Illustrated Guide
Achieving Airtight Buildings

September 2017

BC HOUSING

PREFACE

About this Guide

The *Illustrated Guide – Achieving Airtight Buildings* is published by BC Housing, BC Hydro, and the City of Vancouver. This guide consolidates information on achieving airtightness in buildings, with a specific focus on larger or more complex building types. Various jurisdictions are working to implement airtightness performance and testing requirements. This guide is intended to be an industry resource with respect to designing, building, and testing airtight buildings, while not compromising other aspects of building enclosure performance, including moisture management, thermal performance, and durability.

The information included in this guide applies mainly to mid- and high-rise (Part 3) wood-frame and non-combustible residential buildings within British Columbia. However, it is also applicable for larger or more complex low-rise (Part 9) wood-frame residential buildings and buildings with other occupancies.

Disclaimer

This guide is provided for general information only. The greatest care has been taken to confirm the accuracy of the information contained herein. However, the authors, funders, publisher, and other contributors assume no liability for any damage, injury, loss, or expense that may be incurred or suffered as a result of the use of this publication, including products, building techniques, or practices. The views expressed herein do not necessarily represent those of any individual contributor, BC Housing, BC Hydro, or the City of Vancouver.

Air barrier products and construction practices change and improve over time. It is advisable to regularly consult up-to-date technical publications on building science, products, and practices, rather than relying solely on this publication. It is also advisable to seek specific information on the use of products, the requirements of good design and construction practices, and the requirements of the applicable building codes before undertaking a construction project. Retain consultants with appropriate engineering or architectural qualifications, including airtightness testing agencies, and appropriate municipal and other authorities, regarding issues of design and construction practices, airtightness testing, and compliance with the British Columbia Building Code (BCBC) and Vancouver's Building By-law (VBBL). The use of this guide does not guarantee compliance with code requirements, nor does the use of systems not covered by this guide preclude compliance.

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Produced by: RDH Building Science Inc. | James Higgins, AScT | Daniel Haaland, EIT | Lorne Ricketts, P. Eng.

External Reviewers:

Anil Parekh, CanmetENERGY, Natural Resources Canada
Bill MacKinnon, Remi Charron & Wilma Leung, BC Housing
Bojan Andjelkovic, Gary Hamer & Toby Lau, BC Hydro
Brendan McEwen, City of Richmond
Christian Cianfrone, Morrison Hershfield
Chris Frye & Tom Berkhout, Energy Efficiency Branch, Ministry of Energy and Mines
Colin Genge, Retrotec
Gord Cooke, Building Knowledge
Harshan Radhakrishnan, APEGBC
Jonathan Meads, Concert Properties
Maura Gatensby, AIBC
Mihailo Mihailovic, National Research Council Canada
Norm Connolly, City of New Westminster
Patrick Enright, City of Vancouver
Steven Groves, FortisBC
Susan Hayes, Focal Engineering

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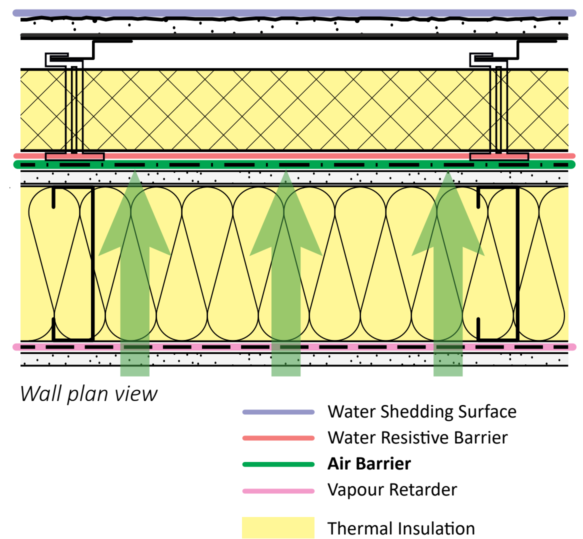
INTRODUCTION

This guide is a useful resource for designing, building, and testing buildings to meet the local building code airtightness requirements, as more and more jurisdictions work to implement airtightness performance and testing requirements. The information and guidance here is generally intended for design and construction professionals and is more applicable to Part 3 and larger, more complex Part 9 buildings such as wood-frame multi-unit residential buildings. While achieving an airtight enclosure is important for all building types, the specific air barrier design considerations, enclosure assembly types, and interface details presented in this guide pertain mostly to conventional, non-combustible or wood-frame buildings.



Wall plan view

The Airtight Enclosure

The building enclosure is a system of materials, components and assemblies that physically separate the exterior and interior environments. It comprises various elements including: roofs, above-grade walls, windows, doors, skylights, below-grade walls and floors. In combination, these assemblies must control water, air, heat, water vapour, fire, smoke and sound. To do this, building assemblies typically use a series of layers, each intended to serve one or multiple functions within the building enclosure.

For example, in walls, cladding acts as the primary water shedding surface. A water resistive barrier is installed behind the cladding along with a drainage gap as a secondary barrier to prevent water ingress. Insulation is installed to limit the flow of heat (i.e. energy transfer) through the enclosure, and a vapour retarder is installed to limit diffusion of water vapour through the wall assembly. An air barrier is installed to limit bulk air movement through the assembly.

Building airflow can typically be characterized as either air leakage, natural ventilation or mechanical ventilation. "Air leakage" is unintentional and uncontrolled airflow through inadvertent openings in an enclosure. *Natural ventilation* is intentional airflow through an enclosure, such as through an open window. *Mechanical ventilation* is intentional and controlled airflow, such as through exhaust fans or air handling units. The focus of this guide is on the air barrier in an enclosure, intended to minimize air leakage.

Building codes require that building enclosures include air barriers. Air barrier design requires careful consideration of materials, components, transitions, and penetration details, each part of a system, providing a durable and continuous air barrier across the entire building enclosure.

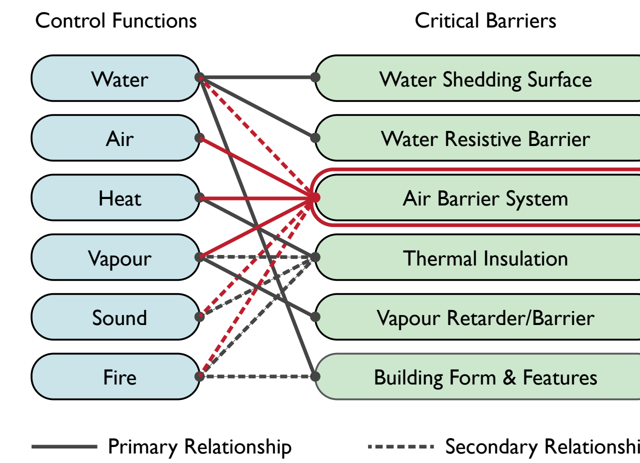
Air Barrier vs Vapour Barrier | The various materials in an assembly cannot be identified as the air barrier without a full understanding of how they are installed. This is especially true with interior polyethylene. It can serve as the vapour retarder and restrict vapour movement solely due to its impermeable characteristics, without requiring additional sealing or support. However, for polyethylene to serve as an air barrier, it must be fully sealed to stop air movement at joints and interfaces. In general, interior polyethylene is becoming less commonly used as part of an air barrier system.

BC Building Code (BCBC) and Vancouver Building By-law (VBBL) Compliance | This guide indicates best practices with respect to air barrier continuity, in order to promote the construction of effective and durable assemblies. In some cases, the guide identifies materials, assemblies, or practices for which a registered professional (B.C. architect or engineer) may be required by the authority having jurisdiction to indicate equivalency for compliance with relevant building regulations.

1 | BACKGROUND

WHY BUILD AIRTIGHT?

The restriction of air movement by the air barriers system is one of the most important functions of the building enclosure and, in some cases, the interior partitions. Air is a transport mechanism for water, vapour, heat energy, and airborne contaminants. As a result, uncontrolled air leakage can lead to moisture issues from condensation and bulk water ingress, excessive heat loss that leads to discomfort and energy waste, as well as poor indoor air quality that affects occupant health and comfort.



Moisture

Water vapour is carried by either air movement or diffusion. In most cases, air movement is the dominant moisture transfer mechanism. Moisture transport through an enclosure can present a condensation risk, especially when relatively warm, moist air moves towards a colder surface. Air leakage can also cause bulk water to enter through the enclosure, as the moisture from rain or snow is driven in by the moving air. Moisture accumulation in the enclosure can lead to mould (and resulting health risks) and possible deterioration.

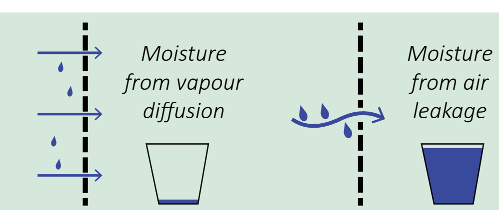
Heat

Air leakage also has a significant impact on building energy use. Uncontrolled air flow increases the heating and cooling loads on the mechanical systems. Achieving energy savings is an important goal of building airtight enclosures, and a primary factor behind the implementation of improved airtightness requirements for buildings.

Comfort and Health

Air leakage across the building enclosure and between internal building zones also contributes to the spread of odours, noise, contaminants, and pests. Poor airtightness means there is little control over where the air comes from and how much infiltration occurs, or what path the air takes to reach the space, both of which impacts air quality. Compartmentalization is also an important part of fire safety between units. An airtight building enclosure, coupled with a well designed mechanical ventilation system, can offer a high-performance solution that improves durability, reduces heat loss, and improves air quality.

Air Leakage Moisture | The amount of moisture transported due to air movement through an air leakage path at normal interior to exterior pressure differences is many times greater than the quantity of water vapour moved through the same permeable material due to vapour diffusion, depending on climate and interior conditions.



WHAT CAUSES AIR LEAKAGE?

Airflow in, out, and within buildings is created by pressure differences from the forces of stack effect, mechanical ventilation systems and wind. Combined, these forces create a complex and constantly shifting pressure profile at the building enclosure.

Stack Effect

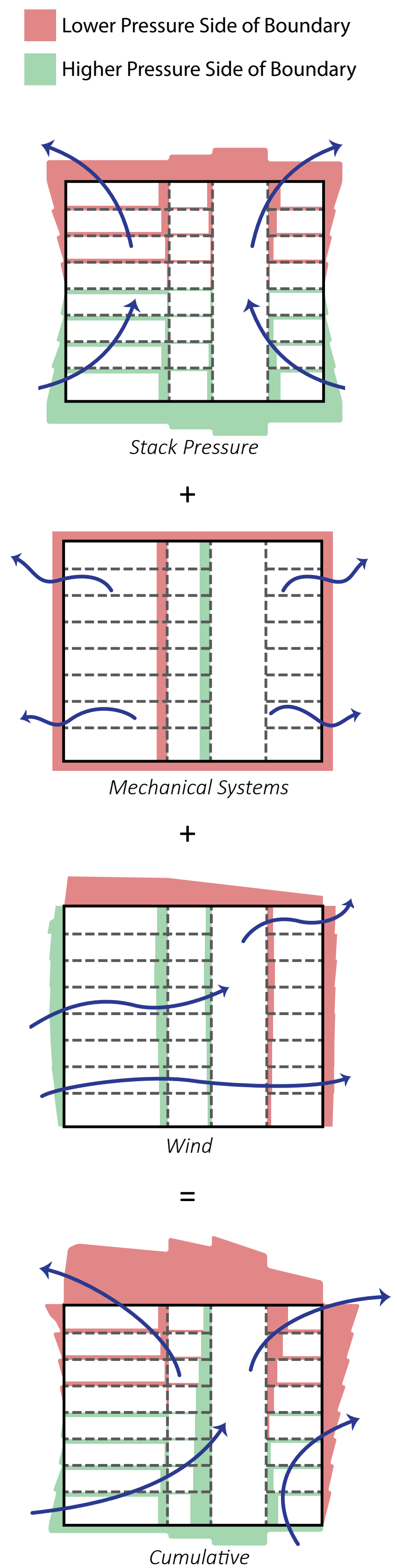
Stack pressure is caused by the combined effect of a change in height and a difference in air density. During colder periods, heated indoor air will typically be less dense than outdoor air. This creates a positive pressure (forcing air out) on the enclosure at ceiling and upper wall levels, and a negative pressure (drawing cooler air in) at the lower portions of the building. If the building enclosure and the interior walls and doors within the building are not airtight, then an overall upward airflow pattern can develop. This flow of air can cause noise, odours, and heat to migrate throughout the building. During the warmer periods, this airflow pattern may be reversed if the indoor air is cooled.

