted using a semi-structured interview protocol (see Appendix 3). Questions were designed to elicit information about the thought process for pricing, to provide deeper insight into pricing factors that may be barriers if mandatory testing were to be implemented. Key points from each interview are provided below.

Interview 1 (Canadian)

- In terms of variables that influence costs, MURBs are the most difficult, especially if they have suite-by-suite ventilation
- The cost of time for the developer is a big deal. That is a lot more expensive than the actual airtightness test. Developer will drive the schedule, and that could have an impact on the cost of doing the test (odd hours, weekends, tight time frame requiring more people on site, etc.)
- In terms of pricing for specific projects, the main consideration is the number of penetrations that must be sealed or managed: "the test itself is cheap; prep is expensive"
- The number of penetrations is estimated based on building type and size.
- If asked to deliver to a target, respondent's company would likely offer two testing options: (1) deliver target with 2-3 visits included and build in enough 'room' or (2) price / visit

Interview 2 (Canadian)

- Company mostly for commercial and institutional buildings. Interested in MURBs but does not perceive that there is a market right now.
- Sometimes uses blower-door tests for diagnostic purposes (unrelated to airtightness per se)
- Key factor in pricing would be building size, "the bigger you go the better or bigger equipment you need. If you're pulling a certain amount of air, you need a certain size fan. So equipment is definitely an initial cost that the contractor [will write] into any contract that they get afterwards"
- Three fans have been adequate to test a wide range of buildings.
- Building owners unaware of potential cost savings from increased airtightness.
- Scheduling is difficult and can increase costs. For some jobs only one day is available to complete testing.
- Company uses drawings and walkthroughs to plan preparation of penetrations. Planning can take a person day, and preparation usually several people over several days. Tests are run with at least two staff.

- → Pricing is per visit, and retesting is often required if client is attempting to meet a standard.
- → Some penetrations are much harder to seal and this can add to costs.

Interview 3 (Canadian)

- → In terms of overall costs, for the developer the big cost is accommodating the construction schedule and stalling construction progress ("if you're doing whole building airtightness tests of a project, you would have to do it when the envelope is complete and before occupancy. That, in most construction projects, is an incredibly short and incredibly busy time")
- → For clients who are accustomed to airtightness testing requirements and build it into their processes, this cost is better managed.
- → Differences between commercial buildings and MURBs are significant because of additional number and complexity of penetrations and compartments. MURBs are built from the ground up and lower units may be locked out as they are completed.
- → Pricing is based on prep time, with at least a day spent on prep for Part 3 buildings. Cost of equipment is also built into pricing. Because the cost of equipment is amortized over a set period, it is possible to charge less per test when more tests are done.
- → Prep work can be a major cost to testing companies. Experience with whole building testing dramatically decreases costs for the testing company as they become more efficient at prep and require less time to fix things that were missed in initial prep and setup.
- → It's important to recognize that the major cost for developers will be fixing any problems, not the cost of tests themselves.
- → It's also important to recognize that whole building airtightness testing can't provide information about where leaks are, and not all leaks are equal in terms of energy or durability impacts. Requirements for airtightness testing may be most useful as a tool to encourage changes to overall building processes, and may not be needed or even useful as a requirement for all buildings. Some type of spot check system for large developers may be preferable.

Interview 3 (American)

- → The biggest cost factors are related to how much is involved in preparing the building for the test. And "that is dominated by what we have to do to prepare the HVAC related penetrations. And how long is that going to take us." For a 40,000 ft^2 low-rise building, it may take two experienced consultants about four hours to get the test ready. It comes down to how many penetrations have to be managed and their location. Depending on the building, you have to use a lift.
- → So, costs for the tester are largely determined by building size and complexity.
- → The type of air barrier is "essentially a non-issue"…."what you [a tester] care about is the number of shafts, number of mechanical penetrations and how the interface is between different components"

- → Preparation requirements also depend on the purpose of the test. If you are testing to a target, you may try with less preparation, and stop if the building passes. For example, closing all the mechanical dampers but not sealing them. If the building fails, then you do the extra work to help it pass. Different test needs also have different formal protocols in terms of how penetrations are dealt with.
- → Good documentation is important. For example, photographing the nameplate on every air handling unit and all the dampers, to document their status during the test. Without this, "you don't know what the test means".
- → Large, leaky buildings increase test costs because it is more difficult to control the air pressure. More fans are needed. The interviewee stated he has used up to 23 fans.
- → In multi-family residential and sometimes office buildings or other occupied buildings, there are costs associated with gaining access to rooms, managing security, etc. In a commercial building, there are times when the building is not being used (e.g. at night) and testing can be done with less coordination.
- → Cost for an occupied building would be about 50% more than for a new, unoccupied building, and this would be built into the labour cost. Other factors in calculating a price are surface area and whether there is an air tightness target. The number of fans needed can be estimated from this.
- → Labour costs can also be increased by scheduling, e.g. working around occupants or trades working on a building under construction.
- → Cost for the building owner is largely based on how many visits are required. It is to the owner's benefit to take measures to air seal before the test is conducted. In some cases they have someone on site who can immediately seal leaks if the building doesn't pass. Next steps in the event that the building fails should be written into the contract.
- → Travel and shipping costs can be significant for the testing agency. In some cases (like with power cords) it is more cost-effective to buy them near the site instead of shipping them.
- → When mandatory testing was implemented, failure rates were high. But when clients were proactive and had a plan review or site inspections during construction, they usually passed airtightness tests. Contractors also learned what was needed to pass the tests.

7.5 Analysis

As it is based on a small sample of data, this analysis should be considered preliminary and serves to suggest some key issues related to industry capacity.

Who is currently providing Part 3 whole building airtightness tests in different regions?

One hundred and forty-six companies or company branches were identified from major centers in regions across Canada as well as less central locations. Specifically, major centers were Vancouver, Calgary, Edmonton, Winnipeg, Toronto, Ottawa, Montreal, and Halifax. The contacted companies included building science firms, engineering companies, sustainability and other consultants, and non-profits, as well as a small sample of energy auditors in more remote areas.

Of these companies/branches, 36 were subsequently identified as being able to provide whole building airtightness testing for Part 3 buildings. A larger portion of the sample was identified as having potential future capacity to develop this type of service. As noted by one interviewee, the market for such testing in Canada is currently limited. However, if more opportunities were available, it is likely that more companies would start to offer Part 3 testing.

Of interest is the finding that companies often offer services significantly beyond their immediate geographic range. This finding may have significance for remote and less-served areas.

How much experience do companies and individuals have? Is there an interest in expanding these services, e.g. among companies that do not currently provide such testing?

Of the 15 respondents who rated their company's overall experience, half stated that their companies have "none" or "some" experience (Table 7-3). Interestingly, however, most (9/14 respondents) said that they had been providing services for more than 5 years. The small number of data points for this question makes responses difficult to interpret, but it is possible that at least some companies offer testing but do relatively few tests (i.e. have untapped capacity).

Consistent with that possibility, results show an overall interest in expanding the services currently offered. When asked "How would you rate your firm's interest in developing whole building airtightness testing services for Part 3 buildings (e.g. larger non-residential buildings) if building codes change to require this type of testing in the future?" 8/22 responses indicated high interest, and 11/22 indicated some or moderate interest.

What costs are involved in providing such testing and what variables affect these costs?

