MAKING HERITAGE BUILDINGS MORE AIRTIGHT

A Condensed Best Practice Guide for Airtightness Testing of Heritage Buildings

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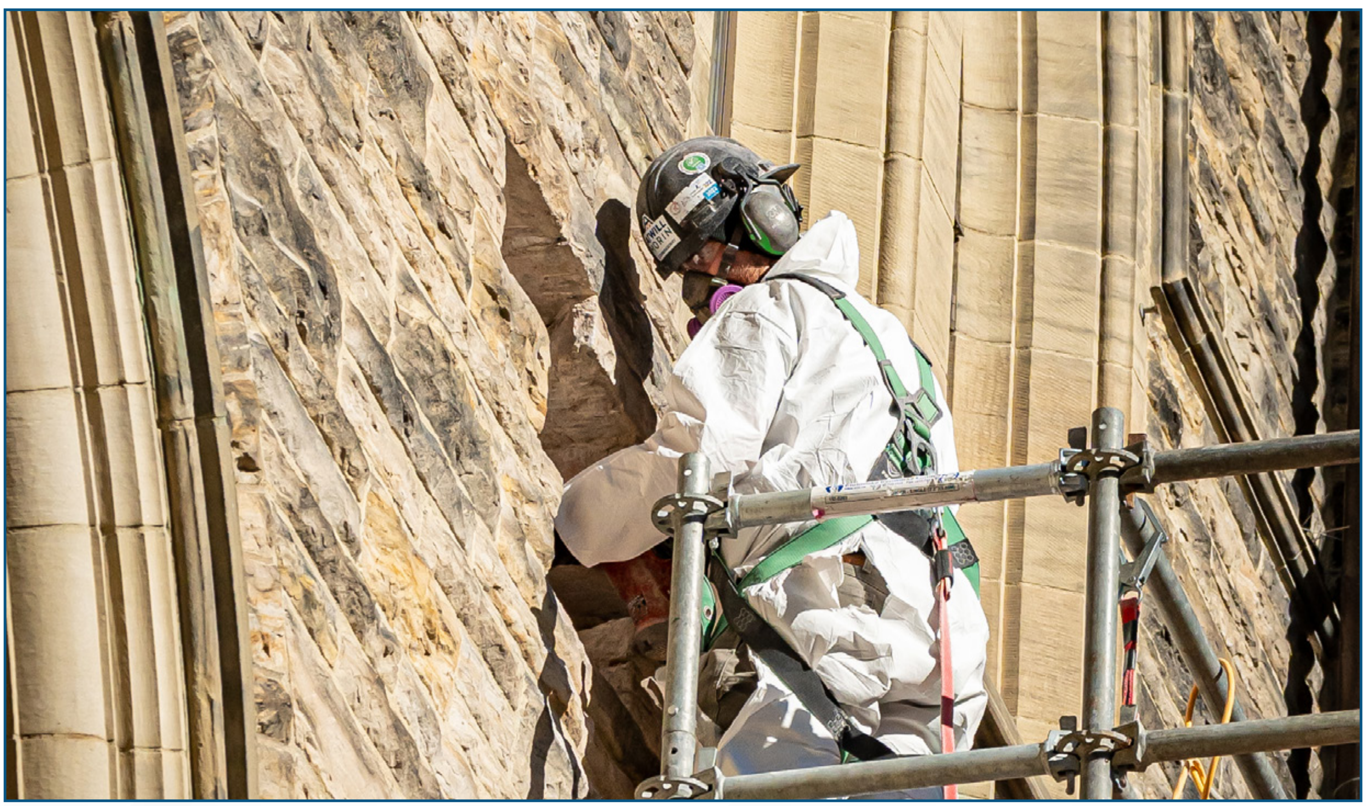
- National Research Council of Canada (NRC)
- PSPC Real Property Services (RPS)
- National Capital Commission (NCC)
- Natural Resources Canada (NRCan)
- Royal Canadian Mounted Police (RCMP)
- The City of Ottawa
- The Bytown Museum



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1. INTRODUCTION

1.1 Context

The Government of Canada has set ambitious *greenhouse gas (GHG) emissions* reduction targets for federal operations through the Greening Government Strategy. The strategy aims to reduce GHG emissions from federal government operations by 40% below 2005 levels by 2025 and achieve net-zero emissions by 2050 [1]. Accordingly, federal departments are expected to embed emissions reduction and climate resilience into the management of their real property portfolios and major projects.

Central to these efforts is the need to improve energy performance across existing buildings. This includes heritage buildings, whose historical and cultural significance makes their preservation particularly important. However, heritage buildings often lack dedicated *air barriers*, leading to higher levels of *air leakage*. *Airtightness testing* helps designers pinpoint areas to improve the *building envelope* during a retrofit project. Improving the *airtightness* of heritage buildings and controlling fresh air supply enhances the building's energy performance and reduces GHG emissions, supporting sustainability and *conservation* goals.

1.2 Purpose

Building on a previous collaboration between the National Research Council of Canada and Public Services and Procurement Canada, the guide *Making Heritage Buildings More Airtight: Best Practice Guide for Testing and Modelling Airtightness of Heritage Buildings* addresses the challenges of airtightness testing in heritage buildings, and how airtightness testing results can inform and advance whole building energy modelling during a rehabilitation project. This condensed guide intends to:

1. Describe the different airtightness test types and methods;
2. Identify best practices for completing airtightness testing on heritage buildings, and;
3. Outline unique challenges and provide mitigation strategies for ensuring accurate airtightness test results in airtightness testing for heritage buildings.

This condensed guide serves as a companion to the technical guide and includes case studies and airtightness testing results gathered from buildings across Canada. The condensed guide is intended to be used by project managers working on major rehabilitation projects to help them understand how airtightness testing can benefit their project and to outline key considerations when specifying airtightness testing. For more detailed information, consult the full technical guide authored by the National Research Council of Canada.

The scope of this guide does not include guidance on safety procedures or protocols. It is recommended that test agencies and individuals follow the recommendations of existing standards, the building owner, and existing guidelines used within the test agency when performing airtightness testing.

Drawing Best Practices From Research, Data Analysis, Industry Experts and Standards

This guide is the product of an extensive research study on airtightness testing for heritage buildings. The aim of the research was to explore how air leakage affects energy performance in heritage buildings, identify common leakage sources and mitigation strategies, establish best practices, and identify realistic airtightness targets that can be achieved after a retrofit project.