Mechanical Systems

Equipment like exhaust, supply and recirculation fans modify the pressure profile within the building and across the building enclosure. Many ventilation systems operate using a pressurized corridor approach, with ventilation air supplied to common areas, and circulated through air pressure under doors or passive vents. This system can create a pressurized building and exfiltration through air leakage points.

Wind

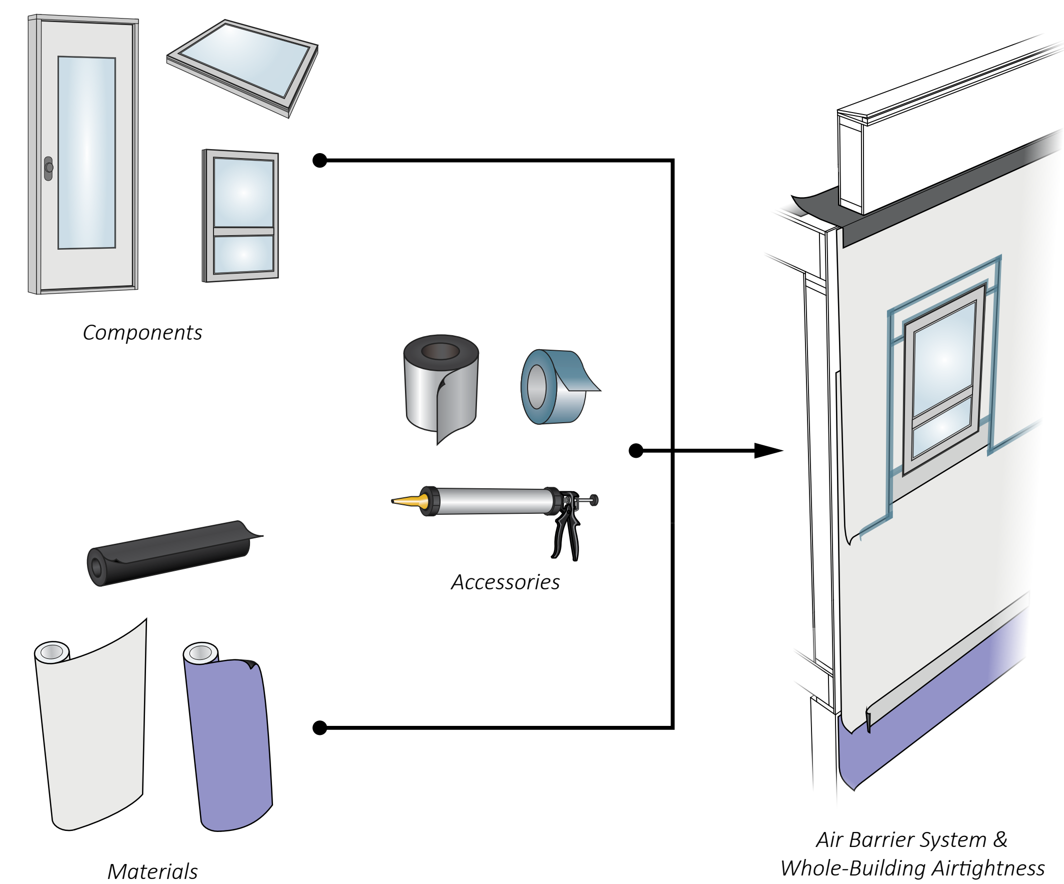
Positive pressure occurs on the windward side of the building, forcing air into the building through openings. At the same time, a negative pressure on the roof and leeward sides draws air out of the building. Wind forces generally create the highest peak pressure difference across the enclosure. However, wind pressure does not typically cause the most air leakage on an annual basis, particularly in tall buildings, because the wind is not sustained. Continuous stack effect pressures and mechanical forces usually create the most overall air movement and thus have a larger impact.



1 | Background

MATERIAL, COMPONENT & BUILDING AIRTIGHTNESS

An effective air barrier consists of a continuous system of materials (building wrap, membranes, etc.), components (doors, windows, etc.) and accessories (tapes, sealants, etc.). These air barrier elements must be airtight individually and when used together. Traditionally, building codes and standards have focused on the air permeance of individual materials and components rather than on the building as a whole. The expectation was if airtight materials were used to construct the building enclosure then the end result would be airtight. However, experience has shown that the majority of air leaks occur at joints and interfaces between these air barrier elements. As a result, the requirements for how airtightness is specified and measured shifted.



This shift has primarily come in the form of whole-building airtightness testing and performance targets. Whole-building airtightness tests measure the performance of the complete and installed air barrier system. As shown in Airtightness Performance on page 10, buildings constructed in jurisdictions with whole-building airtightness targets reach higher levels of airtightness than buildings without those targets.

Increasingly stringent airtightness targets broadened the discussion around air barrier elements beyond material airtightness. Materials and components should be considered in the context of the overall system, not in isolation. Considerations include the specific air barrier details, material compatibility and long-term durability. Given the wide range of materials and details, awareness has grown of the benefit of robust quality control and assurance protocols to verify the compatibility of materials and substrates, as well as the practical challenges faced during construction. Subsequent sections of this guide provide an overview to each of these issues.

AIRTIGHTNESS METRICS

Airtightness testing is typically completed using blower fans to pressurize and depressurize the building. The various measured results of testing, including fan airflow and pressure difference across the enclosure, are used to indicate the overall building airtightness characteristics and performance level.

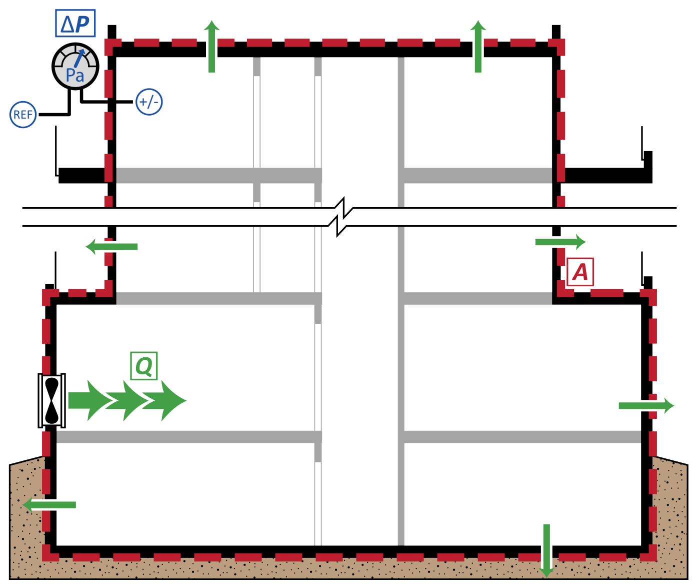
High-powered blower fan installed in a door opening

Airflow / Air Leakage Rate

The total airflow *Q* (L/sec or cfm) is the volume of the air per unit time required to maintain a given pressure difference across the test boundary. Since airflow into a building must equal airflow out of the building, airflow through the fan represents the leakage airflow across the boundary. The airflow must be given at a specific pressure difference (Δ*P)* for it to be meaningful, and is denoted as $Q_{\Delta P}$. The variables ***C***, which is the flow coefficient, and ***n***, which is a dimensionless flow exponent, are used to calculate $Q_{\Delta P}$ using the power law flow equation, indicating the airflow characteristics of the enclosure. These parameters are calculated from the test data as part of several airtightness testing standards and can be used to verify test accuracy (see Testing on page 31).

Normalized Air Leakage Rate (NLR)

Normalized Air Leakage Rate ***q*** (L/s·m² or cfm/ft²) is the airflow $Q_{\Delta P}$ at a given pressure divided by the area of the pressure boundary ***A*** (e.g. the building enclosure area). Normalizing by enclosure area as opposed to the floor area allows for comparison with benchmarks and performance requirements. This is the most commonly used metric for whole-building airtightness measurement and targets.



Airflow / Air Leakage Rate (Power Law Equation):

$$Q_{\Delta P} = C \cdot \Delta P^{n}$$

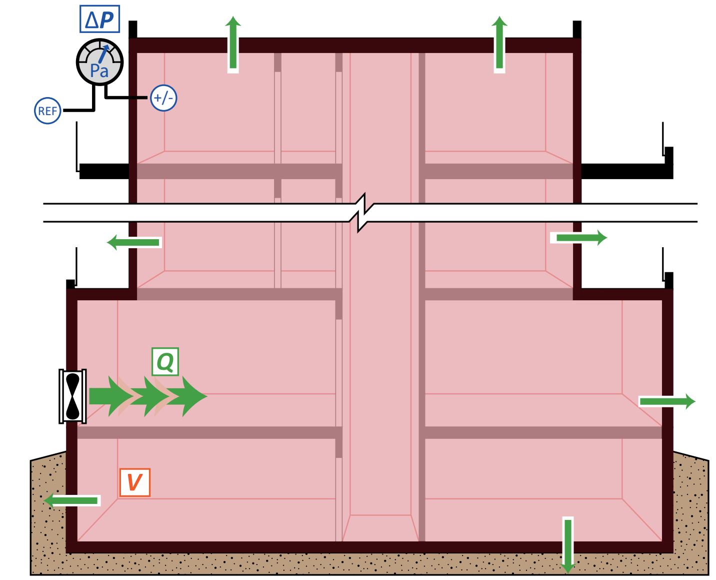
Normalized Air Leakage Rate:

$$q_{\Delta P} = \frac{Q_{\Delta P}}{A}$$

Automatic Airtightness Testing | Often the testing equipment and software used for whole-building airtightness testing will automatically calculate the various airtightness metrics based on the building geometry entered into the software, which can even be programmed to complete the entire airtightness test automatically.

Air Change Rate

Air change rate measures how frequently the building air volume would be replaced due to air leakage at a given pressure difference. This value is determined by dividing the flow rate $Q_{\Delta P}$ by the volume ***V*** of the enclosure. Air change rate is typically measured in air changes per hour (ACH) at a given pressure difference, denoted as $ACH_{\Delta P}$. This measurement is commonly used as a relative indicator of airtightness for smaller buildings such as single-family homes.



Air Change Rate:

$$ACH_{\Delta P} = \frac{Q_{\Delta P}}{V} \cdot \text{(hourly airflow conversion)}$$

Equivalent/Effective Leakage Area

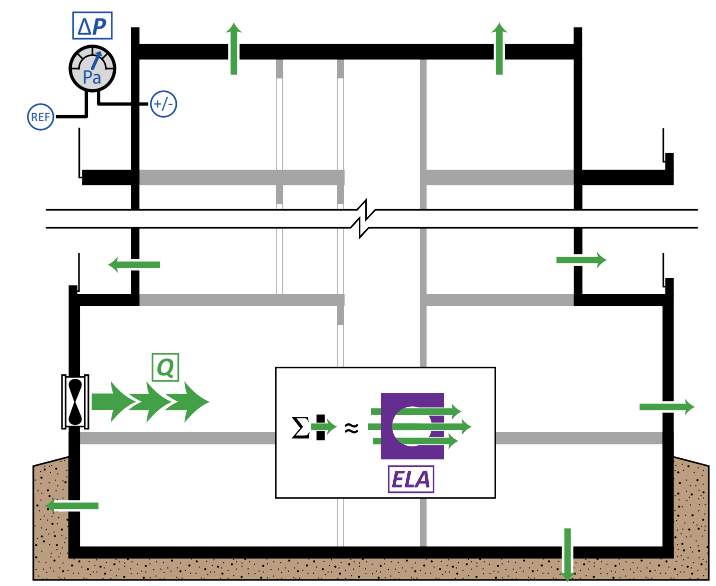
The equivalent leakage area (***EqLA***) or effective leakage area (***EfLA***, in cm² or in²) represents the size of a single hole that would result in the same air leakage as that of all the air leakage pathways through the enclosure combined. Both values assume a specific pressure difference, discharge coefficient (C_D), and air density ***p*** as part of the calculation. The ***EqLA*** and ***EfLA*** use different assumed pressure differences and discharge coefficients.