At this time, it is difficult to make any firm statements about costs. Cost questions on the survey had relatively few responses, possibly due in part to a reluctance to discuss this issue or a lack of in-depth knowledge about factors contributing to overall cost. The available data seems to indicate that building size and penetrations are the most important factors. This is consistent with anecdotal evidence and our own experience as consultants, although it should also be noted that costs vary substantially across projects.

Interviewees provided more insight into cost. Key points include:

- → Costs for the developer or building owner are largely related to scheduling and delays in construction, as well as fixing identified problems to meet a target.
- → Based on a comparison of American vs. Canadian experience described by the interviewees, costs are similar across jurisdictions and would be expected to go down as building owners, operators, contractors, and other stakeholders learn to prepare for testing and accommodate it in their scheduling.

→ Pricing for tests depends on many factors, but aside from building size and penetrations, important factors include the building complexity (e.g. MURBs), presence of building occupants, timeframe allowed for tests, experience of testing personnel, and frequency of tests (which impacts the amortized cost of equipment).

8 NECB Part 8 Airtightness Value

The results of the airtightness testing database provide a basis to compare existing requirements in the 2011 National Energy Code for Buildings (NECB). In this chapter, the database results are compared with the existing default value provided in the NECB Part 8 performance path for modelling. Commentary is provided regarding the appropriateness of the default value, and if applicable, an alternative value or range of values are suggested as well as providing a rationale for an appropriate airtightness value(s) for energy modelling under the NECB.

8.1 Context

This section provides general context of the current Canadian airtightness requirements with respect to building design and modelling. In some cases information here has been included in previous section of this report, but is provided again here for clarity.

8.1.1 NECB 2011 Requirements

Specific to airtightness, the 2011 NECB provides the following requirements:

- → 3.2.4.1 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. However, no specific airtightness target is established in the NECB.
- → 3.2.4.2 requires that "all opaque building assemblies that act as environmental separators shall include an air barrier assembly".

Part 8 of the NECB provides an energy modeling compliance path to permit flexibility and trade-offs for building designs in lieu of the prescriptive or trade-off compliance paths. The purpose of the performance compliance procedure is not to develop an accurate prediction of annual energy use. Rather, the purpose is to develop fair and consistent evaluations of the effects of deviations from prescriptive requirements. That is, the energy modelling is comparative rather than predictive. As such, many simplifying assumptions are specified within the NECB to rationalize the modeling exercise without compromising the intent. For example, simulation excludes savings that would be achieved through manual operation such as adjustment of curtains. Differences between the modelled energy consumption and actual energy consumption also arise due to differences in the assumed and actual occupancy loads, variations in control and maintenance, variations from standard weather data, precision of the simulation program, and a range of other factors.

To perform the calculations necessary to demonstrate compliance through the Performance Compliance Path (Part 8), energy modelling software is used to calculate the building annual energy consumption that corresponds to the inputs for the proposed building design. The software is also used to calculate the building energy consumption for a reference baseline building based on the geometry, occupancy, and operation schedules of the proposed building, but using the prescriptive performance values prescribed by NECB. The maximum building energy consumption is set by the calculated consumption of the baseline building, and the proposed building must be calculated to use equal or less energy on an annual basis.

Part 8 of the NECB contains a number of requirements specific to airtightness and air infiltration:

- → 8.4.3.4 states that air leakage of the proposed building shall be set to a constant value of 0.25 L/(s·m²) of total gross above ground wall and roof areas.
- → A-8.4.3.4.(3) states that "the air leakage value of 0.25 L/(s·m²), which is a typical infiltration rate at 5 Pa, is for calculation purposes and may not reflect the real value encountered under actual operating conditions; it is based on assumed typical operating pressure differentials."
- → 8.4.4.4.(6) requires that air leakage rates of the reference building shall be modeled as being identical to those determined for the proposed building.

Airtightness and air infiltration requirements pertain to opaque walls and roof assemblies only. Floors, areas in contact with the ground, glazing, doors and intentional openings are not included in the requirement.

8.1.2 MNECB 1997 Requirements

The Model National Energy Code for Buildings (MNECB) 1997 was the predecessor to the NECB. There are no requirements or recommendations noted in the MNECB for air barriers. However, in 5.3.5.9 of the document *Performance Compliance for Buildings* (NRC, 1999), an air leakage of 0.25 L/(s·m²) of gross wall area is prescribed. The reference pressure is omitted and the roof is excluded from the areas.

8.1.3 National Building Code Requirements

Air Barrier Material Properties

Section 5.4.1.2 of the National Building Code for Canada (NBC) requires that materials intended to provide the principal resistance to air leakage shall have minimum airtightness of 0.02 L/(s · m²) measured at an air pressure difference of 75 Pa, or conform to CAN/ULC-S741, "Air Barrier Materials - Specification."

Air Barrier System Airtightness

The NBC also provides recommended maximum system air leakage rates at 75 Pa for air barrier systems in opaque, insulated portions of the building envelope. These rates are presented in Table 8.1. These recommended levels are not for whole buildings, as windows, doors and other openings are not included. Also note that these values are very tight compared to the performance values collected in the airtightness database.

TABLE 8.1 NBC RECOMMENDED SYSTEM AIR LEAKAGE RATES

Warm Side Relative Humidity	Recommended Maximum System Air Leakage Rate at 75 Pa [L/(s·m²)]
Less than 27%	0.15
27% to 55%	0.10
More than 55%	0.05

As can be seen the requirement for the air barrier material is significantly more stringent than the requirements for air barrier systems that include joints.

8.1.4 Energy Impacts of Infiltration

The heating and cooling loads caused by infiltration have been studied by a number of researchers. (Emmerich & Persily, 1998)

→ Space heat loads associated with infiltration range from 1 kWh/m² to 80 kWh/m², corresponding to 3% to 42% of space heating energy use of typical commercial buildings. The floor space weighted average is 14 kWh/m² which is 13% of space heating load.

→ For cooling energy consumption, infiltration accounts for up to 26 kWh/m² (12% of cooling energy). The floor space weighted average for cooling energy consumption associated with infiltration is 4.4 kWh/m².

8.2 Discussion

8.2.1 Comparing Test Data to NECB Requirements

A detailed discussion of the database results is presented in Chapter 3. Results are summarised in Table 8.2 and compared to the requirements in the NECB (adjusted to 75 Pa). Based on the overall sample, the recommended airtightness is approximately 50% lower than the results documented in the database, and 100% lower than the results of the Canadian buildings in the database. As noted previously, however, as the requirements in Section 8.4.3.4 pertain to above ground wall and roof areas, it is impossible to assess whether the modelling requirements provide a reasonable estimate of leakage from above ground wall and roof areas since these areas are not independently tested. Furthermore, airtightness measurements and in-service air leakage rates are not necessarily directly comparable as discussed in Chapter 2, and discussed in more detail in Section 8.3 with specific relevance to energy consumption and energy modelling.

TABLE 8.2 AIRTIGHTNESS DATABASE RESULTS & CURRENT NECB VALUE

Database Result	Airtightness [L/(s·m²) at 75 Pa]
Overall	2.15
Canadian Buildings	2.93
US Buildings	1.18
UK Buildings	4.57
NECB 0.25 @ 5 Pa Equivalent at 75 Pa (Assumes n = 0.65)	1.45

8.2.2 Impact of Underestimating Air Infiltration on Energy Modelling Results

The impact of underestimating infiltration in compliance models is that the models will generally underestimate heating and cooling energy, and/or that the balance between heating and cooling energy will be altered (i.e. heating dominated vs cooling dominated) In an effort to make energy modelling results align more closely with actual building performance, it is recommended that the current air leakage and airtightness assumption be reconsidered, both in terms of what building elements are included, and in terms of the overall leakage assumptions.