Data was collected from a range of sources, including industry surveys, existing test standards, and a comprehensive review of previous test results. The study also involved a series of airtightness investigations on nine heritage buildings located across Canada. In total, 150 airtightness tests were completed: 126 building airtightness tests and 24 window airtightness tests. During testing, procedures and standards were intentionally pushed to their limits to better understand how different conditions and approaches could influence results.

The buildings that were assessed as part of the research study included:

- Sir John A. Macdonald Building in Ottawa
- Connaught Building in Ottawa
- Victory Building in Winnipeg
- 330 Rue de la Gare-du-Palais in Québec City
- Dominion Observatory in Ottawa
- RCMP Building in Regina
- Bytown Museum in Ottawa
- Pinhey's Point in Ottawa
- Glebe Community Centre in Ottawa

These buildings were selected based on differences in location, size, architectural complexity and age to reflect the diversity of heritage buildings in Canada. This supported the development of recommendations that are nationally applicable.

The research study produced four key findings:

1. Major retrofit projects should include field airtightness testing and use these results in the building energy model to establish realistic post-retrofit air leakage goals, rather than relying on assumed values.
2. Whole building airtightness testing is the recommended approach for quantitative airtightness testing of heritage buildings, as it provides a reliable means of determining air leakage.

3. Localized component testing can be used to verify the airtightness of an individual window during or following its installation.
4. Qualitative airtightness testing should be completed in combination with quantitative airtightness testing. Using both approaches allows for main sources of air leakage to be more easily identified.

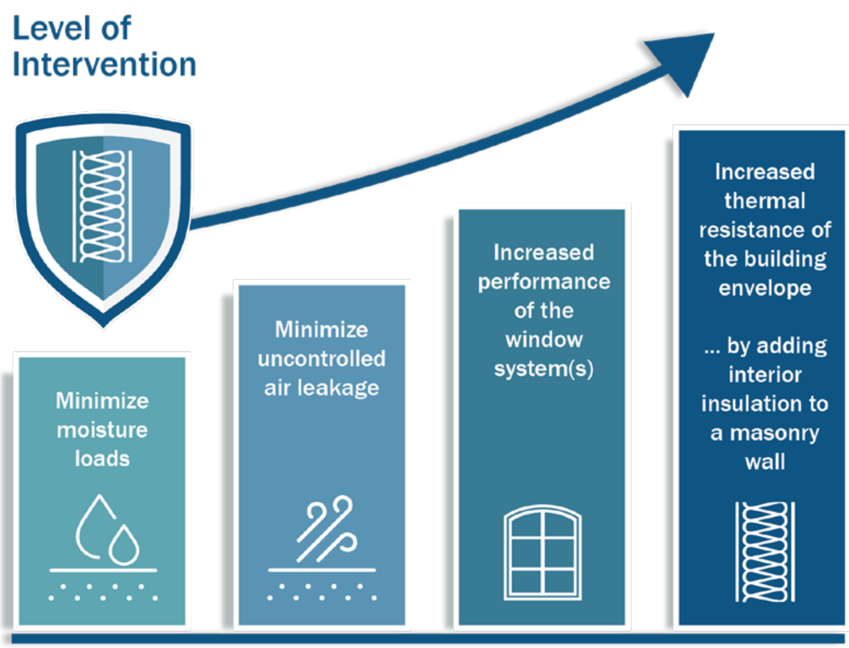
These findings form the basis of this guide and are discussed in greater depth in the sections that follow, along with supporting data, case studies, and specific considerations for airtightness testing.

Glossary terms are italicized in the guide at their first appearance to be easily identified. A full glossary of these terms is available on page 22.

1.3 Overview

There are four recommended strategies for heritage buildings to enhance the energy performance of the building envelope, reduce GHG emissions, and improve occupant comfort. These recommendations are presented in order of increasing levels of intervention:

1. Minimize the exterior moisture loads
2. Minimize uncontrolled air leakage
3. Upgrade the window systems to improve performance
4. Increase thermal resistance of the building envelope by adding interior insulation to a masonry wall



This guide only focuses on the second step: minimizing uncontrolled air leakage.

To effectively minimize the air leakage, airtightness testing should be performed at various times during a *retrofitting* project:

i. During project planning
   a. Establishes a baseline measurement of the building's current leakage rates, and;
   b. Provides a clear starting point and areas of focus for improvement.

ii. During project execution
   a. Ensures that the leakage rates align with the design *specifications*.

iii. At project completion
   a. Measures the final leakage rates,
   b. Verifies the effectiveness of the retrofitting efforts, and;
   c. Ensures that the building meets its energy efficiency goals.

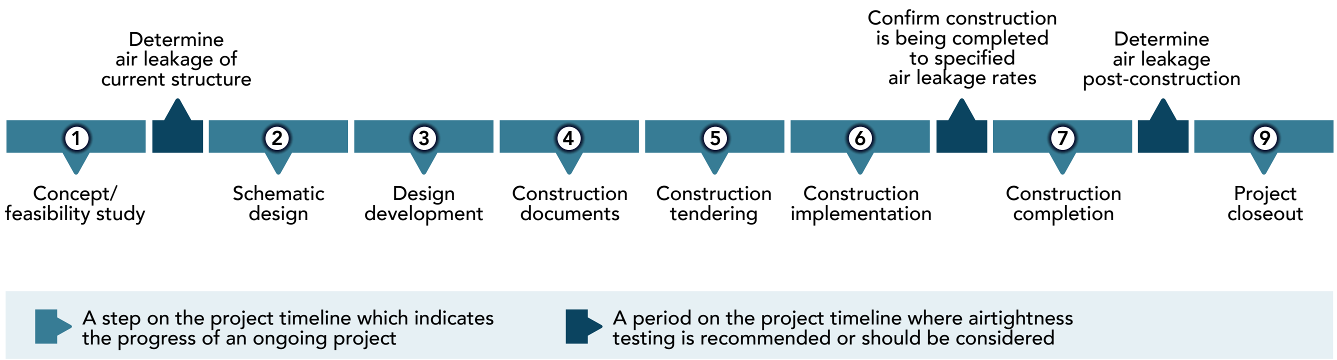


Figure 1: Project timeline for airtightness testing

2. AIRTIGHTNESS TESTING FOR HERITAGE BUILDINGS

Airtightness testing can be grouped into two categories: qualitative and quantitative. Qualitative airtightness testing consists of various visual inspection methods for identifying the location of the air leakage paths. Quantitative airtightness testing determines the amount of air leakage through the envelope or components of a building. Both qualitative and quantitative airtightness testing involve a range of different test types.