While the concept behind this metric is to provide a tool for visualizing the airtightness of a pressure boundary (i.e. the size of the hole), the hole size calculated does not provide an exact measure of the cumulative size of the "holes" in the pressure boundary.

Normalized Leakage Area

Normalized Leakage Area (***NLA***, in cm²/m² or in²/100 ft²) is defined as ***EqLA*** (or ***EfLA***, depending on the test standard), divided by enclosure area.

See Additional Resources on page 43 for a complete list of airtightness metrics and corresponding equations and units. See Quantitative Testing on page 33 for an example Air Leakage Rate calculation.



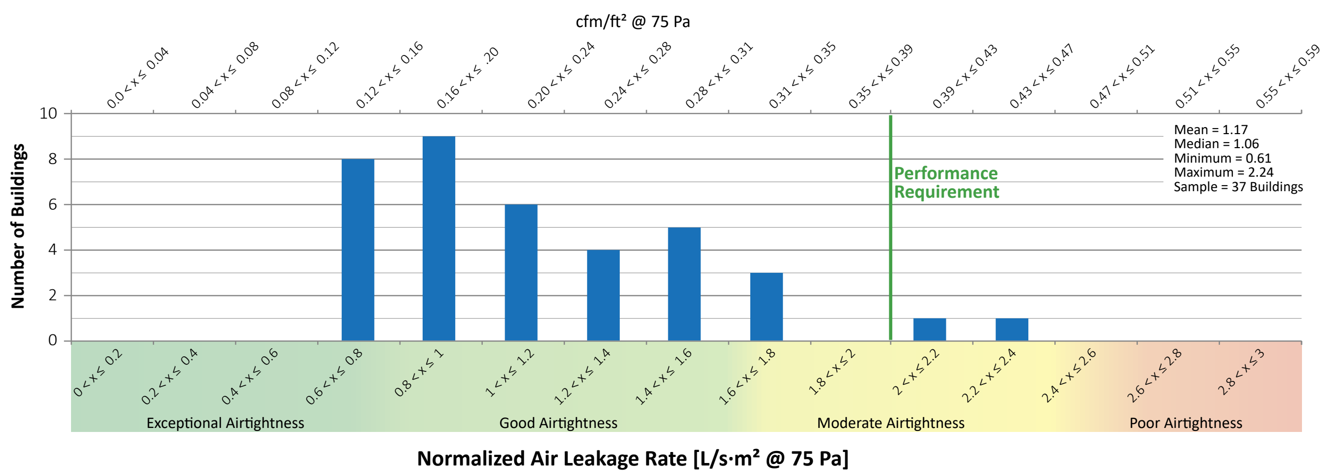
Equivalent/Effective Leakage Area:

$$ELA = \frac{Q_{\Delta P}}{C_D}\sqrt{\frac{p}{2 \cdot \Delta P}} \cdot 10{,}000$$

$$NLA_{q} = \frac{EqLA}{A}$$

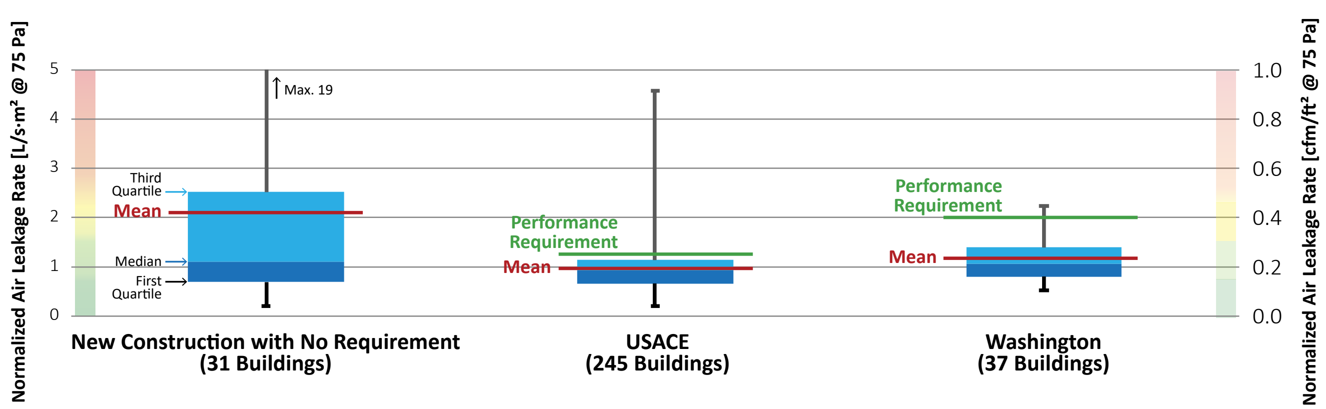
AIRTIGHTNESS PERFORMANCE

While current energy performance and airtightness standards set the requirements for overall building airtightness, it is useful to compare with the results of previous whole-building airtightness testing as a reference for performance. This data provides context for what airtightness levels are expected and achievable. Historical data can be easily compared and analyzed using the Normalized Air Leakage Rate metric. A recent study of whole-building airtightness testing (see Additional Resources on page 43) compiled and analyzed the results of several hundred airtightness tests from Canada, the United States, and the United Kingdom. The chart below shows the distribution of the results of this study in Normalized Air Leakage Rate for buildings tested in Seattle, where airtightness testing is mandatory. For comparison, the chart shows a relative indicator of the levels of airtightness found in each test, rated as exceptional, good, moderate, and poor airtightness. Testing showed that most buildings met the minimum airtightness requirements, with many far exceeding them and achieving excellent results.



Distribution of airtightness test results for buildings in Seattle

In the same study, newer buildings in jurisdictions with mandatory airtightness requirements (United States Army Corps of Engineers (USACE) and Washington State) were compared with those with no airtightness testing requirements. As shown in the chart below, the results indicate that buildings that are built with the intent of meeting a minimum airtightness requirement can consistently achieve and even exceed the minimum target, while new buildings built with no minimum airtightness requirements are generally less airtight. For buildings required to meet the USACE and the Washington state requirements, the majority are well below the minimum airtightness requirements.



Distribution of test results for each set of buildings in different jurisdictions

ENERGY IMPLICATIONS

The potential heat loss due to air leakage through an enclosure with moderate or poor airtightness has a significant and measurable impact on the required heating energy needed for the building. An enclosure with good or exceptional airtightness can lead to major energy savings. As the other components of a building become more energy efficient (via insulated enclosure, efficient mechanical systems, etc.), airtightness plays an even larger role in heating energy demand.

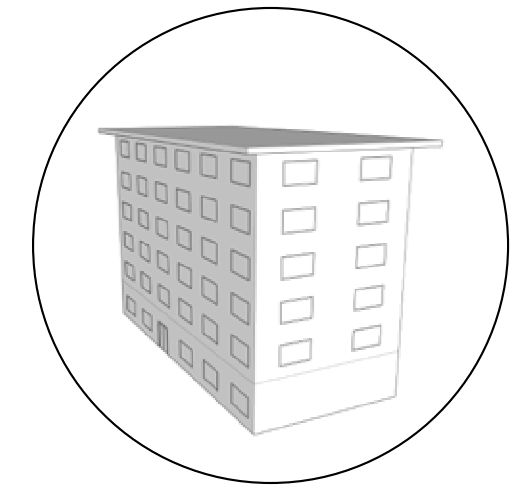
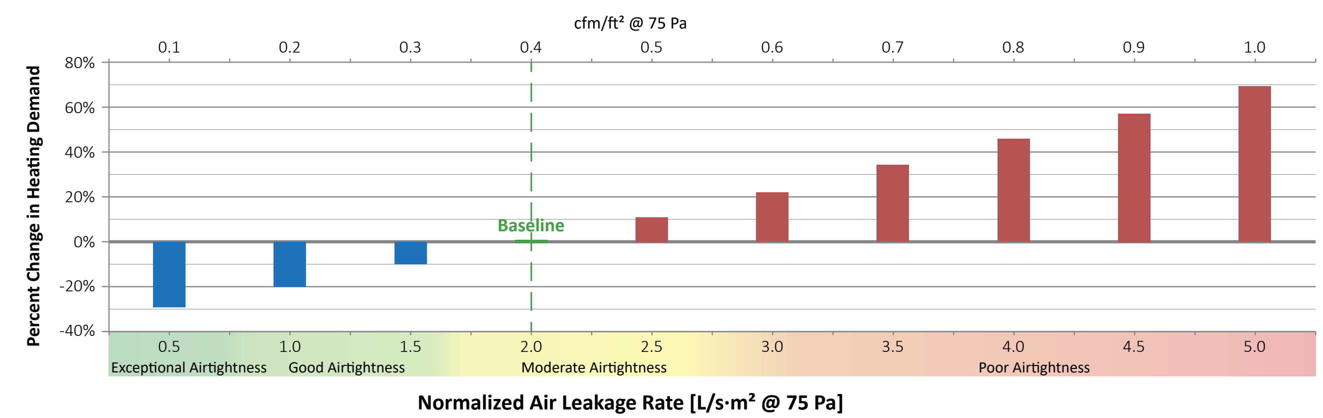


Illustration of the size and shape of the archetype six-storey building modelled

Example

The chart below shows the effect of airtightness on heating energy demand for an example archetype six-storey, 4,700 m² wood-frame, multi-unit residential building in Climate Zone 4 (southwest B.C.) with the following energy efficient design characteristics:

- Effective RSI-4.4 (R-25) walls and USI-1.53 (U-0.27) windows
- Heat recovery ventilation (60% efficient)
- Drain water heat recovery and low-flow fixtures
- LED lighting and occupancy sensors in corridors



Heating energy demand changes due to improved airtightness

This chart shows that if a baseline Normalized Air Leakage Rate target of 2.0 L/s·m² (0.4 cfm/ft²) is missed and instead a poorer rate of up to 5.0 L/s·m² (1.0 cfm/ft²) is obtained, the energy required to heat the building would be nearly 70% greater. To put this into perspective, this modelled archetype building would need over 1,600 m² (17,200 ft²) for solar panels to generate the same amount of energy. Even with other significant energy-efficient design characteristics in place, this shows the importance of achieving an airtight enclosure.

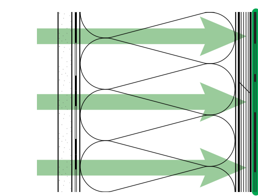
On the other hand, by improving airtightness and achieving a Normalized Air Leakage Rate of 0.5 L/s·m² (0.1 cfm/ft²), the amount of energy required to heat the building is nearly 30% lower than what would be required for the baseline building. The potential energy savings from improved enclosure airtightness can help meet energy efficiency requirements and improve utility cost savings.