8.2.3 Air Infiltration Calculations in Hourly Energy Models

Hourly energy modeling software tools utilize a range of procedures to calculate air infiltration rates. While in some cases these models include some type of infiltration model which attempts to calculate infiltration based on exterior environmental conditions such as wind speed and temperature, often this type of calculation is not performed, and the accuracy of these models is limited. More commonly, in-service air leakage rates are assumed to be a constant value, which greatly simplifies the modelling process, but likely does not accurately reflect in-service conditions. Aligning energy model input assumptions with the capabilities and limitations of energy models will improve the consistency of application and the accuracy of results.

8.3 Airtightness versus Infiltration

While it is possible to compare the results of airtightness testing with the recommended infiltration rate of NECB as has been done in the preceding sections of this chapter, it is important to realize that this is not comparing like-with-like. The NECB recommends an infiltration rate, while airtightness testing simply measures the resistance of the building enclosure to airflow. As discussed in Chapter 2, infiltration depends both on the airtightness of the building enclosure as well as on the pressure differences which are created by stack effect, wind, and mechanical ventilation systems.

Importantly, it is the airflow, rather than the airtightness, which is of significance with respect to moisture durability, indoor air quality, occupant comfort, and building energy consumption. While improving the airtightness of buildings provides an opportunity to reduce infiltration and exfiltration through the building enclosure, this is only one aspect of airflows into, out of, and within buildings. Because of this, airtightness research alone does not provide sufficient information to recommend a one-size-fits-all infiltration rate for energy modelling purposes. Furthermore, a one-size-fits-all infiltration rate is unlikely to be appropriate as this approach:

- → does not account for variability in exposure, climate, airtightness, presence of operable windows, different building types, different mechanical systems (and different operating pressures), etc., and
- → does not account for different infiltration rates in different parts of the building.

Figure 8.1 illustrates how the airtightness of a building tested at a pressure of 75 Pa can then potentially be used to calculate the associated air leakage, but that a range of potential in-service pressure differences are possible, so it is not possible to predict the in-service air leakage rates from airtightness alone. This is compounded by the fact that in-service airtightness can be drastically impacted by operable windows.

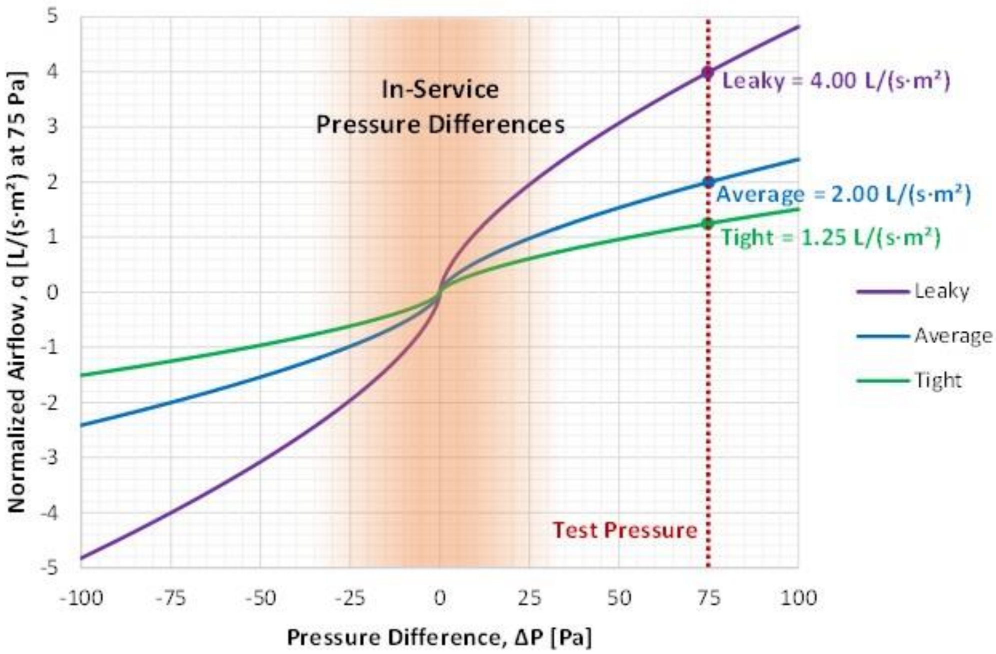

Figure 8.1: Chart showing how airtightness test results can potentially be extrapolated down to in-service conditions, but that in-service pressure differences are unknown

There are numerous infiltration models which have been developed, but these are either not implemented in energy modelling software, or when included in the software, are seldom used.

Due to the substantial number of relevant factors, understanding of building airflows is significantly more complex than airtightness alone and is currently not well captured within building design and energy modelling practices. Further research is needed in this area to better understand the impacts of building airflows, and subsequently to develop recommendations for the design, construction, and modelling of new buildings, as well as to support potential updates to building codes and standards.

9 Summary

This study of the airtightness of large buildings used a combination of data collection, surveying, and literature review to evaluate the state of the Canadian industry with respect to airtightness. This evaluation included development of a database of airtightness testing results for buildings throughout the word, with a specific focus on buildings in Canada and the United States. Existing airtightness performance and testing requirements and procedures were reviewed, summarized, and compared. Surveying was conducted to evaluate the impact or potential impact of airtightness requirements, and also to evaluate industry capacity. Finally, the airtightness performance values compiled in the database were compared to in-service air leakage values provided in Part 8 of the NECB. This study supports the following general conclusions.

- → Airtightness performance and testing requirements have been implemented in other jurisdictions (such as Washington State, USACE, and GSA). A number of these test standards have adopted a target of 2.03 L/(s·m²) (0.40 cfm/ft²) at 75 Pa, and various jurisdictions have shown that this target is achievable using currently available construction technology and practices. Furthermore, these jurisdictions have demonstrated that the airtightness of buildings improves significantly when requirements are implemented.
- → To date, overall perceptions of whole building airtightness testing seem positive. There are perceived benefits for many, and anecdotal evidence suggests a sense that increased airtightness requirements are a manageable change. A recurrent theme was the need to ensure adequate availability of testing services to meet demand if code changes made testing mandatory.
- → Mandatory airtightness testing in other jurisdictions has served to improve the quality of air barrier systems, and in particular the level of workmanship and quality control. The requirements are set in such a way that most buildings are passing, and those that do not are rarely repaired in any significant way. The knowledge that a building will be tested provides motivation to contractors and trades to do higher quality work.
- → Numerous whole building airtightness testing procedures and methodologies exist and have been successfully applied to the testing of hundreds of large buildings. These standards could be readily used or adapted as necessary for use in airtightness testing requirements.
- → A pervading theme with respect to the implementation of airtightness performance and testing requirements in the State of Washington is a lack of education. Many lessons about coordination and preparation for testing were learned through mistakes, and more information either within the codes or provided through training programs could have potentially reduced these initial difficulties.
- → Most survey respondents agreed that there are moderate cost implications associated with airtightness testing aside from the cost of the test itself, though in jurisdictions where testing is mandatory, the total economic impact does not appear to have stunted development.