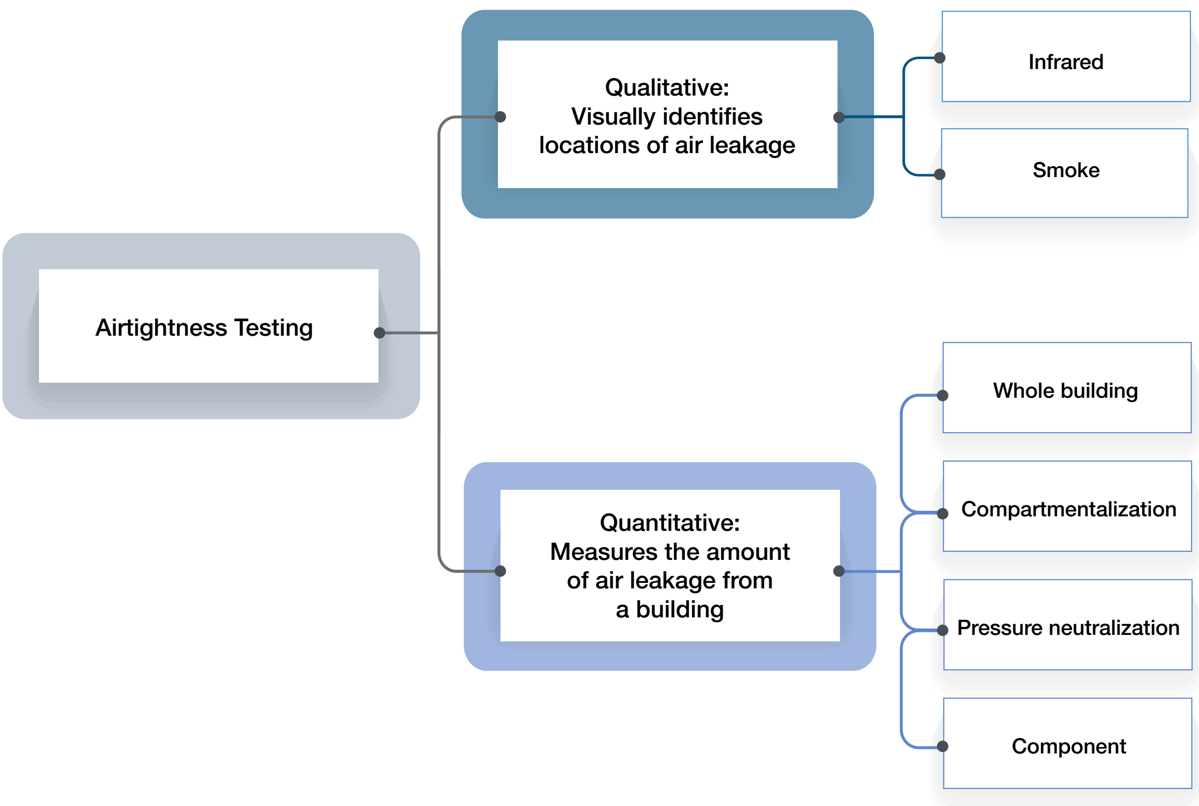


Figure 2: Types of airtightness testing

2.1 Qualitative airtightness testing

Qualitative testing strategies can be used to visually identify locations of air leakage. Qualitative tests are most effective as visual indicators in the early stages of retrofit projects. Infrared thermographic imaging and smoke tracer testing are two of the most common and cost-effective techniques used.

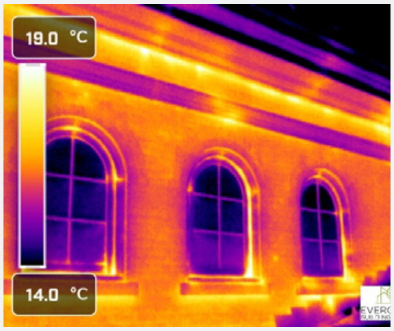


Figure 3: Glebe Community Centre pressurization thermographic scan

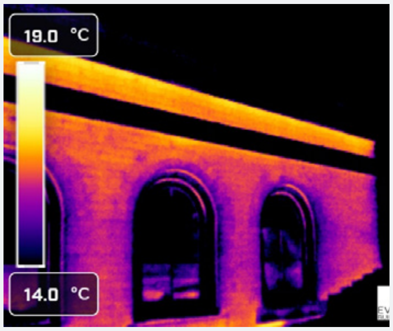


Figure 4: Glebe Community Centre depressurization thermographic scan

Figure 5: Glebe Community Centre location reference photo

2.1.1 Infrared thermographic imaging

Infrared (IR) thermographic imaging can help to identify locations of air leakage in the building envelope. Infrared imaging captures temperature variations on surfaces, providing a thermal image that shows the different temperatures as colours. The thermographic scan of the building envelope (both interior and exterior) must be taken in accordance with ASTM E1186 *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems* [2].

To differentiate between air leakage from other heat sources in an IR image, two comparison IR images are taken:

1. While the fans are *pressurizing* the building (figure 3),
2. While the fans are *depressurizing* the building (figure 4).

In comparing these two images, the areas of air leakage will become apparent.

During building pressurization, calibrated fans are used to blow air into the building. The added air increases the internal *pressure*, causing air to escape through existing air leakage pathways in the building envelope. This leaking air shows up as plumes in the IR images, making the locations of air leakage identifiable.

Building depressurization uses calibrated fans to expel indoor air and reduce indoor pressure. Outdoor air will enter the building through leaky areas, further accentuating the temperature difference at points of air leakage.

It is ideal to use calibrated fans to create the pressure difference required to take valid IR images showing air leakage. However, it is sometimes possible to get the required pressure difference using just the building mechanical systems if the project budget does not allow for the use of calibrated fans. A building science engineer will be able to advise on this.

Infrared thermographic imaging requires a thermal difference between the indoor and outdoor temperature, which may make using it in summer months challenging. According to the standard; *Air Leakage Site Detection in Building Envelopes and Air Barrier Systems* (ASTM 1186-17), the indoor-outdoor temperature difference must be at least 5 °C. The best time to take IR images is in the morning before sunrise so the absorbed heat from the sun has had time to dissipate from the building. To ensure accurate IR results, it is recommended to specify a Level II Certified Infrared Thermographer to conduct the test.