Multiple high-powered blower fans installed in a door opening

PRINCIPLES OF DESIGN

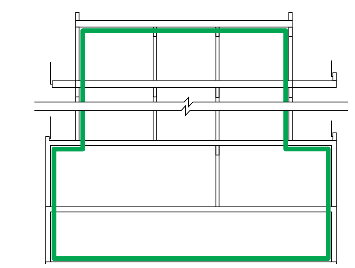
The design of an effective air barrier system requires materials, components, and accessories that can be combined to control air leakage. While relatively straightforward to achieve in the field of an assembly, ensuring continuity of the air barrier at interfaces and penetrations of the building enclosure is critical to the air barrier performance. An effective air barrier should have the following features:

Air Impermeability



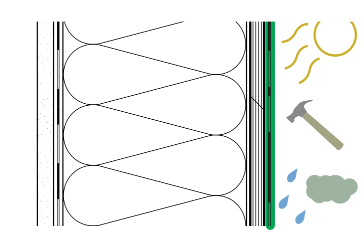
All materials, components, and accessories making up the air barrier system must be able to prevent air flow. This is typically defined by building codes as an air permeability less than 0.02 L/s·m^2 (0.004 cfm/ft^2) at 75 Pa.

Continuity



Continuity is the single most important criteria for an effective air barrier system, but also one of the most challenging. Designers and contractors must ensure continuity of the air barrier is achieved around penetrations, transitions, and interfaces in the enclosure. The system must completely enclose the space.

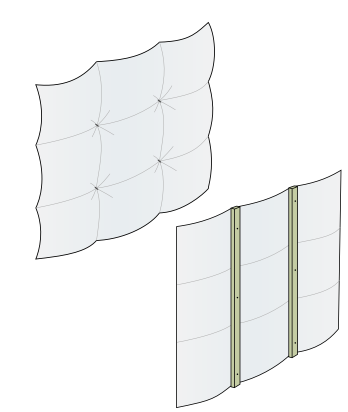
Durability



The air barrier system must be designed to last for the entire service life of the building or of the materials that cover it. To do so, it may be necessary to regularly maintain sealants or other components of the system, which should be designed to be easily accessible. The system should resist mechanical forces, UV exposure, moisture, chemicals, and other contaminants, throughout the life of the building. Interfaces in particular should be designed to be resilient and be able to accommodate the expected deflections, for example at floor slabs.

The durability of the enclosure system itself is important. Air barrier selection must account for vapour movement within the system and exterior moisture loads. Exterior vapour-impermeable membranes may risk trapping moisture inside the assembly. Air barrier materials used as the water resistive barrier must be appropriately installed to provide the necessary protection from moisture loads. See Further Reading in Additional Resources on page 43 for more guidance on assembly durability and vapour/moisture management.

Strength and Stiffness



From construction to occupancy, the air barrier system must resist forces acting on it. The design should account for mechanical forces such as those created by wind and stack effect pressures as well as allow for dimensional changes in the structure caused by thermal expansion and moisture absorption. A combination of fasteners, tapes, sealants, strapping, exterior insulation, or fully adhered products may by used to achieve this requirement.

AIR BARRIER APPROACHES

Air barrier systems are usually two conventional types: exterior air barrier systems, with the primary airtight elements placed at the exterior side of the enclosure, and interior air barrier systems, with the primary airtight elements installed at the interior side of the enclosure. Within these systems there are various approaches and components used to achieve the air barrier.

Exterior air barrier approaches use an airtight layer, usually a dedicated membrane, installed over the exterior face of the building structure, and made continuous with tapes, membranes, and sealants over joints, transitions and penetrations. The interior approaches use an airtight layer applied from the interior of the enclosure, interfacing with the various interior elements, transitions, and penetrations. In general, the exterior approach is simpler, because it does not interface with numerous interior elements like framing or service penetrations for electrical and plumbing. Also, because the components of the exterior air barrier are often also used as the water resistive barrier (for example spun-bonded polyolefin on walls), the effort and care required to achieve a continuous layer to resist moisture intrusion also contributes to the overall continuity of the air barrier.

However, the exterior air barrier still must interface with interruptions at the outside of the building, such as balconies, canopies, and some service penetrations. The design and detailing should account for these challenges. See Detailing on page 20 and Coordination & Sequencing on page 28 for further guidance.

Interior approaches, often using polyethylene sheet or interior finishes as the primary airtight element, must account for the numerous interruptions at the interior. The detailing and effort required to make the interior surfaces airtight across these elements is more difficult compared with using an exterior approach. This guide assumes an exterior air barrier approach is used.

Exterior face of a building with minimal interruptions and interfaces except windows

Wall framing and floor assembly interfacing with the exterior wall assembly at the interior side

Air Barrier Performance | The key advantage of exterior air barrier approaches is that interior penetrations for services like plumbing and electrical, and disruptions at floors, stairs, and interior walls, do not affect the continuity of the air barrier. Whole-building air leakage tests have shown that exterior air barrier approaches consistently perform better than interior air barrier approaches, especially for large buildings.

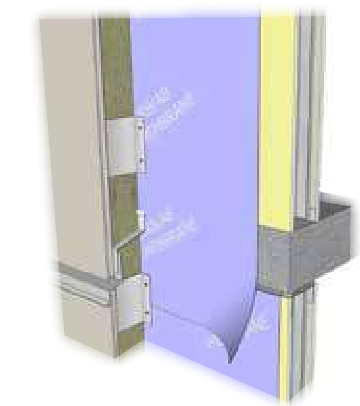
EXTERIOR AIR BARRIER SYSTEMS

Sheathing Membrane Approach

Mechanically fastened systems use an airtight sheathing membrane, attached to the exterior sheathing with fasteners and washers. Joints, penetrations, and laps are made airtight using sealant, tape, and self-adhered sheathing membrane strips. This is a commonly used exterior air barrier system for low-rise wood-frame construction. Care should be taken to ensure the sheathing membrane is adequately attached to the building during construction and it should be supported by strapping or cladding to avoid damage. This approach is not typically appropriate for taller buildings or those with higher design wind loads.

Self-adhered sheathing membranes rely on adhesion to both the substrate and at membrane laps. The membrane should be installed so that it is fully adhered to the substrate upon initial installation. The membrane should also be installed onto a suitable dry substrate that provides continuous backing.

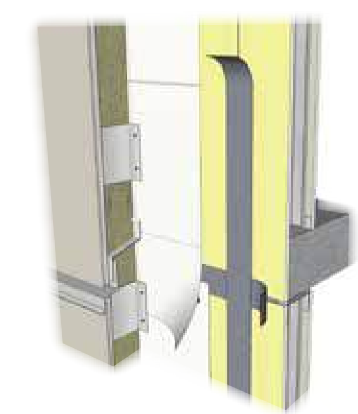
The sheathing membrane is also usually used as the water resistive barrier, and must be installed and detailed as such.



Sheathing membrane approach

Sealed Sheathing Approach

The exterior sheathing, when sealed at joints and interfaces, can also act as the primary air barrier element. This approach uses the exterior sheathing together with either sealant, liquid applied sheathing membrane, strips of membrane, or sheathing tape to create a continuous air barrier at the sheathing joints. A sheathing membrane is often required with this approach to provide the water resistive barrier

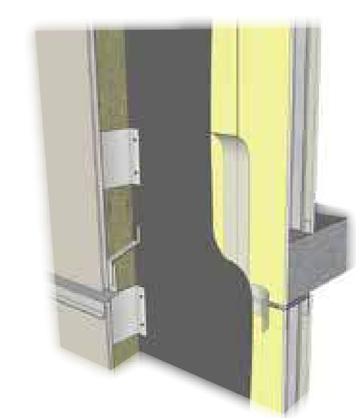


Sealed sheathing approach

Liquid Applied Membrane

Exterior liquid applied membranes share many of the advantages of self-adhered membranes and are especially useful for complex detailing. Liquid applied membranes rely upon a supporting substrate to provide a continuous backing in order to achieve an airtight barrier. Joints typically require specific detailing considerations and often incorporate membrane reinforcement. The substrate and weather conditions can have a significant impact on curing time and adhesion. The manufacturer's instructions should be strictly followed.

Liquid applied membranes are generally used as the water resistive barrier, and must be installed and detailed as such.



Liquid applied membrane

INTERIOR AIR BARRIER SYSTEMS

Sealed Polyethylene Approach

In this system, polyethylene sheets are sealed to the interior framing to form the air barrier. All joints in the polyethylene are also sealed and clamped between the framing and the interior finish. Locations where interior finishes are not normally provided require specific measures to ensure the polyethylene is supported. This system is more often used in wood-frame construction and is less common in non-combustible buildings.

The various interfaces between the exterior walls and interior elements such as staircases, interior walls, floor framing and service penetrations make the sealed polyethylene approach a difficult air barrier system to implement successfully. Therefore, it is not recommended for large buildings, or buildings where high-performance airtightness is required.

Sealed polyethylene approach

Airtight Drywall Approach

In the airtight drywall approach, the interior gypsum board and framing members provide the air barrier. Continuity between different materials is created with sealants or gaskets. Special attention is required to seal penetrations in the gypsum board at electrical fixtures and other services, as well as the intersection of partition walls with exterior walls and the ceiling. The various interfaces at the exterior walls make the airtight drywall approach a potentially difficult air barrier system to implement. This system is sometimes used in wood-frame construction and is often used as the air barrier approach for interior compartmentalization (see page 22).

Airtight drywall approach

OTHER APPROACHES

Various other air barrier systems can be used on either side of the enclosure assembly. Spray foam, while commonly used as an insulation product, can also be used as the air barrier. It can be applied to either the exterior face of the enclosure or the interior. Exterior spray foam approaches will generally perform better than interior approaches as described in previous pages.

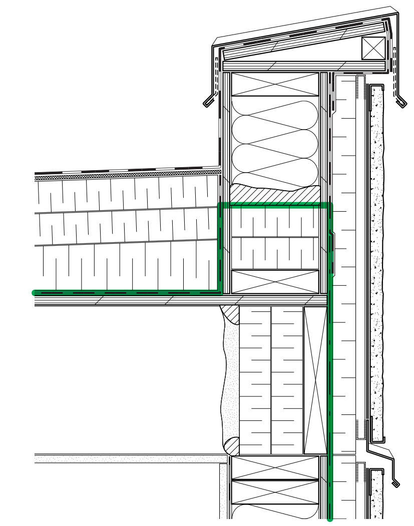
Panelized systems, such as insulated metal panels, use proprietary air sealing methods, such as internal gaskets, or rely on sealant applied once installed. Prefabricated conventional wall panels, using an exterior air barrier systems applied in the factory, are also becoming a more common approach in residential construction. The panels are installed on site with a gasket or sealant air seal at the perimeter joints between panels and at interfaces. The primary challenge with panelized and modular systems is the joints between components, especially where concealed gaskets are used.

OTHER ASSEMBLIES

Roofs

An exterior air barrier is likely the simplest approach for most low slope roofs, because the exterior surface of the roof structure will often have less intersections and penetrations. The air barrier can also be transitioned more easily to the exterior wall surface at the roof perimeter. A self-adhered membrane can be applied over the roof structure before the insulation or roofing material is installed, with air barrier continuity maintained at penetrations using membranes, sealant, and tape. In some cases, the roof membrane itself or the substrate (for example a concrete slab) could provide the air barrier.

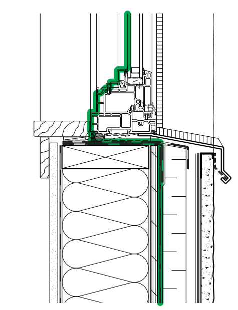
An interior air barrier, most often polyethylene sheet installed at the ceiling surface, is difficult to make fully airtight, because interior penetrations, intersections, dividing walls, and the transition to the wall air barrier are obstructions to a continuous barrier. (See additional guidance on detailing air barrier transitions later in this chapter.)