- → Generally there is currently limited capacity for whole building airtightness testing in Canada. To accommodate the potential implementation of a mandatory testing requirement, the quantity and distribution of services would need to be improved, and generally firms indicated that they would be interested in further developing their services in this area.
- → Typical whole building airtightness is significantly higher than the input assumptions in NECB; however, it is impossible to compare the database results with the requirements of the NECB directly since the database provides whole building airtightness while the NECB requirements are for above grade walls and roof assemblies only. Aligning test methods with code assumptions is recommended to permit comparability. Furthermore, measured enclosure airtightness does not correspond directly with in-service air leakage as in-service infiltration and exfiltration will depend on the pressure differences created by wind, stack effect, and mechanical ventilation systems. Additionally, while enclosure airtightness is measured in one state, operable windows can potentially alter the in-service airtightness of the enclosure by orders of magnitude. As a result of the large number of factors which impact in-service air leakage rates, a single value for infiltration likely will not address the complexity of estimating infiltration and exfiltration.
- → Improved methods are being developed to estimate infiltration loads in energy models and it is recommended that further research be completed to develop understanding of how measured whole building airtightness relates to in-service air leakage rates. In particular this could include measurement of actual in-service air leakage rates and correlation with measured airtightness, and rates predicted by infiltration models. (Ng, Persily, & Emmerich, 2014; Gowri, Winiarski, & Jarnagin, 2009)
- → Any airtightness or air leakage performance metrics which are specified in building codes should be consistently referenced between codes (i.e. NECB and NBC, airtightness of whole building versus just walls etc.) to reduce confusion and improve consistency in application. Furthermore, metrics which are provided for the purposes of energy modelling should be aligned with the available inputs and capabilities of commonly used energy modelling software tools.

10 Closure

We trust that this report on whole building airtightness of large buildings meets your needs at this time. Please feel free to contact us with any questions.

Yours truly,

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Appendix A

Industry Impact Surveying Distribution List

Canadian Construction Industry Associations with an Interest in Whole Building Airtightness			
Province	**City**	**Association Name**	**Status**
AB	Edmonton	Alberta Construction Association	Contacted with initial request to participate
AB	Calgary	Calgary Construction Association	Contacted with initial request to participate
AB	Edmonton	Edmonton Construction Association	Contacted with initial request to participate
AB	Edmonton	Construction Owners Association of Alberta	Contacted with initial request to participate
AB	Calgary	Alberta Building Envelope Council	Contacted with initial request to participate
AB	Edmonton	Consulting Engineers of Alberta	Contacted with initial request to participate
AB	Edmonton	Alberta Association of Architects	Phase II survey distributed.
AB	Calgary	BOMA Calgary	Contacted with initial request to participate
AB	Edmonton	Alberta Construction Safety Association	Contacted with initial request to participate
BC	Vancouver	BC Construction Association	Contacted with initial request to participate
BC	Delta	British Columbia Building Envelope Council (BCBEC)	Phase II survey distributed.
BC	Burnaby	Association of Professional Engineers and Geoscientists of BC	Contacted with initial request to participate
BC	Vancouver	Architectural Institute of BC	Contacted with initial request to participate

BC	Vancouver	BOMA BC	Contacted with initial request to participate
BC	Richmond	Building Officials' Association of BC	Contacted with initial request to participate
BC	New Westminster	British Columbia Construction Safety Association	Contacted with initial request to participate
MB	Winnipeg	National Air Barrier Association	Phase II survey distributed
MB	Winnipeg	Winnipeg Construction Association	Contacted with initial request to participate
MB	Winnipeg	Manitoba Building Envelope Council	Contacted with initial request to participate
MB	Winnipeg	Consulting Engineers of Manitoba	Contacted with initial request to participate
MB	Winnipeg	Manitoba Association of Architects	Contacted with initial request to participate
MB	Winnipeg	Manitoba Building Officials Association	Contacted with initial request to participate
MB	Winnipeg	Manitoba Construction Safety Association	Contacted with initial request to participate
MB	Winnipeg	Merit Contractors Association of Manitoba	Contacted with initial request to participate
MB	Winnipeg	ASHRAE Manitoba Chapter	Contacted with initial request to participate
NB	Fredericton	NB Building Officials Association	Contacted with initial request to participate
NS	Dartmouth	Construction Association of Nova Scotia	Contacted with initial request to participate
NS	Halifax	Nova Scotia Association of Architects	Contacted with initial request to participate
NS	Halifax	BOMA NS	Contacted with initial request to participate

NS	Dartmouth	Nova Scotia Construction Safety Association	Contacted with initial request to participate
NS	Halifax	Consulting Engineers of Nova Scotia	Contacted with initial request to participate
NT	Yellowknife	Northern Safety Association	Contacted with initial request to participate
ON	Toronto	Ontario Association of Architects	Contacted with initial request to participate
ON	Ottawa	Canadian Construction Association	Contacted with initial request to participate
ON	Richmond Hill	Toronto Construction Association	Contacted with initial request to participate
ON	Mississauga	Mississauga Construction Association	Contacted with initial request to participate
ON	Ottawa	Mechanical Contractors Association of Canada	Contacted with initial request to participate
ON	Ottawa	Construction Education Council	Contacted with initial request to participate
ON	Ottawa	Canadian Construction Documents Committee	Contacted with initial request to participate
ON	Toronto	Construction Specifications Canada	Contacted with initial request to participate
ON	Ottawa	Building Envelope Council Ottawa Region	Contacted with initial request to participate
ON	Markham	Ontario Building Envelope Council	Contacted with initial request to participate
ON	Toronto	Building Industry and Land Development Association (BILD)	Phase I survey completed. Phase II survey distributed.
ON	Toronto	Professional Engineers Ontario	Contacted with initial request to participate
ON	Kingston	Engineering Institute of Canada	Contacted with initial request to participate

ON	Ottawa	Association of Consulting Engineers Canada	Agreed to distribute Phase II survey.
ON	Toronto	Consulting Engineers of Ontario	Contacted with initial request to participate
ON	Toronto	BOMA Canada	Contacted with initial request to participate
ON	Toronto	BOMA Toronto	Contacted with initial request to participate
ON	Ottawa	BOMA Ottawa	Contacted with initial request to participate
ON	Toronto	BOMI Canada	Contacted with initial request to participate
ON	Woodbridge	Ontario Building Officials Association	Phase I survey completed. Phase II survey distributed.
ON	Mississauga	Ontario General Contractors Association	Contacted with initial request to participate
ON	Kingston	The Canadian Society for Engineering Management (CSEM)	Contacted with initial request to participate
ON	Kingston	Canadian Society for Mechanical Engineering	Contacted with initial request to participate
ON	Ottawa	Energy Council of Canada	Contacted with initial request to participate
ON	Mississauga	Heating, Refrigeration and Air Conditioning Institute of Canada	Contacted with initial request to participate
ON	Toronto	Consulting Engineers of Ontario	Contacted with initial request to participate