2.1.2 Smoke tracer/theatrical fog airtightness testing

During a smoke tracer test, a theatrical fog machine or a smoke pencil is used to detect air leakage pathways; this provides immediate results that can be easily interpreted (figure 6). These tests are conducted in accordance with ASTM E1186 *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*. For large-scale smoke testing, the interior testing space is filled with theatrical fog and the building is pressurized. This pushes the fog out of the building through air leakage pathways (figure 7). From the exterior, these pathways are identified by escaping fog.

For small-scale smoke testing, a smoke pencil can be used to identify leakage pathways. The smoke pencil is brought to areas suspected of air leakage and smoke is applied in small doses. Depending on how this smoke moves through the air, air leakage pathways can be identified.

Figure 6: Smoke testing

Figure 7: Theatrical fog visible from the exterior

2.2 Quantitative airtightness testing

For quantitative airtightness testing, fans are used to pressurize and depressurize a test area. The airflow that is required to maintain specific pressures is measured, allowing the air leakage to be calculated. The boundary condition of the test area depends on the type of quantitative airtightness test that is being performed. Quantitative airtightness testing types include:

1. Whole building
2. Segmented
   a. Compartmentalization (unguarded)
   b. Pressure neutralization (guarded)
   c. Localized or component testing

2.2.1 Whole building airtightness testing

Whole building airtightness testing is a process used to assess the level of airtightness of the entire building envelope at once. This type of testing involves temporarily installing calibrated fans to openings (typically exterior doors). These fans are used to control the pressure within the building (figure 8). During a pressurization test, the fans increase the interior pressure of the building, causing indoor air to escape through areas of the envelope that are not airtight. In a depressurization test, fans decrease the interior pressure of the building, drawing outdoor air into the building through those same leakage pathways.

Figure 8: Blower door assembly for pressurization and depressurization

There are two types of whole building airtightness testing: operational envelope testing and building envelope testing.

Operational envelope testing measures the air leakage through the entire building envelope and the mechanical systems. Mechanical ventilation is closed through the system's dampers during operational testing (figure 9). Building envelope testing measures the air leakage through the building envelope only; mechanical ventilation is sealed off by external means (figure 10).

Performing operational and building envelope testing together can quantify the performance of the building envelope and how much of the air leakage occurs through the building's mechanical systems.

One challenge to whole building testing is *stack effect*. Stack effect occurs in large buildings when pressure builds up on the higher floors due to rising heat (figure 11). This pressure difference makes it challenging to establish a uniform interior pressure of 75 Pa required for the airtightness test, as there will be increased pressure on the top floors. This can be addressed using pressure taps on higher floors to reduce pressure, which will facilitate maintaining a uniform pressure.

Whole building airtightness testing should be undertaken by the test agency in accordance with ASTM E3158: *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multi-zone Building* [3]. ASTM E3158 addresses challenges in testing larger buildings, providing methods to evaluate airtightness while considering exterior conditions and building size. It includes pressure equalized testing for

Figure 9: Configuration of mechanical systems during "as-operated" testing

Figure 10: Configuration of envelope testing with sealed ventilation

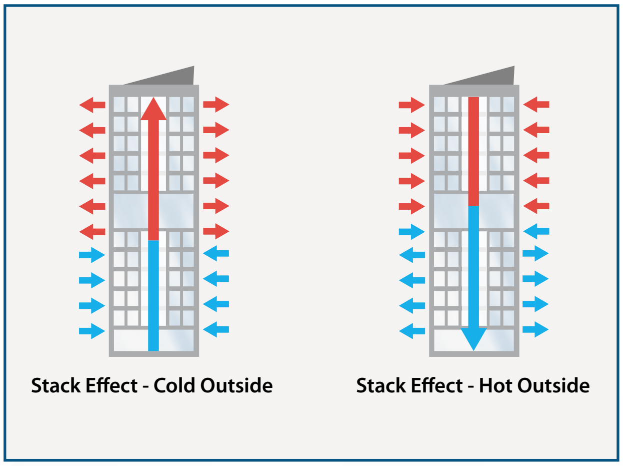


Figure 11: Stack effect

zonal airtightness and describes two test boundary conditions: building envelope (excluding HVAC openings) and operational envelope (including HVAC openings).

If necessary, the standard CAN/CGSB 149.15 – *Determination of the Overall Envelope Airtightness of Buildings by the Fan Pressurization Method*, can be used for testing houses and small buildings with air-handling systems. The standard is suitable for single-zone buildings. It requires only a depressurization test and does not specify qualitative assessment methods.

2.2.2 Segmented testing

Segmented testing involves testing only certain sections of the building for air leakage. There are various types of segmented tests which can be employed: Compartmentalization airtightness testing (unguarded), pressure neutralization airtightness (guarded), and localized or component airtightness testing.

2.2.2.1 Compartmentalization airtightness testing (unguarded testing)

Compartmentalization airtightness testing involves isolating a test zone (e.g., one floor or one room) from the rest of the building by closing all doors and windows and sealing any penetrations that might cause airflow between zones, such as vents or ducts.

One challenge to this type of testing is that air leakage results include both the leakage through the building envelope and the interior partitions. While the goal of this type of testing is to completely zone off a section of the building, this is not entirely possible in practice and can lead to higher recorded air leakage values across the building envelope. This testing is more applicable to multi-unit residential buildings where a certain level of airtightness is required.

When performing compartmentalization testing, the test agency should complete the test in accordance with ASTM E3158: *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multi-zone Building*.

2.2.2.2 Pressure neutralization airtightness testing (Guarded testing)

Pressure neutralization airtightness testing aims to address the limitations of compartmentalization airtightness testing. Testing involves adding adjacent "guard" zones around the desired isolated area (often an entire floor) to quantify air leakage to the envelope. Adjacent "guard" zones are pressurized to the same pressure as the test zone to negate the air leakage into these zones and only measure the air leakage to the envelope. The airtightness values from the tested zones are then extrapolated to the rest of the building and the whole building air leakage value is estimated. When performing pressure neutralization testing, the test agency should complete the test in accordance with ASTM E3158: *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multi-zone Building*.

Figure 12: Sir John A. Macdonald Building [7]

CASE STUDY

SIR JOHN A. MACDONALD BUILDING

How interconnectedness affects quantitative airtightness testing

Pressure neutralization (guarded) airtightness testing involves isolating test zones and adjacent “guard” zones to quantify air leakage. Interconnectedness through mechanical systems poses an obstacle to this type of testing and makes it difficult to measure airtightness in isolated areas.