Air barrier at roof/parapet

Windows

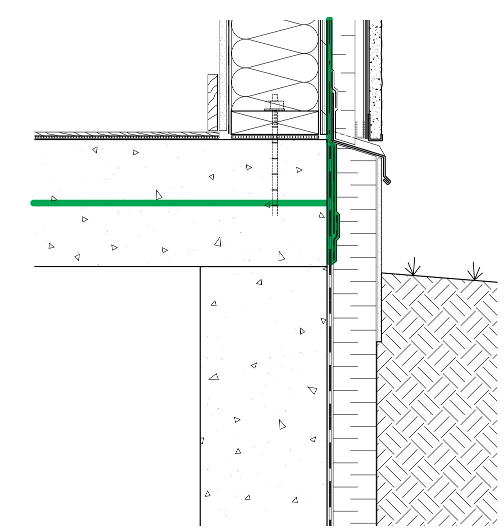
Product testing and rating standards are used to pre-qualify available window products as to their airtightness, but these standards apply to the products only. Fenestration products will differ on how they are designed to tie into adjacent air barrier materials and components. Specific manufacturer data and instructions should be consulted for each fenestration product to verify the air barrier (and other critical barrier) detailing. Typically, punch windows and window wall systems are sealed at the interior, while curtain wall systems are sealed at the exterior shoulder of the frame. When completing air sealing of fenestration products, it is important to consider the overall design so as to maintain intentional pressure moderation and drainage of window frame cavities and of the rough opening.



Air barrier at window sill

Concrete and Below Grade

For most assemblies that use a concrete structure, the concrete component is often the primary air barrier. However, a dedicated air barrier material in addition to the concrete can provide improved performance, because cracking of the concrete poses a risk to long-term air barrier performance. For example, the air barrier can often be combined with the below grade waterproofing. Penetrations and intersections would also be easier to make airtight when there is a dedicated air barrier membrane to transition to.



Air barrier at podium/below grade

MATERIAL SELECTION

The BCBC and the VBBL requirements for air barrier materials state that the material must “have an air leakage characteristic not greater than 0.02 L/s·m² measured at an air pressure difference of 75 Pa” or the material must conform to CAN/ULC-S741, “Air Barrier Materials – Specification.” While the specific code requirements provide a good basis for the minimum performance level of the air barrier materials used, material selection should go beyond simply the tested air leakage resistance and also consider other factors critical to in-service performance.

Durability

Durability refers to long-term performance of the material in service under expected operating conditions, and the robustness of the material as it is installed and while it is exposed during construction before being covered or protected with finishes.

Damage to materials can result from wind pressure, abrasion, heat, moisture, and ultra-violet radiation. This is significant when the air barrier is left exposed during construction prior to the installation of exterior finish components like cladding. The air barrier should be protected from the elements as early as possible and may require extra temporary protection to accommodate the construction schedule.

Sheet materials that are not adequately tear resistant or properly secured to the building may be prone to damage from the effects of wind, especially at upper floors, during construction and in service. Adhered membranes may provide more durable performance for large buildings, since the material can be fully supported and secured to the building without relying on fasteners or tape, provided adequate membrane adhesion is achieved.

Damaged air barrier during construction

Material Compatibility

Material compatibility refers to chemical compatibility to avoid degradation of interfacing components, as well as substrate and bond compatibility to ensure proper adhesion of membranes, sealants, and tapes to the various air barrier materials.

For example, bituminous membranes are not compatible with a number of common roofing and flashing materials such as PVC membranes, asphaltic polyurethanes, and silicones. This chemical incompatibility can result in plasticizer migration, where the chemical plasticizers from one material (for example PVC) move to another material through direct contact. Over time, this can cause the receiving material to become soft and lose its cured structure, and can cause the former host material to become brittle and crack, as well as cause aesthetic changes. The result is a potential failure in the air barrier.

2 | Design

Adhesion

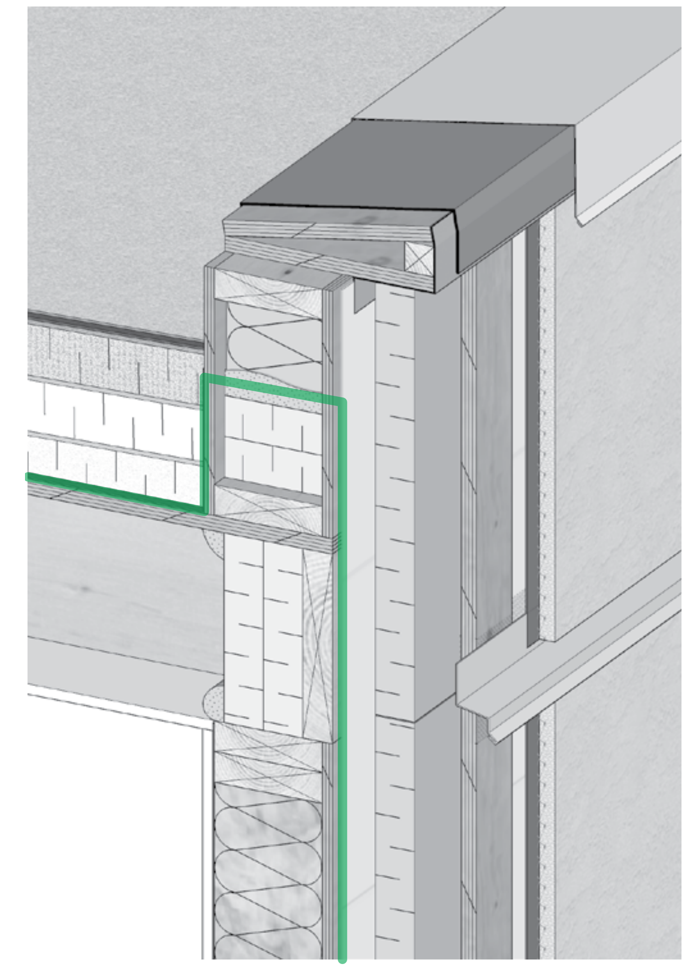
It is difficult to establish good adhesion between silicone or urethane sealant materials and synthetic sheathing membrane materials, such as polyethylene or spun-bonded polyolefin products. Where possible, a transition membrane, such as foil-faced self-adhered membrane, or specialized sealant products designed specifically for adhesion to synthetic materials are recommended. Refer to the product manufacturer’s literature for compatibility guidelines, or consider completing preliminary mock-ups or material testing to ensure chemical and adhesive compatibility before using a specific combination of materials.

Constructability

Air barrier performance and the overall airtightness of a building is highly dependent on the quality of the installation. The selection and design of materials and details is critical. This includes consideration of construction sequencing, site access, and the abilities of trades. It may help to include product representatives and trades in preliminary design discussions in order to better understand the installation process for different air barrier systems and components.

Adhered air barrier materials that require primer for adequate adhesion may pose a sequencing difficulty, because the substrate areas may need to be accessed multiple times over the course of the installation. This would include the application of the primer and then the installation of the membrane.

Systems that use multiple different components and accessories, as well as complicated interfacing, must have detailed construction drawings to make the installation sequence clear and the air barrier intent obvious. Select systems that use a consistent approach to establishing airtightness across penetrations and interfaces.



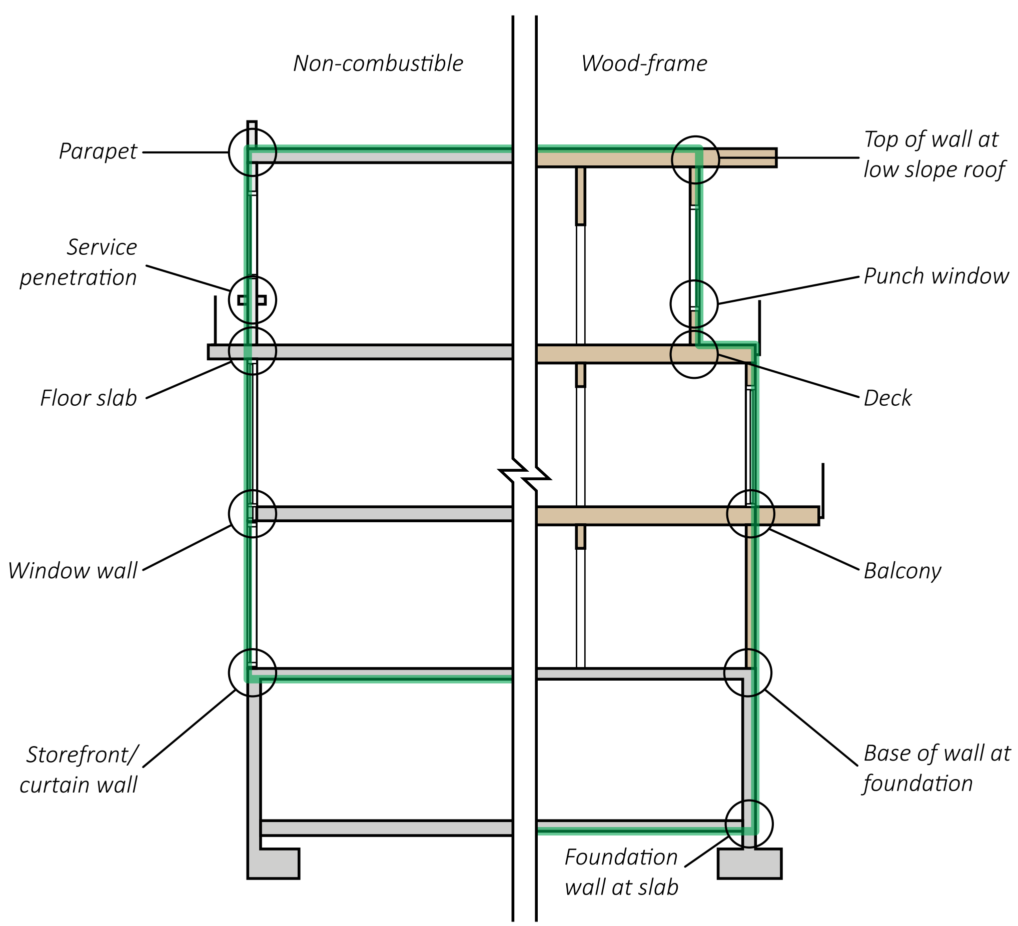
Air barrier at roof/parapet showing transition through multiple components and assemblies

Design/Tender Phase Mock-ups | Mock-ups can be used during the design phase and as part of the tender process in order to test the performance of the air and water control barriers and to verify the design intent. Enclosure assemblies and systems that use new technology unproven in the local industry should be tested before they are specified or used.

DETAILING

The most important aspect of designing an airtight enclosure is detailing the interfaces and penetrations, because this is where discontinuities are most likely to occur. While the individual air barrier materials and components provide control of air movement for each individual assembly, how and where each assembly intersects and the continuity of the air barrier across these joints should be the focus of the detailing work. Whether at the base of wall, windows, service penetrations, roof to wall interface, or countless other detail locations, the details should provide a clear indication of the air barrier continuity across the building enclosure.

A best practice technique for ensuring continuity of the air barrier is to draw a continuous line to identify the air barrier on building plans, sections, and details. The line should continue around the entire building enclosure and connect back to itself with no discontinuities. It should be possible to trace the air barrier without lifting one's pen off the paper. A detail should be prepared for all air barrier interface locations, clearly showing how continuity is maintained. Reviewing these transitions early on and collaborating with the affected trades will allow locations with constructability or sequencing issues to be identified and help determine if a revised detail is necessary. See Further Reading in Additional Resources on page 43 for more guidance on detailing at transitions and penetrations in the air barrier over non-combustible and wood-frame construction.



Common critical enclosure interfaces requiring specific details showing air barrier continuity

Details should consider construction sequencing and overall robustness. For example, wherever possible, air barrier transitions in wood-frame construction should be designed to allow complete construction of the primary wood framing before installation of the air barrier components such as membrane and sealant. This way the work of different trades can be separated, and the air barrier installation can be more easily coordinated.