ON	Etobicoke	Ontario Association of Certified Engineering Technicians and Technologists (OACETT)	Contacted with initial request to participate
ON	Mississauga	ASHRAE Toronto Chapter	Contacted with initial request to participate
ON	Ottawa	Association of Consulting Engineering Companies	Contacted with initial request to participate
ON	Toronto	IBPSA Canada	Phase I survey completed (local chapter rep). Phase II survey dsitributed (local chapter)
ON	Hamilton	Hamilton Burlington Society of Architects	Contacted with initial request to participate
QB	Montreal	Association de la Construction du Quebec	Contacted with initial request to participate
QB	Montreal	Quebec Building Envelope Council	Contacted with initial request to participate
QB	Montreal	Consulting Engineers of Quebec	Contacted with initial request to participate
QB	Montreal	Ordre Des Architects Du Quebec	Contacted with initial request to participate
QB	Gatineau	Canadian General Standards Board	Contacted with initial request to participate
QB		BOMA Quebec	Contacted with initial request to participate
QB	Anjou	Quebec Construction Safety Association	Contacted with initial request to participate
QB	Montreal	Canadian Society of Civil Engineering	Contacted with initial request to participate
Sask	Regina	Saskatchewan Construction Safety Association	Contacted with initial request to participate
SK	Saskatoon	General Contractors Association of Saskatchewan	Contacted with initial request to participate

SK	Saskatoon	Saskatoon Construction Association	Contacted with initial request to participate
YK	Whitehorse	Association of Professional Engineers of Yukon	Contacted with initial request to participate
National	N/A	National Building Envelope Council (NBEC)	Contacted with initial request to participate
National	N/A	Canadian Mortgage and Housing Corporation (CMHC)	Contacted with initial request to participate
National	N/A	Natural Resources Canada (NRC)	Contacted with initial request to participate
National	N/A	Canadian Association of Certified Energy Advisors (CACEA)	Contacted with initial request to participate
National	N/A	North American Insulation Manufacturers Association (NAIMA)	Phase I survey completed. Agreed to distribute Phase II

Appendix B

Companies Identified as Offering Airtightness Testing Services

The companies listed below were identified as having some level of capacity to conduct whole building airtightness testing for Part 3 buildings or to develop this service in future. Companies were identified by cross-checking across a variety of information sources, such as company websites, direct contact with company representatives, lists produced by third parties (e.g. Building Envelope Councils), and past project reports (e.g. containing descriptions of airtightness testing).

This listing is intended to provide a snapshot of nation-wide expertise and is not an exhaustive list. For example, there are many energy appraisers across Canada who conduct blower door tests for Part 9 buildings who were not researched for this list, but who may have enough expertise to expand to Part 3 buildings.

City	Company Name	Capacity – Current or Potential	Notes
Alberta			
Calgary	CCI Group	Potential	General expertise in airtightness (e.g. air leakage testing for windows and doors)
Calgary	DIALOG	Potential	General expertise in building enclosures and engineering. Listed on ABEC website
Calgary	Entuitive	Potential	Advised by company contact that they are interested in offering this service in this area and have capacity to do this in future
Calgary	IRC	Potential	IRC website indicates a range of related services
Calgary	JRS Engineering	**Current**	
Calgary	MMM Group	**Current**	
Calgary	Morrison Hershfield	**Current**	
Calgary	Stantec Consulting	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Canmore	MMM Group	**Current**	
Edmonton	MMM Group	**Current**	

City	Company Name	Capacity – Current or Potential	Notes
Edmonton	Morrison Hershfield	**Current**	
Edmonton	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Edmonton	Wade Engineering	Potential	Company performs energy audits. Does not currently offer WB airtightness testing
British Columbia			
Courtenay	RDH	**Current**	
Fraser Valley	Levelton	**Current**	
Nanaimo	Morrison Hershfield	**Current**	
Okanagan	Strata	**Current**	
Richmond	Levelton	**Current**	
Vancouver	Apex Building Sciences Inc.	Potential	General expertise in airtightness (e.g. thermography, air leakage testing for windows and doors)
Vancouver	CCI Group	Potential	General expertise in airtightness (e.g. air leakage testing for windows and doors)
Vancouver	City Green Solutions	Potential	Offer residential airtightness testing
Vancouver	IRC Building Sciences Group	Potential	General expertise in building enclosures and air leakage. Offer thermography and performance/condition assessments
Vancouver	JRS Engineering	**Current**	

City	Company Name	Capacity – Current or Potential	Notes
Vancouver	Morrison Hershfield	**Current**	
Vancouver	RDH	**Current**	
Vancouver	RJC	Potential	General expertise in building enclosures and air leakage. Offer thermography and technical audits.
Vancouver	Stantec	Potential	Company contact indicated that they may have capacity through building commissioning department
Vancouver	Strata	**Current**	
Victoria	Morrison Hershfield	**Current**	
Victoria	RDH	**Current**	
Victoria	WSP	Potential	Halsall recently became part of WSP; Halsall has current capacity
Victoria	City Green Solutions	Potential	Offer residential airtightness testing
Victoria/ Nanaimo	Levelton	**Current**	
		Manitoba	
Winnipeg	AmeriSpec Inpection Services of Winnipeg	Potential	Offer residential air leakage testing
Winnipeg	Energuy Canada Ltd	Potential	Offer residential air leakage testing
Winnipeg	MMM Group	Potential	MMM has capacity through other offices
Winnipeg	Morrison Hershfield	Potential	Morrison Hershfield has capacity through other offices

City	Company Name	Capacity – Current or Potential	Notes
Winnipeg	QCA Building Envelope Ltd	**Current**	
Winnipeg	Stantec	**Current**	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Winnipeg	WSP	Potential	Halsall recently became part of WSP; Halsall has current capacity in other locations
	New Brunswick		
Fredericton	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
Fredericton	Stantec	Potential	Service offered at other locations
Halifax	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
Moncton	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
Moncton	EXP	Potential	Offer building enclosure performance testing for multi-unit residential buildings
Moncton	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Saint John	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air

City	Company Name	Capacity – Current or Potential	Notes
			quality, mechanical and wall assembly performance, etc.
Saint John	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Sydney	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
Unknown	AmeriSpec of Canada	Potential	Company experience with Part 9 testing in another location
Newfoundland/Labrador			
St. John's	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Goose Bay	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
St John's	Morrison Hershfield	**Current**	
St. John's	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
Nova Scotia			
Dartmouth	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Halifax	IRC	Potential	IRC website indicates a range of related services

City	Company Name	Capacity – Current or Potential	Notes
Halifax	MMM Group	**Current**	
Halifax	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Halifax	Thermal Wise	**Current**	
Halifax	WSP	Potential	Halsall recently became part of WSP; Halsall has current capacity
St. John's	Thermal Wise	**Current**	
Sydney	CBCL Limited	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
Northwest Territories			
Yellowknife	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Yellowknife	Williams Engineering	Potential	Case study lists experience with airtightness testing
Nunavut			
Iqaluit	EXP	**Current**	Yes, company contact confirmed that they offer service in this area through their Ottawa office
Ontario			
Brampton	DAVROC	**Current**	
Burlington	Morrison Hershfield	**Current**	
Cambridge	Building Knowledge	Potential	Offer residential air leakage testing and work with MURBs
Kitchener	AJ Energy Consultants	Potential	Offer residential air leakage testing and work with MURBs