This concept was pushed to the limit during testing at the Sir John A. Macdonald Building. Even though attempts were made to isolate test zones by sealing mechanical systems, the contractor had challenges managing the connectivity between zones. This resulted in the guarded airtightness tests not meeting the requirements of ASTM E3158 - *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building* [3], leading to inaccuracies in the measured total airflow rates.

Key takeaway: The high connectivity between zones of heritage buildings can lead to inaccurate measured airtightness rates when pressure neutralization testing is performed. To avoid these inaccuracies, whole building airtightness testing should be performed instead.

BUILDING INFORMATION

Original Construction: 1932

Rehabilitation Date: Completed 2015

Floor Area: 6,000 m^2

No. of Storeys: 3

Owner: Federal Government

Heritage Designation: Classified Federal Heritage Building

2.2.2.3 Localized or component airtightness testing

A localized or component airtightness test is a method of measuring the air leakage of a specific component or element of a building, such as a window or a door. To perform a localized airtightness test, an airtight chamber is built around the test component. A small, calibrated fan is attached to the airtight chamber and is used to create a pressure difference between the interior and exterior of the chamber. The airflow rate required to maintain this pressure difference is measured by a pressure gauge. During localized or component testing, the test agency will undertake air leakage testing according to ASTM E783: *Standard Test Method for Field Measurement of Air Leakage* Through Installed Exterior Windows and Doors. Although this standard is primarily intended for field tests in new construction, it can also be used to establish a baseline measurement before retrofitting [4]. When testing components in existing buildings, it is usually not possible to include the rough opening in the test: the test will only include the component itself.

Figure 13: Localized component testing

3. BEST PRACTICES

Key best practices have been developed to guide airtightness testing in heritage buildings.

3.1 Use airtightness testing results as a basis for energy modelling

Using accurate input data for airtightness is crucial for predictive energy modelling. Building energy modelling and performance analysis involves creating virtual models to simulate the thermal dynamics of a building and the energy performance characteristics of its mechanical, electrical, and plumbing systems. There are assumed airtightness values based on modern commercial building codes, standards, and databases of previous projects that can be used for modelling new commercial buildings, but they should be used with caution for heritage buildings. These assumed values do not accurately represent heritage buildings and are typically overestimated. Conducting airtightness testing ensures more precise airtightness data inputs for the energy model, which leads to accurate predictions of energy use and costs. This accuracy is essential for making pre- and post-retrofit goals more realistic, optimizing HVAC systems, and improving indoor environmental quality. Ultimately, precise airtightness data helps meet sustainability goals by effectively identifying ways to reduce energy use and emissions, ensure compliance with building codes, and enhance overall building performance.

3.2 Perform whole building airtightness testing

Whole building airtightness testing is the most accurate quantitative testing type to measure the air leakage in heritage buildings and should be used over compartmentalization and pressure neutralization airtightness testing methods whenever possible. This is largely due to heritage buildings having highly interconnected spaces that make zone isolation difficult for segmented test types. For example, air leakage between internal zones during compartmentalization and pressure neutralization testing leads to inaccurate airtightness measurements. If these values are extrapolated to the whole building, the results can be skewed and unreliable. Heritage buildings also have high levels of air leakage through the envelope, which may not be consistent between zones. This can lead to an inaccurate estimate of the whole building air leakage rate if testing is only based on one zone. Performing whole building airtightness testing is the best way to obtain accurate results for total air leakage across heritage buildings.

3.3 Use localized or component testing in specific situations

Localized or component airtightness testing can be useful to verify the airtightness of specific building components. It is beneficial to perform this testing during construction or component replacement projects, such as window and door replacements, to ensure that components are properly installed. When replacing a door or window, component testing before the project starts is beneficial to establish baseline values [5]. Those values can then be compared to test results after installation to check for improvements and confirm accurate installation. The results of component testing reflect only the individual component and do not reflect the whole building performance; they should not be used to estimate the whole building air leakage.

3.4 Perform qualitative and quantitative testing together

It is beneficial to perform both qualitative and quantitative airtightness tests on a building to obtain effective results. Since qualitative testing only identifies the location of air leakage and quantitative testing only measures the amount of air leakage, results from both test types are required to develop a comprehensive understanding of the building airtightness. Integrating these results provides further insight into improvement opportunities and helps identify the most cost-effective retrofit strategies for enhancing the building envelope.

4. AIRTIGHTNESS TESTING CONSIDERATIONS

There are many different factors that can impact airtightness testing results. These factors need to be considered when performing tests to ensure effective airtightness testing.

4.1 General considerations

General airtightness considerations are not exclusive to heritage buildings and should be applied to airtightness testing on all buildings.

4.1.1 Weather conditions

Weather conditions such as outdoor air temperatures, wind speeds, and gusts can influence the results of quantitative airtightness testing.

4.1.1.1 Outdoor air temperatures

Cold outdoor temperatures can impact the validity of airtightness testing results. Specifically:

- Outdoor temperatures below -5 °C can cause adhesion issues with tape used for sealing mechanical systems.
- Outdoor temperatures below -20 °C can damage interior systems such as plumbing during pressurization.
- Outdoor temperatures below -20 °C can mean that the stack effect in tall buildings prevents valid results.

Due to these temperature constraints, it is best to plan testing during shoulder seasons when outdoor temperatures are between -5 °C and 15 °C.

4.1.1.2 Wind speeds and gusts

To ensure accurate airtightness testing results, it is important to consider the impact of wind conditions:

- High wind speeds can negatively affect the validity of results. According to standards CGSB 149[5] and ASTM E158, wind conditions during testing should be no more than 20 km/hr.
- Wind speeds provided by weather networks do not necessarily reflect the actual wind conditions the test site experiences. Specific site conditions, including the presence of surrounding trees or nearby buildings, can impact wind speeds and should be considered.
- Windy conditions can make it difficult to maintain the 5 Pa pressure difference across the building required by ISO 9972, potentially invalidating results.

It is important to have a firm understanding of the wind conditions at the building site before beginning testing to decide whether a test should be rescheduled. It is prudent to prepare alternate plans in case the testing needs to be rescheduled.

4.1.2 Personnel requirements and time on site

The number of required personnel and amount of time it takes to perform airtightness testing depends on the size and complexity of the building. Generally, there should be one person for each blower door setup and one additional person to run the test. Assistance will be needed to efficiently seal mechanical penetrations, ensure the seals remain intact during testing, and prevent occupants from opening or closing windows during testing.