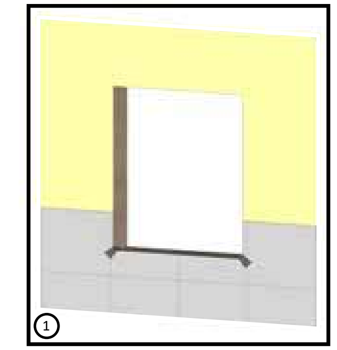
Consider installing exterior elements (not integral to the enclosure or structure) using standoffs and intermittent attachment points. This can allow the air barrier to only be interrupted with point penetrations, rather than extended interfaces like at balconies or roofs.

3D Sequence Drawings

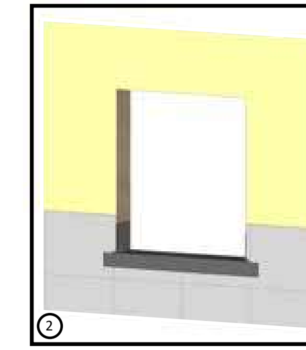
To achieve an airtight large building, air barrier design transitions to stop both inward and outward air movement (in more than just the two-dimensional plane shown on a typical detail drawing). This aspect of detailing may require three-dimensional drawings, both for design development and as part of the construction documents, to convey all aspects of an air barrier interface. The most critical locations are often difficult to illustrate on 2D drawings alone.

Further detailing guidance is available in:

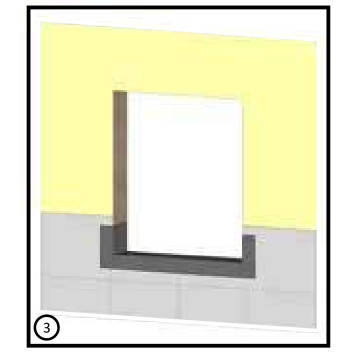
1. Building Enclosure Design Guide, BC Housing
2. Guide for Designing Energy-Efficient Building Enclosures, FPInnovations
3. See Further Reading in Additional Resources on page 43



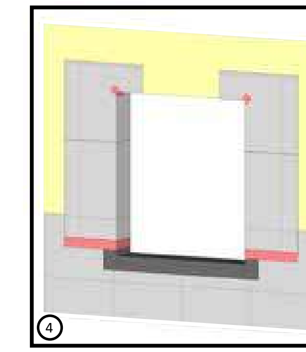
Lower membrane and self-adhered gussets at corners



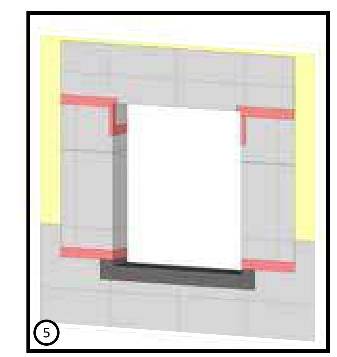
Self-adhered sill membrane with upturn at jambs



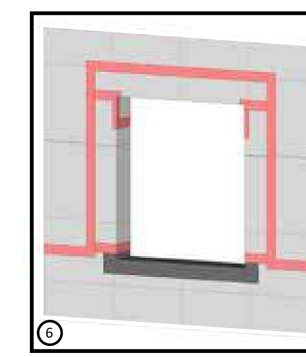
Self-adhered jamb membrane



Jamb pre-strip sheathing membrane taped to self-adhered membrane



Head pre-strip sheathing membrane taped to jamb membrane



Field sheathing membrane lapped over and taped to pre-strip membrane

Three-dimensional sequence drawings showing the steps for a punched window air barrier and water resistive barrier membrane installation

Early Detailing | Detailing is an integral part of the overall design process even in early stages of design development. It should be used to inform and develop the overall design while there is still flexibility in placement and configuration of elements. Leaving discussion of details until later in the design process could lead to complicated or costly corrective measures.

INTERIOR COMPARTMENTALIZATION

Why Compartmentalize?

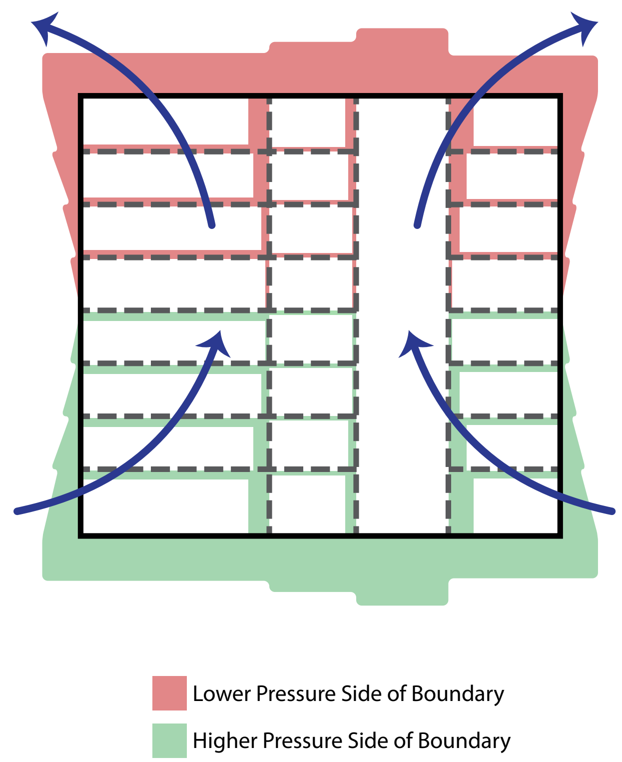
Separating interior spaces from one another is important for many of the same reasons that interior space is separated from the exterior environment. Preventing uncontrolled air flow between zones (floors, suites, offices, etc.), is important for effective heating, ventilation, and air-conditioning operation, as well as for fire and smoke protection, indoor air quality, and noise control. Building codes and building certification programs have introduced interior separation requirements for many building types and space use categories.

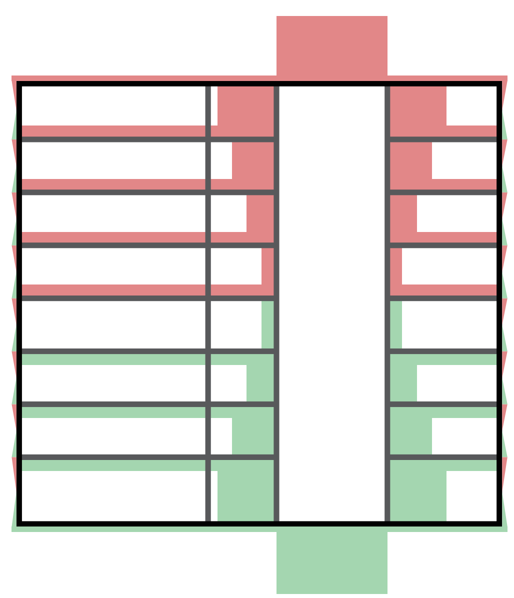
Interior compartmentalization is also an important method in reducing the forces of stack effect. The potential for airflow throughout the interior of the building is reduced when each of the interior spaces are separated with an air barrier. Airtight walls and floors will reduce the pressures generated by stack effect at the enclosure by limiting the effective stack height. The potential forces from stack effect still occur at the boundaries of interior shafts, so airtightness of these shafts is important.

Typical Air Barrier Approaches for Compartmentalization

While interior air barriers are generally protected from the exterior elements that may cause damage, tall buildings or buildings with large openings may still put significant pressures on the compartmentalizing air barrier system. The design of interior air barriers can also be challenging due to penetrations and difficulty in sequencing.

A typical air barrier for compartmentalization consists of the air barrier materials for the field of the wall, floor, or ceiling, and methods for sealing transitions and penetrations in the air barrier. The primary air barrier material may be a dedicated product (e.g. a polyethylene sheet) or one of many common interior building materials already in place that are sufficiently air impermeable. These include gypsum wall board, concrete, or other interior sheathing.





Stack effect pressure across the enclosure is greatly reduced when all zones in the building are separated with an air barrier

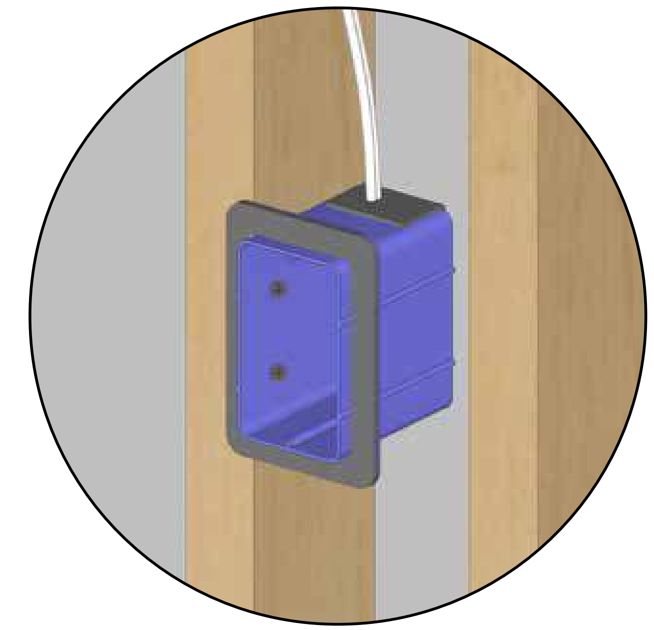
Interior compartmentalization must be designed and constructed with the same level of detail and effort as the enclosure air barrier. Designers should include details for interior penetrations and interfaces, and the construction team must account for the time and effort required for this work.

Interior Partitions

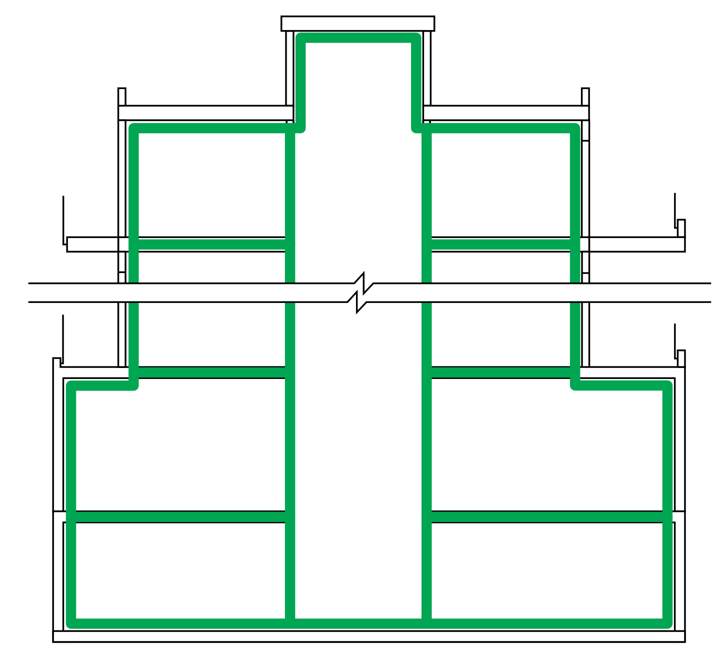
Compartmentalization at interior walls is generally achieved using the airtight drywall approach. A continuous air barrier is achieved for each individual unit, located at the interior-most plane of the perimeter walls and ceiling, with a separate strategy for the floor, often using the floor sheathing or slab. It is important to remember that interior doors can also be part of a compartmentalization strategy and may require gaskets at the perimeter, interfacing with the adjacent air barrier system. Service penetrations for electrical, heating, and plumbing must also be made airtight with sealant or gaskets.

Entries, Stairwells, and Elevators

Stairwells and elevator shafts should also be compartmentalized as separate spaces, similar to suites or other units in a building. These large continuous spaces can experience significant pressures from stack effect, and can allow airflow across the entire height of the building. Continuous airflow through the shaft can transfer odours and contaminants between floors, draw conditioned air out from occupied areas, and push outdoor air in. Airflow through shafts can be reduced by adding an airtight vestibule at the entry to these spaces, using separate shafts between the interior and exterior spaces like the parking garage, and making the doors airtight.