City	Company Name	Capacity – Current or Potential	Notes
London	IRC	Potential	IRC website indicates a range of related services
Markham	SPL Consultants	Potential	Offer related services (performance audits and thermography analysis)
Mississaug a	IRC	Potential	IRC website indicates a range of related services
Ottawa	IRC	Potential	IRC website indicates a range of related services
Ottawa	Morrison Hershfield	**Current**	
Richmond Hill	Brown Beattie	Potential	Offer air and water leakage testing; unclear whether this includes whole building airtightness testing
Stayner	McGregor Allsop Limited	**Current**	
Sudbury	IRC	Potential	IRC website indicates a range of related services
Toronto	Carson Dunlop Weldon and Associates Ltd.	Potential	Offer residential air leakage testing
Toronto	CCI Group	Potential	General expertise in airtightness (e.g. air leakage testing for windows and doors)
Toronto	CH2M Hill	Potential	
Toronto	Clearsphere	Potential	Offer residential air leakage testing
Toronto	Cricket Energy	Potential	Offer residential air leakage testing and work with MURBs
Toronto	Entuitive	Potential	Have participated in whole building airtightness testing but do not offer as core business
Toronto	EXP	**Current**	

City	Company Name	Capacity – Current or Potential	Notes
Toronto	McGregor Allsop Limited	**Current**	
Toronto	MMM Group	**Current**	
Toronto	Morrison Hershfield	**Current**	
Toronto	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Toronto	WSP	Potential	Halsall recently became part of WSP; Halsall has current capacity
Waterloo	Building Science Consulting Inc.	**Current**	
Waterloo	IRC	Potential	IRC website indicates a range of related services
Windsor	Glos Associates Inc	Potential	Offer building condition audits/assessments
Prince Edward Island			
Charlottetown	CBCL	Potential	Offer extensive building conditions assessments and have expertise around code compliance, indoor air quality, mechanical and wall assembly performance, etc.
Charlottetown	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Summerside	House Master PEI	Potential	Offer residential air leakage testing
Quebec			
Amos	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity

City	Company Name	Capacity – Current or Potential	Notes
Becancour	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Laval	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Montreal	ARUP	Potential	Offer building commissioning and envelope performance/design services
Montreal	CCI Group	Potential	General expertise in airtightness (e.g. air leakage testing for windows and doors)
Montreal	EXP	Potential	Offer performance testing and research
Montreal	IRC	Potential	IRC website indicates a range of related services
Montreal	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Montreal	WSP	Potential	Halsall recently became part of WSP; Halsall has current capacity
Saint-Anne-des-Monts	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Saint-Laurent	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Quebec	C.L.E.B. inc.	**Current**	
Saskatchewan			
Regina	IRC	Potential	IRC website indicates a range of related services

City	Company Name	Capacity – Current or Potential	Notes
Regina	MMM Group	Potential	MMM has capacity through other offices
Regina	Sun Ridge Residential Inc.	Potential	Offer residential air leakage testing
Saskatoon	AmeriSpec	Potential	Offer residential air leakage testing
Saskatoon	Sun Ridge Residential Inc.	Potential	Offer residential air leakage testing
Saskatoon	Total Home Solutions Inc	Potential	Offer residential air leakage testing
Saskatoon	MMM Group	Potential	MMM has capacity through other offices
Saskatoon	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Yukon Territories			
White Horse	Morrison Hershfield	**Current**	
Whitehorse	Stantec	Potential	Unclear whether this service is offered at this location, but Stantec has organizational capacity
Whitehorse	Olsen's Resource Consulting	Potential	Offer residential air leakage testing
Whitehorse	Sands Construction	Potential	Offer residential air leakage testing
Whitehorse	Theo's Construction	Potential	Offer residential air leakage testing
Whitehorse	Wayne Wilkinson Consulting	Potential	Offer residential air leakage testing

City	Company Name	Capacity – Current or Potential	Notes
Whitehorse	Yukon Housing Corporation	Potential	Offer residential air leakage testing
Whitehorse	Yukon Housing Corporation	Potential	Offer residential air leakage testing
Whitehorse	manwiththefurnaceon@yahoo.ca	Potential	Offer residential air leakage testing
Whitehorse	Mitt Stehelin	Potential	Offer residential air leakage testing
Whitehorse	Joel Luet	Potential	Offer residential air leakage testing
Whitehorse	Greg Dumka	Potential	Offer residential air leakage testing
Total companies with current capacity			**13**
Total companies with potential capacity			**36**
Total company locations with current capacity			**36**
Total company locations with potential capacity			**91**

Appendix C

Interview Protocol for Follow-Up

The following script was used as a guide for follow-up interviews with survey respondents who offered to provide more information.

Interviewer: I would like to ask you a few questions as follow-up for the survey that we are conducting for the Canadian National Energy Code for Buildings (NECB) Task Group on Building Envelopes (TG¬BE). I would like to spend 10 minutes or so if you have the time now.

[response]

Interviewer: Okay, I would like to record our conversation to make my note taking easier. Is this okay with you? We will not use the recording for any other purpose.

[response]

Interviewer: Great. You may recall that the survey is one part of a wider study to review the current status of issues surrounding whole building airtightness testing of buildings in Canada. Specifically, as a follow-up, I would like to ask you two questions about what influences the cost of the testing.

So first, for large buildings covered by Part 3 of the code, what are the variables that, in your experience, impact the costs of whole building airtightness tests?

[response and discussion; limit to a few minutes but follow-up on interesting points]

Interviewer: Okay, the second question is a fun one. I would like you to help assign a rough price to testing two example buildings. You can, of course, give me approximate costs and feel free to talk through why you would choose those numbers. We'll assume that both buildings are in the city where your office is.

> Building 1 is a 10 storey multi-unit residential building
>
> 6 suites per floor 5000 sq. ft. floor plate (50,000 sq. ft. total building area)
>
> "x" enclosure area
>
> The enclosure is floor-to-ceiling window wall and spandrel panels for majority, some areas self-adhered membrane, and inverted roof
>
> Ventilation is through the corridors, AC and heating per unit.

[response]

> Okay, Building 2 is a community centre and library. Mostly one floor but with a three story component.
>
> 12,000 sq ft. floor plate and 22,000 sq ft in total
>
> "x" enclosure area
>
> For the enclosure, we have about 40% glazing with most of that punched windows and a large curtainwall section near the entrance. The remainder is brick veneer over self-adhered membrane/exterior gypsum/steel studs, and exposed membrane roof.
>
> Roof top HVAC units.

[response]

Interviewer: Okay, well great. Thank-you for your time today. It is really helpful to have more detailed information here.

Appendix D

Survey Questions

Industry Capacity for Whole Building Airtightness Testing

The following survey is being conducted for the Canadian National Energy Code for Buildings (NECB) Task Group on Building Envelopes (TG-BE) by RDH Building Engineering (RDH) and Building Science Consulting (BSCI). This survey is one part of a wider study to review the current status of issues surrounding whole building airtightness testing of buildings in Canada.

RDH and BSCI have been asked to collect information about the capacity of the Canadian construction industry to undertake whole building air leakage testing of Part 3 buildings. We will start by asking several questions about your company and then ask about your experience with airtightness testing. **We hope to gain information and perspectives from companies that offer airtightness testing, companies that hire them, and companies that do not currently conduct or purchase airtightness tests. We value feedback from all three groups.**

Please answer the following questions. The time to complete them will be about 5 minutes. At the end of the survey, you will have an opportunity to provide additional follow-up information.Thank you for your participation.