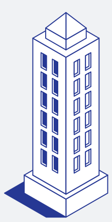
Building Sizes			Estimated number of personnel required	Estimated time required to complete testing
	Small Buildings	Up to 400 m^2 floor area with two floors	1–2 practitioners	1–3 hours
	Medium Buildings	Up to 4,000 m^2 with five floors	2–3 practitioners	4–12 hours
	Large Buildings	Up to 8,000 m^2 with eight floors	3+ practitioners	2–3 days

Figure 14: Estimated time and number of personnel required for airtightness testing

4.1.3 Selecting the number of blower door assemblies for testing

When the test agency is determining how many fans are required for the test, they will assume a leakage rate. This leakage rate, along with the building envelope's surface area, is used to estimate the total air leakage of the building. Practitioners use different baselines for air leakage rates to estimate how many fans will be needed. Most practitioners use assumed leakage rates of 3 or 5 NLR_{75}, ASHRAE's leaky (3.0 NLR_{75}), average (1.5 NLR_{75}) and tight (0.5 NLR_{75}) values, or their past experience. An assumed value of 5 NLR_{75} can be used as a conservative estimate for selecting the number of blower door assemblies for testing.

Fan setup for the blower door assembly includes up to 3 fans (figure 15). Plates are placed over the unused blower fan ports if they are not being used (figure 16).

Figure 15: Blower door fan assembly

Figure 16: Blower door fan assembly using only one fan

4.1.4 Network requirements

A consideration that needs to be made when setting up multiple fans for whole building airtightness testing is ensuring the fans will be able to communicate with each other. This can be accomplished via a wired connection using ethernet cables or a wireless connection (Wi-Fi or Bluetooth).

- A wired connection involves running the cables throughout the building and taping them down to avoid creating a tripping hazard (figure 17).
- A wireless connection involves creating a hotspot, with some technologies allowing for the primary blower door to serve as this hotspot. This set-up enables the other blower doors and the computer to connect wirelessly.

Although it requires more initial effort to set up, a wired connection is preferred, as it offers a stable and reliable method of communicating during testing (figure 18). A wireless connection is easier to set up but it can be unreliable at times depending on the distance between the blower doors, the number of fans, or obstructions.

The potential for connection to be lost between blower doors can be problematic, as it can lead to delays in airtightness testing, and in some cases, may require testing to be redone entirely. It may pose a greater risk in heritage buildings, as mass masonry walls can increase obstructions for wireless connections. Due to the concerns with wireless connections for heritage buildings, wired connections should be used whenever possible to avoid any disruptions to fan communications.

Figure 17: Wired network for airtightness testing

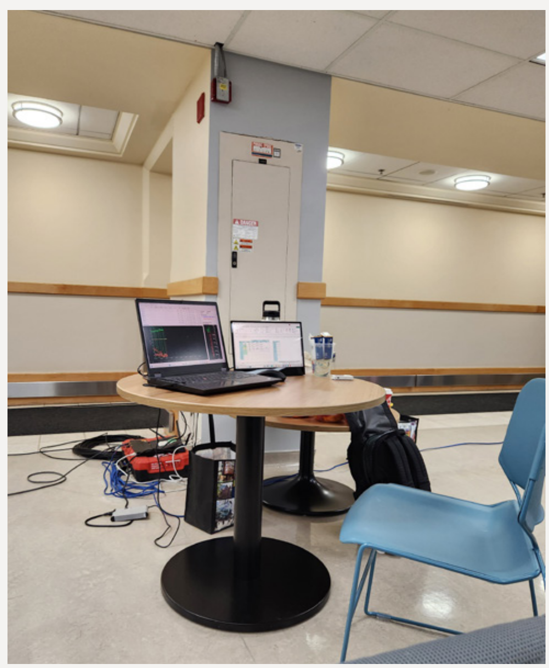


Figure 18: Wired network for airtightness testing connected to a laptop

4.1.5 Equipment transportation requirements

For larger buildings that require additional blower doors, ample space must be allocated for their transportation. If testing is to be conducted in a different city, practitioners should consider:

- Shipping the equipment well in advance to ensure it arrives on time for testing. Shipping the equipment by air rather than ground, as this can be more economical and save crew members travel time.
- Renting blower doors locally where the building is being tested, but practitioners must ensure they are compatible with their software and properly calibrated.

4.1.6 Building operators

In larger buildings, a building operator with a master key should be present to help the test agency access the whole building. Specifically, they are needed to:

- Open mechanical and electrical rooms.
- Shut down systems.
- Override alarms.
- Offer general help related to building operations.
- Resolve any issues that arise during testing.
- Notify occupants about the airtightness testing.

4.1.7 Occupants

Quantitative airtightness testing in large buildings can take a long time, increasing the risk of occupant interactions causing issues. Testing should ideally be conducted outside of business hours to reduce the number of occupants present. If testing must occur during business hours, it is recommended to have someone monitor exterior windows and doors to ensure they remain closed during testing. Even if testing occurs overnight or on weekends, it is important to monitor for occupants opening windows or doors, as this can disrupt the airtightness testing values and necessitate repeating the test.

4.1.8 Windmill effect of blower doors

The potential for the fans of the blower doors to “windmill” is a problem that is unique to quantitative airtightness testing in large buildings. The “windmill” effect of a blower door occurs when a breaker has tripped, causing the blower to lose power and become inoperable. As the other fans continue to draw air into or out of the building, the inoperable blower can begin to rotate, imitating operation. Therefore, it is important to regularly check that the blower door fans are operational to avoid negatively impacting the airtightness test results.

4.1.9 Security

Security requirements of a building can pose a challenge to the airtightness testing process. Additional planning and coordination may be required to ensure that the testing can be conducted safely and effectively while maintaining appropriate security measures. For example, security requirements of government-owned buildings can pose barriers on airtightness testing:

- Security clearance may be required to enter the building, and even then, access to certain areas of the building may be limited.
- Security concerns may require that the airtightness testing process be conducted during certain times or with limited access, which may impact the timing or scheduling of the testing.

4.1.10 Metrics

Airtightness is usually measured as *air changes per hour (ACH) or normalized air leakage rate (NLR)*. ACH measures how frequently the building air volume would be replaced due to air leakage at a given pressure difference. NLR measures airflow at a given pressure divided by the building boundary area and is the most common metric for whole building assessments.