Example of an airtight electrical box with built-in gasket at the wire penetration and at the perimeter flange for sealing to the interior gypsum board



Compartmentalization of all zones with an air barrier

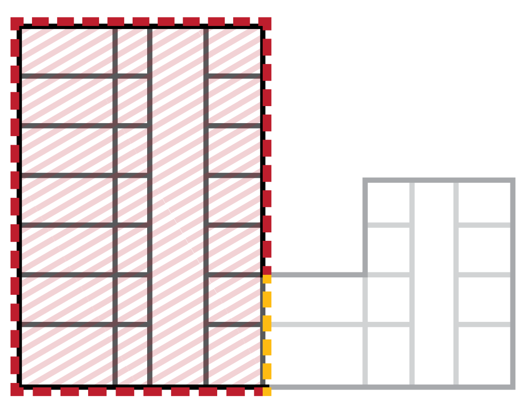
MECHANICAL DESIGN

As buildings are built more airtight, proper mechanical ventilation becomes more important both for occupant health and comfort, as well as for enclosure performance and durability. Where buildings could previously rely on some air leakage through the enclosure to provide or augment the supply of fresh air and to provide make-up air for unbalanced ventilation systems (i.e. exhaust only), the mechanical ventilation design in new buildings should assume minimal air leakage through the enclosure. Instead, ventilation air requirements should be met with dedicated systems, designed to deliver ventilation air through ducting directly to occupants. Balanced ventilation air intake and exhaust is also important, because unbalanced mechanical systems will likely have difficulty drawing adequate make-up air through the airtight building enclosure. This can impact the performance of the ventilation system and create significant pressure differences.

While airtightness can require a more carefully considered ventilation system design, a more airtight enclosure and compartmentalized interior spaces can also make balancing a central mechanical system easier and its performance more reliable, since it will be less affected by external forces such as stack effect and wind. Decentralized ventilation systems, such as individual heat recovery ventilators (HRVs), are also a good option for controlled ventilation of different building zones and are easier to balance than larger centralized systems.

PHASED OCCUPANCY

For buildings in which phased occupancy is planned, it can be difficult to test the entire building once it is completed, and it may be necessary to test prior to occupancy to meet the requirements of the authority having jurisdiction. When using a phased occupancy approach, the air barrier design should account for various stages of occupancy in the building. Airtightness testing of completed phases is extremely difficult if the building design does not include separations between phases. This includes separate mechanical systems and the ability to test the completed phases of the building alone. This is often done through pressure equalized testing, where fans are used to minimize air leakage through partitions between phases that may not be fully airtight and are not part of the enclosure area being tested. The building design should include explicit guidance on where the separation of phases is to occur, and measures to make the separations relatively airtight to facilitate equalization and limit unintended bypasses. This pressure equalization can be difficult to achieve with complicated building designs. Refer to Alternate Test Methods on page 41 for further guidance on testing separate areas of a single building.



The air barrier design (red) should clearly indicate where separations (yellow) are needed between building phases

3 | CONSTRUCTION

MATERIAL INSTALLATION CONSIDERATIONS
COORDINATION & SEQUENCING
QUALITY CONTROL PROCESSES

MATERIAL INSTALLATION CONSIDERATIONS

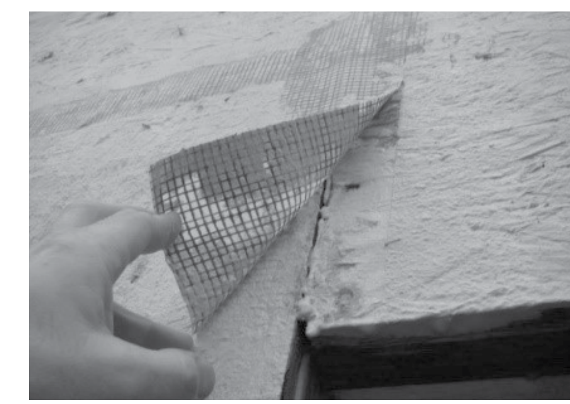
The construction phase is equally as important as the design phase in achieving whole-building airtightness. The installation process for each component of the air barrier should be well planned, with considerations given for the various installation requirements, product limitations, and common deficiencies.

Pre-Installation Trade Meetings

Organize trade meetings to give clear instruction and hands-on training by appropriately qualified personnel, to clarify the various installation requirements for the air barrier products used, such as membranes, tapes, and sealants. The meetings can also help determine the appropriate sequencing to allow unobstructed access, adequate cure times, avoid damage, and coordinate installation where multiple trades are involved.

Weather

Weather is a governing factor for installing most exterior air barrier components, as cold temperatures and moisture may affect adhesion, cure times, and can even lead to damage of installed materials. Materials should be selected based on the installation conditions to ensure adequate adhesion. Wherever possible, air barrier products and substrates should be protected from adverse weather conditions. This is a particular concern for air barrier products that also act as vapour retarders because they can trap moisture in the completed assembly. Manufacturers of high-quality air barrier materials will often provide instructions and test results for their products to show they can be used in challenging weather conditions.



Delamination of reinforcing mesh due to rain exposure before curing

Substrate Preparation

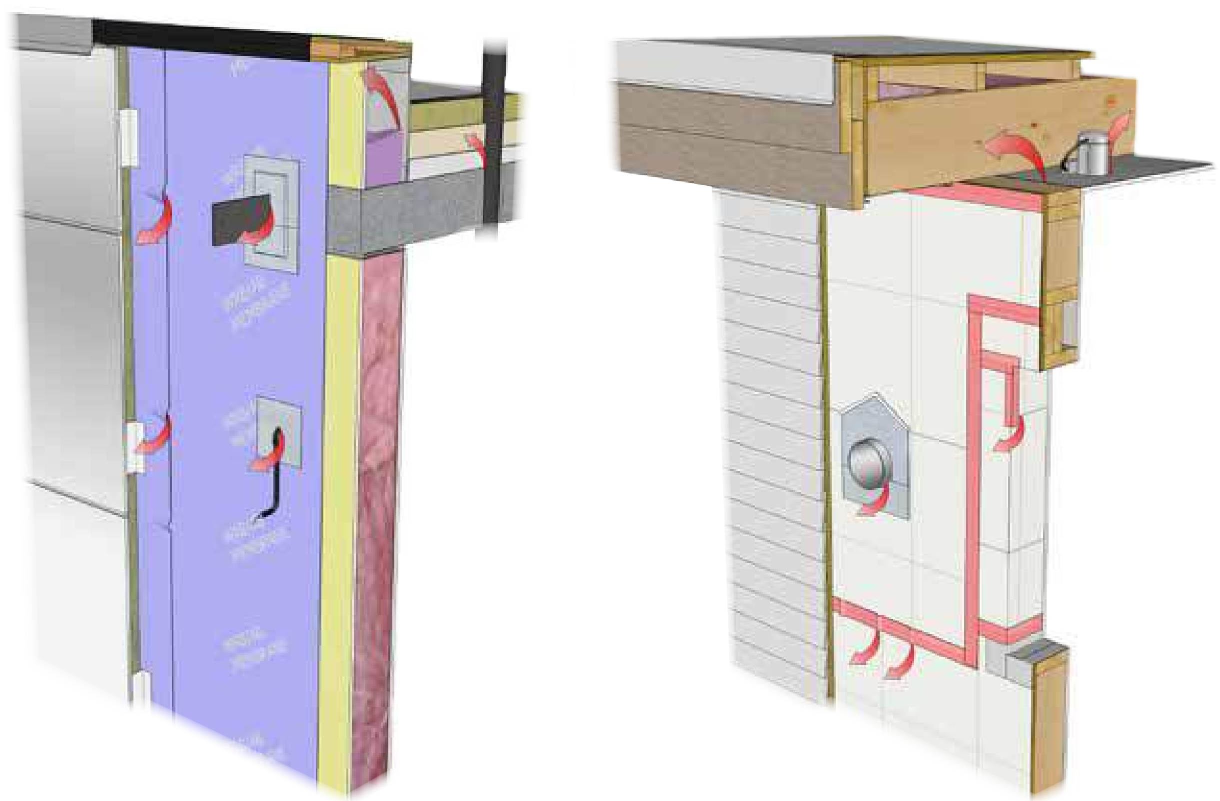
Substrate preparation is another important aspect of air barrier installation, both for initial installation and long-term durability and airtightness. Typically, the substrate must be clean and dry, and within a manufacturer's recommended temperature range at the surface, to be suitable for membrane installation. Primer is also often required for the installation of adhered sheet materials and some sealants when adhered to wood, concrete, gypsum board, metal, or other substrates. Always refer to the manufacturer's specific instructions for surface preparation. Include substrate preparation in planning and sequencing, because steps such as primer application require the substrate to be accessed on at least two separate occasions.

Insufficient adhesion of the membrane likely due to incorrect substrate preparation

Common Deficiencies

Common deficiencies and challenging areas for exterior air barrier installation can occur at all areas of the air barrier system. The integrity of the air barrier relies upon the quality and completeness of the installation work. Some common air barrier deficiencies and likely deficiency locations include:

- Structural and service wall penetrations using sealant and membranes
- Wrinkled/fish-mouth/incomplete membrane laps
- Roof-to-wall and other interfaces where various transition materials are used
- Roof/ceiling penetrations
- Window membrane and perimeter sealing
- Interior ceiling penetrations and partition walls at an interior air barrier
- Above-grade to below-grade transitions
- Complex building forms and enclosure shapes such as fin walls and projections



Examples of air barrier deficiencies for common roof and wall assemblies

Air Barrier Review | A primary focus of the building enclosure consultant or other design professional should be on the continuity of the air barrier installed on site. Regular site reviews, along with the appropriate testing, should be completed as often as possible so that all aspects of the air barrier installation are reviewed prior to being covered with cladding or finishes.

Mock-ups

Mock-ups generally consist of a small portion of the building enclosure detailing completed before the main installation takes place. These can be either the first part of the building or an independent structure, disassembled after use (often referred to as a "performance mock-up").

Mock-ups should include representative interfaces and components and be of sufficient scope to verify sequencing, installation methods, air barrier performance, and other critical barrier functions. The mock-up is the primary opportunity for the design team to confirm that the performance is adequate and the design intent has been satisfied, and for the construction team to address potential constructability or coordination issues. It might require multiple iterations to satisfy all parties.

Solving issues before full-scale construction is more efficient. If possible, the mock-up should be constructed to allow for qualitative testing (as described in Testing on page 31) to help identify any air barrier deficiencies before they are repeated more broadly.

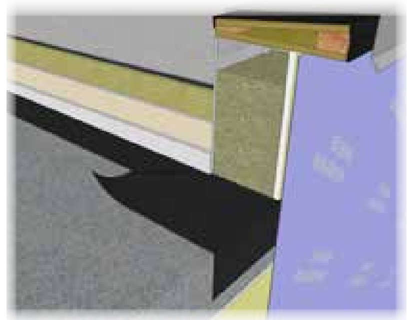
Performance mock-up hut with various representative interfaces and components

Qualitative (smoke tracer) airtightness testing of a parapet detail mock-up

Mock-ups of various wall penetrations

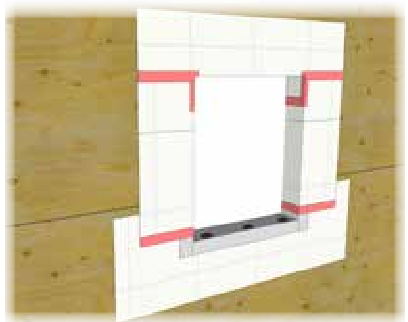
COORDINATION & SEQUENCING

Construction coordination and sequencing must accommodate many different building activities. However, the air barrier installation can often become an after-thought. Common coordination and sequencing challenges for the air barrier are:



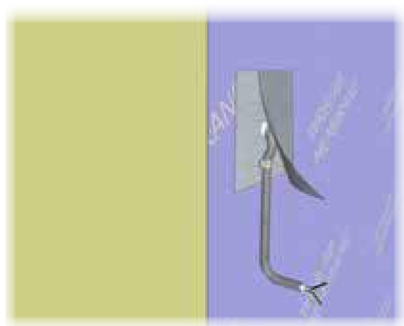
Framing/Structure

Building components outside the primary structure, such as balconies, parapets and canopies, are usually installed along with the primary assemblies. However, these may not include provisions for continuity of the air barrier through the structural components at the exterior enclosure. The assembly of the building should allow for air barrier materials to be installed behind the secondary structural components, even without the full air barrier installation taking place. This practice is commonly referred to as "pre-stripping".