*Questions marked with an * are required.*

***1. Please indicate your company's primary location:**

Province/Territory:

City:

***2. Please identify the role that your company plays in the industry. Check all that apply.**

- Architecture
- Engineering
- Building Science Consultant
- Green Building Consultant
- Building Performance Program Provider
- General Contractor
- Material Supplier
- Material Testing Agency
- Trade Contractor
- Industry Trade or Professional Association
- Other (please specify)

***3. What kind of buildings does your company typically work on? Please check all that apply.**

- Multi-unit residential (low-rise up to 5 stories)
- Multi-unit residential (high-rise greater than 5 stories)
- Commercial (greater than 3 storeys high and 600 m²)
- Institutional (greater than 3 storeys high and 600 m²)
- Industrial (greater than 3 storeys high and 600 m²)
- Other (please specify)

***4. Does your company currently provide whole building airtightness testing services?**

- yes
- no

5. Please indicate the primary geographic area where your company does most of its airtightness testing, if different from the location of your main office.

Province/Territory:

City:

6. More specifically, where do you provide these services? Please check all that apply.

- ☐ Only within the city that our office is located in.
- ☐ In the city that our office is located in and also within driving distance
- ☐ Throughout the province that our office is located in.
- ☐ In multiple provinces
- ☐ Nationally

7. Which types of buildings do you provide this service for? Please check all that apply.

- ☐ Residential and small buildings (Part 9)
- ☐ Larger buildings (Part 3)
- ☐ New buildings only
- ☐ Existing buildings only
- ☐ Both new and existing buildings

8. Please list the test protocols that your company uses.

9. Approximately how many years have you been offering airtightness testing services?

- ○ Between 0 and 1
- ○ Between 1 and 5
- ○ More than 5

Industry Capacity for Whole Building Airtightness Testing

10. How much experience has your company had with providing whole building airtightness testing services?

- ◯ None or almost none (we have done no more than a few tests)
- ◯ Some (we have done 10-15 tests since we began offering this service)
- ◯ A significant amount (we have done 15-100 tests since we began offering this service)
- ◯ A high amount (we have done over 100 tests since we began offering this service)

11. What cost range do most of your tests fall into?

- ◯ Less than $3,000
- ◯ Between $3,000 and $10,000
- ◯ Between $10,000 and $25,000
- ◯ More than $25,000

12. Please indicate the primary geographic area where you work. This may be different from the location of your company's main office.

Country:

Province/State:

City:

***13. Do you hire or contract with other companies to perform whole building airtightness testing for Part 3 buildings in your region?**

- Yes
- No

14. Are you aware of other companies that offer this service in your region ?

- ◯ Yes
- ◯ No

15. On average, for the type of buildings you work on, how much does a typical whole building airtightness test cost in your area?

- ○ Less than $3,000
- ○ Between $3,000 and $10,000
- ○ Between $10,000 and $25,000
- ○ More than $25,000

16. There are a number of factors that influence the cost of whole building air leakage testing. Using your experience, and thinking about the types of buildings that you typically work with, please indicate how much each may increase the overall cost of an airtightness test.

	Major factor (25% or more of the total cost)	Significant factor (10-24% of total cost)	Minor factor (5-9% of the cost)	Negligible factor (less than 5% of the total cost)
Building area greater than 1,000 square meters	◯	◯	◯	◯
Building height greater than three stories	◯	◯	◯	◯
Phased construction delivery	◯	◯	◯	◯
Testing agency involved only in test (not in pre-testing project phases)	◯	◯	◯	◯
Certification of testing through a third party	◯	◯	◯	◯
Experience of testing agency	◯	◯	◯	◯
Existing building	◯	◯	◯	◯
Type of air barrier system installed	◯	◯	◯	◯
Cost of equipment	◯	◯	◯	◯
Interference with other activities on site	◯	◯	◯	◯
Number of penetrations	◯	◯	◯	◯
Requirements for staff training	◯	◯	◯	◯
Administrative costs (e.g. maintaining records of certifications)	◯	◯	◯	◯

Please list other factors that we haven't included, and indicate whether they are major, significant, minor, or negligible factors.

17. How would you rate your firm's interest in developing whole building airtightness testing services for Part 3 buildings (e.g. larger non-residential buildings) if building codes change to require this type of testing in the future?

- ◯ Low interest. I don't think that we will ever offer whole building airtightness testing services for Part 3 buildings.
- ◯ Some interest. We could be interested but would need to consider a number of significant factors such as training, staff and equipment availability, etc.
- ◯ Moderate interest. We would be interested and have no reason to think that we would not be able to offer these services.
- ◯ High interest. This service would be a good match for our company. We would be highly interested in developing this part of our business.

***18. Would you or someone from your company be interested in providing RDH/BSCI with additional information for this survey by phone or email?**

- ◯ Yes
- ◯ No

19. Thank you for your interest in providing more information. Please provide contact information where we can reach you.

Name	
Company	
Email	
Phone	

Impact of Whole Building Air Leakage Testing Requirements

The following survey is being conducted for the Canadian National Energy Code for Buildings (NECB) Task Group on Building Envelopes (TG-BE) by RDH Building Sciences (RDH) and Building Science Consulting (BSC). RDH & BSC have been asked to collect information about the potential impacts of adding whole building air leakage testing requirements to the NECB.

This survey is primarily geared toward people/companies/organizations that operate in jurisdictions that require air leakage testing in order to assess the impacts of mandatory testing.

Please answer the following questions. The time to complete this survey is about 10 minutes.

*1. What is your primary region of work?

State

City (or cities)

*2. What involvement does your company/organization have in the construction of new buildings? (check all that apply)

- ☐ Architecture
- ☐ Engineering/Consulting (Mechanical/HVAC)
- ☐ Engineering/Consulting (Envelope)
- ☐ Construction (GC or sub trade)
- ☐ Testing/Commissioning Agency
- ☐ Owner/Developer
- ☐ Building code development/enforcement
- ☐ Other (please specify)

*3. What type(s) of new buildings are you typically involved with?

- ☐ Small residential (single family, Duplex, Townhouse)
- ☐ Multi-family residential (low & mid-rise: up to 7 stories)
- ☐ High-rise (residential or commercial: 8 stories or higher)
- ☐ Commercial (non high-rise)
- ☐ Industrial
- ☐ Institutional

Impact of Whole Building Air Leakage Testing Requirements

***4. Does your company/organization currently provide whole building air leakage testing services?**

- ◯ Yes
- ◯ No

***5. Approximately how many whole building air leakage tests have you been directly involved with (witnessing and/or performing)?**

- ◯ Less than 10
- ◯ 10-20
- ◯ 21-30
- ◯ 31-40
- ◯ More than 40

***6. Of the buildings that you have been involved with, approximately what percentage did not meet the specified air leakage target?**

- ◯ All of them met the target
- ◯ 1-10% did not meet the target
- ◯ 11-20% did not meet the target
- ◯ 21-30% did not meet the target
- ◯ 31-40% did not meet the target
- ◯ More than 40% did not meet the target

7. Of those that did not meet the target, was any remedial work done?

- ◯ Yes, significant repairs were done throughout the building enclosure
- ◯ Yes, some problem areas were identified and repaired
- ◯ Yes, minor deficiencies were identified and repaired
- ◯ No, leakage areas were identified and reported but no repairs were done
- ◯ No, leakage areas were not identified and no repairs were done
- ◯ Other (please specify)

Impact of Whole Building Air Leakage Testing Requirements

8. If leakage areas were identified, what were the most common problem areas?

- [ ] Roof to wall transitions
- [ ] Base of wall or floor line transitions
- [ ] Mechanical penetrations
- [ ] Dampers
- [ ] Soffits
- [ ] Windows/doors
- [ ] Other (please specify)