Generally, obtaining NLR ($L/s/m^2$) is preferable over ACH (h^{-1}) because it is more widely used globally and is easier to convert to imperial units. Since air leakage occurs throughout the building's surface, normalizing the flow rate by the surface area makes sense. While ACH is simpler to understand, the volume-based metric makes it harder for smaller buildings to meet reduction targets, since they tend to have large surface-to-volume ratios. Both NLR and ACH provide useful information, so it's recommended to report both $L/s/m^2$ @ 75 Pa and ACH @ 50 Pa, though ACH @ 50 Pa is secondary for quantifying envelope improvements.

4.2 Considerations when testing heritage buildings

This section describes several common characteristics of heritage buildings that pose barriers for airtightness testing.

4.2.1 Targets

Each code and standard has its own method for determining performance targets based on previous studies. Some standards, such as Passivhaus Institut (PHI) and Passive House Institute United States (PHIUS), have very stringent airtightness targets to achieve higher building energy efficiency. The building envelope and volume directly influence the performance targets [6]. Further investigation is needed to determine the most appropriate performance target for heritage buildings. Generally, airtightness targets are set by the client or based on the contractor's experience; it is challenging to establish reasonable targets for heritage buildings due to the lack of sufficient data to support this decision.

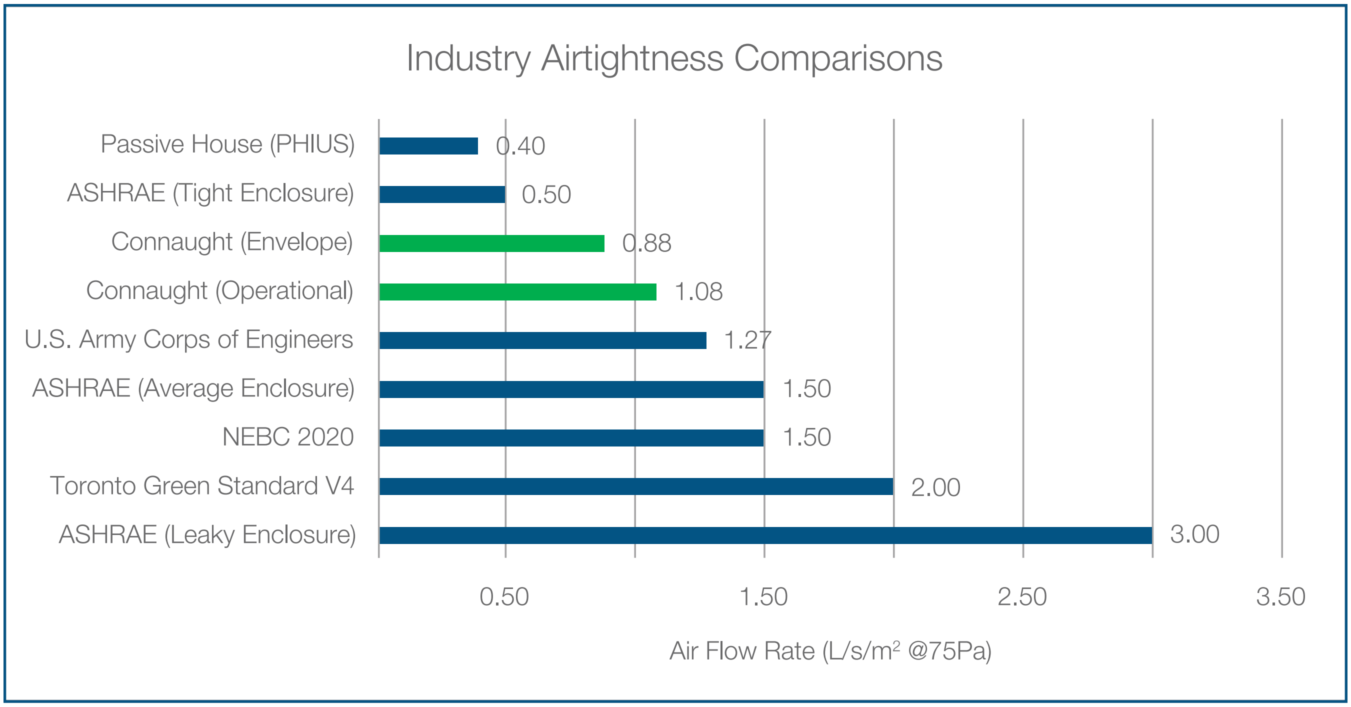


Figure 19: Airtightness targets outlined in Standards

The figure above illustrates standard air leakage values as defined by existing building codes and standards. It highlights the acceptable range of air leakage rates across different acceptable standards. By comparing the measured air leakage rates against these standards, practitioners can assess whether a building meets the required airtightness levels.

4.2.2 Leakage levels

The potentially high leakage levels associated with heritage buildings can pose challenges during airtightness testing:

- Difficulty with the testing procedure due to varying equipment and power supply required based on building size and leakage rate.
- Additional time required to confirm the number of available openings in a building to determine the number of fans required.
- Difficulty with maintaining proper test conditions during windy conditions in leakier buildings.

4.2.3 Unique geometries and features

The unique architectural elements and geometries found in heritage buildings may pose challenges during airtightness testing:

- Additional time required to construct assemblies if doorways are not a standard shape or size so that the blower doors can be installed.
- Difficulty with calculating surface area or volume of the building, which is required for air leakage calculations.
- Additional time required for on-site measurements for verification of building scale, as heritage building drawings may lack an accurate scale.

Figure 20: Dominion Observatory [8]

CASE STUDY

DOMINION OBSERVATORY

How the Dominion Observatory exemplifies the unique geometries found in heritage buildings

The case study for the Dominion Observatory demonstrates how structural and architectural elements can create challenges for airtightness testing. Taking measurements to calculate the building surface area and volume was difficult and time consuming due to elements such as the dome and various curvatures.

Key Takeaway: Plan airtightness testing timelines to account for potential setbacks and challenges due to unique architectural elements

BUILDING INFORMATION

Original Construction: 1904

Rehabilitation Date: 1974

Floor Area: 1,496 m^2

No. of Storeys: 3

Owner: PWGSC

Heritage Designation:
Classified Federal Heritage Building

4.2.4 Presence of designated substances

Many heritage buildings were constructed during a time when asbestos-containing materials were commonly used, and most likely have been constructed with materials that contain asbestos (i.e., pipe insulation, plaster, caulking, paint, tiles). A designated substance report should be provided to the test agency for review. If there is asbestos present in the building, it is recommended that only pressurization testing be done as part of quantitative airtightness testing.

Figure 21: Power supply for blower door fans

4.2.5 Power supply

In heritage buildings, the electrical power supply may be limited or outdated, making it difficult to power the equipment required to conduct quantitative airtightness testing.

A typical blower door fan requires a single dedicated 120AC circuit to reach its maximum airflow rate capacity. Therefore, if six blower door fans are required to reach the pressures outlined in applicable test standards, then six separate 120 VAC circuits are required. Obtaining this many circuits for heritage buildings can be difficult; test agencies should be prepared to bring portable 120 VAC generators and extension cords on-site in case there is insufficient electrical capacity.

5. CONCLUSIONS AND FUTURE OPPORTUNITIES

This condensed guide outlines key best practices and considerations for conducting airtightness tests in heritage buildings. Incorporating these best practices and considerations enables project managers to make informed decisions in heritage retrofit projects. Airtightness testing is one of several different methods used to enhance energy performance in heritage buildings and should be implemented alongside other strategies to ensure a comprehensive retrofit.

Improving the airtightness of heritage buildings is crucial for achieving sustainability and conservation goals. Airtightness testing enhances a building's energy performance, thus contributing to the reduction of GHG emissions and aligning with the Government of Canada's ambitious targets. In order to achieve effective airtightness testing, it is important to consider the following best practices:

- Use airtightness testing results to inform energy modelling.
- Perform whole building airtightness testing over segmented testing methods.
- Use component testing only in situations where the effectiveness of component installation needs to be verified.
- Perform qualitative and quantitative airtightness testing together.

For further information on airtightness testing for heritage buildings, refer to the technical guide *Making Heritage Buildings More Airtight: Best Practice Guide for Airtightness Testing of Heritage Buildings* published by the National Research Council (2025).

In addition to the best practices outlined in this document, future considerations to advance airtightness testing in heritage buildings were also considered.

These consist of the following:

1. Make testing a standard part of future heritage building rehabilitations and update existing standards based on this guide's findings.
2. Improve guidelines and processes for using airtightness results in building energy modelling, including developing advanced algorithms to better capture airtightness effects in energy modelling software.
3. Explore how drone-mounted infrared cameras can be used to assess building airtightness and leakage.

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GLOSSARY

Air Barrier: The materials and components that together control/limit airflow through an assembly and limit the potential for heat loss and condensation. There are varying degrees of classification of air barrier, based on the rate at which air transfers through at a specified pressure difference.

Air Changes per Hour (ACH): A standard normalized metric for whole-building air leakage. It is total volumetric flow rate divided by conditioned volume. When measured under test conditions, the pressure difference of the test, ΔP, is typically indicated with a subscript (e.g., $ACH_{\Delta P}$).

Air leakage: Unintentional/uncontrolled airflow through inadvertent openings in a building enclosure from the higher-pressure side to the lower-pressure side.

Airtightness: The measured rate of air leakage across a building envelope under a controlled pressure difference, quantifying the envelope's resistance to unintended airflow.

Airtightness test: A test performed on a building for the purpose of determining a quantitative result (e.g., an air leakage rate), of collecting qualitative performance information (e.g., to support the identification of air leakage paths), or identifying both quantitative and qualitative information.

As-operated: A building preparation option provided in CGSB 149.10-2019 whereby the building is prepared by leaving most intentional openings in the state they would be under normal operation.

Best practice: The specific methods used to achieve the test objectives detailed in this Guide.

Blower door: A device consisting of a fan that is mounted into a doorway or other building opening to pressurize or depressurize a building enclosure while simultaneously measuring airflow.

Blower: A ducted centrifugal fan used in a heating, ventilating, and air-conditioning system.

Building envelope: The parts of the building that separate the inside conditioned space from the unconditioned or outside space while facilitating climate control (e.g., wall, door, window, and roof). Referred to as one type of environmental separator in building codes.

Conservation: All actions or processes that are aimed at safeguarding the character-defining elements of a historic place to retain its heritage value and extend its physical life, involving actions of preservation, rehabilitation, restoration or a combination of these actions.

Depressurize: To induce a pressure within a building (or portion of a building) that is lower than the exterior atmospheric pressure (or surrounding spaces).

Greenhouse gas (GHG) emissions: Gaseous emissions released into the atmosphere, primarily from human activities such as fossil fuel combustion, industrial processes, and deforestation, which trap heat and contribute to climate change by intensifying the greenhouse effect.

Heritage building: For the purposes of this Guide, heritage buildings are defined as any building built pre-1970. The reason for separating test results based on the 1970 threshold is because it was in the 1970s that the incorporation of air barriers into the building envelope design/construction started. While the incorporation of air barriers was not instantaneous, this point in time marks the most notable change to building envelope design/construction. Additionally, this guide focuses on mass masonry wall construction.

Infrared (IR) thermographic imaging: Process of generating a thermogram (image depicting thermal gradient) by using an infrared imaging system, usually with some means of temperature calibration.

Normalized Air Leakage Rate (NLR): Airflow measurement divided by the area of the building enclosure, and is denoted as $NLR_{\Delta P}$ with units of L/s-m2 $_{\Delta P}$ throughout this report (1 L/s-m^2 = 0.2 cfm/ft^2).

Pressurize: To induce a pressure within a building (or portion of a building) that is higher than the exterior atmospheric pressure (or surrounding spaces).

Pressure: The force per unit area exerted by the atmosphere (e.g., atmospheric air pressure) or that is created by mechanical devices (e.g., compressors, fans or pumps). It can have two components: static pressure, which is the actual pressure of the fluid, which is associated not with its motion but with its state. Dynamic pressure is associated with the velocity of the airflow.

Pressure tap: The specific point with a pressure measurement system where pressure is measured. Typically, this is at the end of pressure tubing, or an open port on a manometer.

Qualitative test: A test that allows for the comparison of outcomes, based on observations rather than numerical measurements of the building envelope, to identify air leakage locations and patterns without producing specific air leakage rates, providing valuable diagnostic insights for improving building performance.

Quantitative test: A test that produces objective, measurable values that quantify building envelope airtightness, allowing for data-driven insights into the building envelope’s integrity and impact on building energy use.

Retrofit: A specific part of the rehabilitation process, specifically an alteration to increase the performance of a system or component beyond that in which it was originally designed.

Specifications: Written details for the work that needs to be completed in an airtightness test. These details include information such as the scope of the work, test dates, and test plan.

Stack effect: Physical phenomenon where a pressure difference (and resulting airflow where permitted) is caused by the combined effect of a change in height and a difference in air density.

Test agency: A team (2 or more people) who conducts the execution of an airtightness test.