***9. Aside from the cost of the test itself, do you feel that whole building air leakage requirements increase the total cost of construction?**

- ○ No, or not significantly
- ○ Yes, there is significant cost involved
- ○ Yes, there is moderate cost involved
- ○ Other (please specify)

***10. In your experience, do whole building air leakage testing requirements have any economic impacts on the following:**

	Significant cost increase	Moderate cost increase	Low cost increase	No effect	Cost savings
labor	○	○	○	○	○
material	○	○	○	○	○
design effort	○	○	○	○	○
Construction schedule/sequencing (in terms of time lost or saved)	○	○	○	○	○
Remedial work (in the case of a failed test)	○	○	○	○	○

Other (please specify)

Impact of Whole Building Air Leakage Testing Requirements

***11. In general, do you feel that whole building air leakage requirements are beneficial & worthwhile in terms of increased building performance & quality of design/workmanship?**

- ◯ Yes, it is both beneficial and worthwhile
- ◯ It is somewhat beneficial, but overall not worthwhile
- ◯ It is not beneficial and not worthwhile
- ◯ Other (please specify)

***12. Choose one of the following statements that best represents your opinion of current whole building air leakage target in your jurisdiction:**

- ◯ The target leakage is just fine the way it is
- ◯ The target leakage is too stringent – it's too hard to pass a whole building test
- ◯ The target leakage is very lenient – anybody can pass a whole building test
- ◯ Other (please specify)

13. Are there any other impacts (financial or otherwise) of whole building air leakage requirements that have not been addressed in this survey? Please comment.

Thank you for your participation. If you have any questions about this survey or the wider study please contact Denali Jones at djones@rdh.com

Whole Building Airtightness Testing and Building Codes

Industry Survey Information

The following survey is being conducted for the Canadian National Energy Code for Buildings (NECB) Task Group on Building Envelopes (TG-BE) by RDH Building Engineering (RDH) and Building Science Consulting Inc. (BSCI). This survey is one part of a wider study to review the current status of issues surrounding whole building air leakage testing of buildings in Canada.

RDH and BSCI have been asked to collect information about the potential impacts of adding whole building air leakage testing requirements to the NECB. This survey is primarily geared toward people/companies/organizations that operate in jurisdictions where air leakage testing is voluntary.

Please answer the following questions.Questions marked with an * are required.

Thank you for your participation.

Respondent Background

The following information will assist us in analyzing survey results.

*1. Please indicate your primary work location:

Province/Territory: ______

City: ______

*2. Please indicate your qualifications (check all that apply).

- ☐ Engineer
- ☐ Architect
- ☐ Technologist
- ☐ Skilled Trade Contractor
- ☐ Energy Advisor or Energy Auditor
- ☐ Other (please specify)

______

Whole Building Airtightness Testing and Building Codes

***3. Please indicate your involvement in the construction of new buildings. Please check all that apply.**

- [ ] 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 which of the following building types you are typically involved with:**

- [ ] Low-rise residential (e.g. single-family homes and townhouses less than 3 storeys high and less than 600 m2)
- [ ] Other buildings less than 3 storeys high and less than 600 m²
- [ ] Multi-unit residential (low-rise up to 5 stories)
- [ ] Multi-unit residential (high-rise greater than 5 stories)
- [ ] Commercial (greater than 3 storeys high and 600 m²)
- [ ] Institutional (greater than 3 storeys high and 600 m²)
- [ ] Industrial (greater than 3 storeys high and 600 m²)

Comments

Whole Building Airtightness Testing and Building Codes

***5. Please choose the option that best describes your experience with airtightness testing requirements.**

- ◯ I work in an area where airtightness testing is mandatory and there are prescribed airtightness targets
- ◯ I work in an area where airtightness testing is voluntary and my company chooses to meet voluntary standards for most of our projects
- ◯ I work in an area where airtightness testing is voluntary and my company chooses to meet voluntary standards for some of our projects
- ◯ I work in an area where airtightness testing is voluntary and my company does not use airtightness testing on our projects
- ◯ Don't know/does not apply to me

Please list airtightness requirements (if any) that your company has experience with.

Respondent Background - Mandatory Jurisdictions

only shown to those who work in mandatory areas (based on question 5)

6. Please indicate the jurisdiction that you work in where whole building airtighness testing is mandatory.

7. Choose one of the following statements that best represents your opinion of current whole building airtightness requirements in this jurisdiction:

- ◯ The requirements are much too stringent – it’s much too hard to pass a whole building test
- ◯ The requirements are somewhat too stringent – it's too hard to pass a whole building test
- ◯ The requirements are just fine the way they are
- ◯ The requirements are somewhat too lenient – it's too easy to pass a whole building test
- ◯ The requirements are much too lenient – it's much too hard to pass a whole building test

Please comment on why you chose your answer

Benefits and Challenges of Airtightness Testing

Whole Building Airtightness Testing and Building Codes

8. Please rate the importance of each of the following items from 1-5 (where 1="not important" and 5="very important") as reasons for doing whole building airtightness testing.

	1	2	3	4	5
Energy (e.g. to reduce infiltration/exfiltration losses or gains)	◯	◯	◯	◯	◯
Moisture control (e.g. condensation or water penetration)	◯	◯	◯	◯	◯
Indoor air quality (e.g. contaminant control)	◯	◯	◯	◯	◯
Acoustics	◯	◯	◯	◯	◯

Please list any additional reasons and indicate their importance.

9. Aside from the cost of the test itself, do you feel that whole building airtightness testing increases the total cost of construction?

- ◯ No, or not significantly
- ◯ Yes, there is moderate cost involved
- ◯ Yes, there is significant cost involved
- ◯ Other (please elaborate)

10. If you feel there is added construction cost due to whole building airtightness testing, please rank the following from lowest to highest cost impact (where 1=lowest and 5=highest)

	1	2	3	4	5
Increased labour cost	◯	◯	◯	◯	◯
Increased material cost	◯	◯	◯	◯	◯
Increased design effort	◯	◯	◯	◯	◯
Changes in construction schedule/sequencing	◯	◯	◯	◯	◯
Cost of remedial work (in case of a failed test)	◯	◯	◯	◯	◯

Whole Building Airtightness Testing and Building Codes

11. Based on your current knowledge, please give your opinion about the quality of typical whole building airtightness testing services in Canada.

	Great	Okay	Neutral/no opinion	Needs improvement	Unacceptable
Qualifications of testing personnel	◯	◯	◯	◯	◯
Cost of services	◯	◯	◯	◯	◯
Availability of services	◯	◯	◯	◯	◯

Qualifications of testing personnel — Please add any comments:

Cost of services — Please add any comments:

Availability of services — Please add any comments:

12. Are there any other impacts (financial or otherwise) of whole building airtightness testing that have not been addressed in this survey? Please comment.

13. In general, do you feel that whole building airtightness requirements are worthwhile in terms of increased building performance and quality of design/workmanship?

◯ Yes, whole building airtightness requirements are definitely worthwhile

◯ Yes, requirements are somewhat worthwhile, but not enough to offset the costs involved

◯ No, requirements are not worthwhile

◯ I'm not sure

Please add any additional comments

Additional Information

***14. Would you or someone from your company be interested in providing RDH/BSCI with additional information related to this survey?**

◯ Yes

◯ No

Contact Information

15. Thank you. Please provide contact information below.

Name

Company

Address

Email

Phone