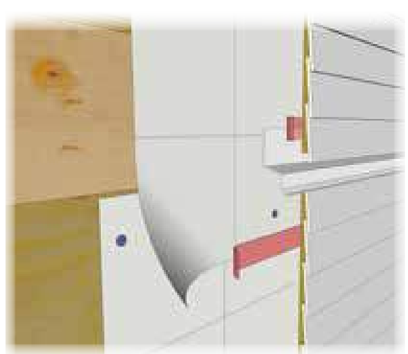
Openings

Rough openings are often one of the first areas to receive enclosure components and are usually prepared with membrane well before the air barrier is in place at the field of the wall. Besides airtightness of the window or door installation, it is important to leave adequate room at the perimeter of openings to allow for tie-in of the field membrane, and, if applicable, positive membrane laps for materials placed below the pre-installed components. The use of a liquid applied membrane can remove this sequencing challenge due to simpler tie-in procedures.



Penetrations

Service penetrations through the exterior wall can be made at any time during construction. Electrical or plumbing trades may not be aware of the impact of their activities on the various air barrier components without explicit instruction for how new penetrations are to be dealt with. Coordination is critical to ensure that penetrations made in the air barrier are sealed.



Flashings

While the aim of integrating flashings with the water-resistive barrier (often the same membrane used for the air barrier) is to provide positive laps and joints wherever possible, this can greatly complicate the air barrier detailing. Installing the flashings after the air barrier is complete, using membrane strips, tapes, or sealant to create the necessary transitions for the water-resistive barrier, is preferred rather than including the flashing as part of the air barrier.

QUALITY CONTROL PROCESSES

On-site quality control of air barrier installation is a complex process. It is fundamentally important to achieving an airtight building and requires substantial oversight. Although the design documents may include details and instruction for all air barrier interfaces and penetrations, the builder is ultimately responsible for ensuring all aspects of the system are installed and complete. Site mock-ups serve to demonstrate the air barrier installation processes and regular reviews of the air barrier installation promotes consistent and complete work as part of the ongoing quality control process. Frequent field reviews early on can minimize delays for instruction, verification, and remediation. The building enclosure consultant should be notified with sufficient time to review the air barrier, especially at critical details, throughout the construction process. However, the consultant will not always be present and there is a risk of discontinuities being missed or created in the air barrier throughout the construction process.

A successful approach to mitigate this risk is to designate an "air boss", who is a member of the construction team responsible specifically for the air barrier. This person should be appropriately trained on and knowledgeable of air barrier strategies, the specific air barrier systems being used on the project, as well as requirements for building airtightness testing. The air boss is responsible for the following items during construction:

- Regular review of the installation of all air barrier components, especially at penetrations, details, and interfaces.
- Offering air barrier installation guidance and instructions where appropriate.
- Tracking all air barrier penetrations, details, and interfaces that require further attention from the building enclosure consultant, where applicable.
- Coordinating and assisting in both qualitative and quantitative airtightness testing.
- Implementing and overseeing modifications and repairs as needed to meet airtightness requirements.

With one person dedicated to keeping track of the continuity and completeness of the air barrier, it is easier to achieve overall airtightness.

Qualitative Testing | As described in the next section, qualitative air barrier testing, such as infrared thermography or smoke tracer testing, can play an important role in quality control of the air barrier during construction. It allows for testing prior to completion, and detection and remediation of deficiencies while air barrier components remain accessible. Testing should be included as part of the on-site quality control and assurance protocol.

Wood-frame building over concrete podium, designed to allow completion of the air barrier before balconies are installed on clips

4 | TESTING

TEST TIMING

Airtightness testing should begin as early as possible in the construction phase. This includes testing of performance mock-ups before testing the whole building, in order to provide early identification of potential air leakage issues. Early testing is the best way to allow improvements to the enclosure to be made and to verify the enclosure is on track to meet the performance requirements.

A good option is the regular use of qualitative testing methods, which help to visualize air leakage paths at air barrier details and transitions and quickly check the performance of the air barrier system. Perform qualitative testing as early as possible at all complex or irregular details and transitions, as well as at common details where consistency is needed and the potential impact is large. The qualitative testing should verify air barrier installation and identify discontinuities. Regular and effective qualitative testing will substantially improve the likelihood of the building passing the more stringent, involved, and expensive quantitative testing performed towards the end of construction.

Quantitative testing measures enclosure air leakage rates. Reported air leakage rates are based on quantitative airtightness testing performed towards the end of construction. At a minimum, this means that the air barrier installation is complete, plumbing traps are filled, and mechanical systems are installed and sealed as required by the test standard. Quantitative testing should occur as early as possible as the building is completed, because it is easier and cheaper to correct potential air barrier deficiencies before all air barrier elements are completely covered up, construction activity is winding down, or occupancy has occurred. Airtightness testing should be included as one of the many building commissioning tasks that require active participation from the construction team. Full-scale quantitative testing should be included as a specific line item on the construction schedule, and will usually require at least one full day with no other activity taking place on site.

When scheduling testing, consider any potential challenges in gaining access to suites and providing power to the equipment. Interior doors and restrictions to air flow will need to be held open to establish the single-pressure-zone condition. This can present a significant scheduling or security concern when whole floors or buildings are being tested. For these reasons, testing should occur pre-occupancy.

Late Testing | Delaying airtightness testing to later stages of the project typically increases the difficulties and costs associated with repairing air barrier defects. Qualitative testing throughout the construction process can reduce the risk of this occurring. Construction sequencing and air barrier system selection should be done with consideration for completing the air barrier as early as possible. If enclosure elements cannot be readily tested in place during construction, qualitative testing should be used during the mock-up phase.

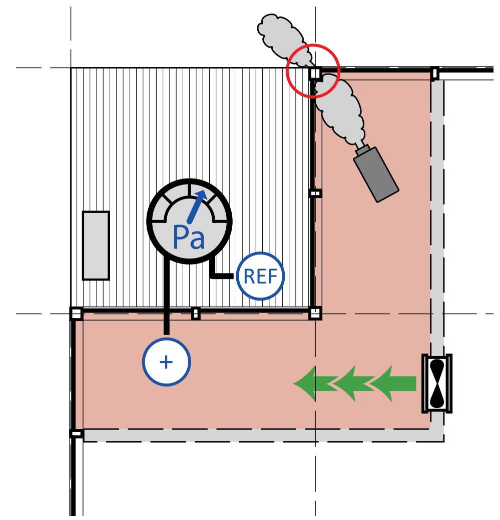
QUALITATIVE TESTING

Qualitative testing can be used at the mock-up stage, during construction, and as part of final testing to identify air leakage paths and deficiencies. This testing should take place early in the construction phase because of its typical use of visual indicators to locate air leakage paths and relatively low cost. However, qualitative testing does not provide an air leakage rate.

The ASTM E1186 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems test standard includes several different procedures for qualitatively assessing the air leakage of the enclosure. The two most commonly used procedures are the smoke tracer and infrared thermography methods.

Smoke Tracer Testing

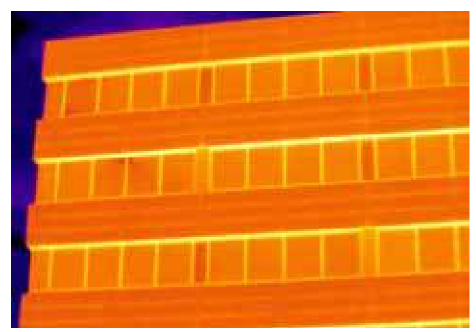
Smoke tracer testing uses theatrical fog applied on the high-pressure side of the building enclosure. Leakage points are observed where smoke penetrates through and appears on the low pressure side. Typically, smoke is applied on the interior where it is more easily contained and leakage is observed from the exterior. Leakage points can then be investigated further and repaired as needed. This test method can be used at any stage during construction, so long as the test area can be pressurized relative to the exterior. Constructing a test chamber that can be pressurized independently from the rest of the building can facilitate early-stage testing. Combining qualitative airtightness testing with water penetration testing can make the on-site testing more efficient overall.

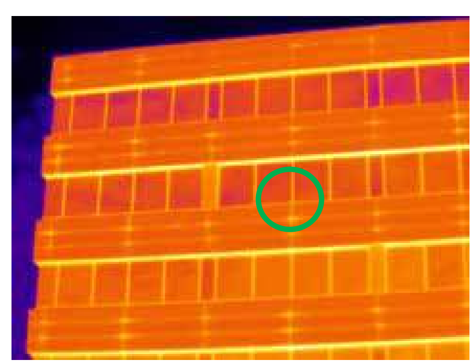


Schematic of smoke testing set-up at a corner detail

Infrared Thermography

The infrared thermography method is best carried out in a two-step process, and relies on a colder outdoor temperature compared with indoors. First, the building is pressurized, and heated indoor air exfiltrates through the leakage openings and heats the surrounding enclosure. The building is scanned to get a baseline reading of the different detail locations and view warm spots or "thermal anomalies". The building is then depressurized and cold air is drawn through any air leakage openings, cooling the building around these locations. A second scan is then done to identify the location and severity of air leakage through the enclosure. This approach is important to be able to differentiate between air leaks and thermal bridges. Locations where thermal anomalies under pressurization and depressurization differ are typically associated with air leakage. Building pressurization can be done using dedicated fans or using the building's mechanical system. This method can also be used from the inside, in reverse order, with cold areas considered as the thermal anomalies.


Infrared photo during building depressurization


Infrared photo during building pressurization (areas with thermal anomalies are potential air leakage locations)

4 | Testing

QUANTITATIVE TESTING

Measuring airtightness to meet a performance target requires quantitative testing. The most common quantitative testing methods use fans, but other methods exist that are discussed at the end of this section.

FAN-BASED QUANTITATIVE MEASUREMENTS

A fan-based approach tests the airtightness of a pressure boundary, typically the whole building, using a uniform test pressure difference induced across all areas at once. In order to achieve this condition, interior restrictions to airflow must be removed and exterior openings must be sealed.

Fan-based quantitative airtightness testing methods use calibrated fans to create an elevated and uniform pressure difference across the building enclosure. The fans and accompanying equipment are designed to measure the airflow rate they supply in conjunction with the pressure difference across the enclosure. The amount of airflow through the fans is usually measured at several pressure differences, in order to verify test accuracy, provide consistency, and allow for extrapolation of the results. The air leakage rate is then determined using conservation of mass by equating the flow through the fans to the flow through the building enclosure.

Blower doors, such as those commonly used for residential airtightness testing, follow this approach. The blower door is installed temporarily in a door or other appropriate opening using an adjustable enclosure and fan mount. The fan is typically operated by a software-based control system that connects to pressure taps installed at several locations across the building enclosure. A single blower door can be used for small buildings, while multiple fans can test larger buildings. Variations on the fan-based approach include using a single large fan or a building's mechanical system in lieu of standalone fans.

For additional information on the test parameters and a comparison of the specific requirements of the various test standards, refer to the Test Standards Comparison on page 49 and Further Reading on page 50 in Additional Resources. See also **Appendix A | Building Airtightness Targets in Codes and Standards Across B.C.**, which outlines the current whole-building airtightness performance targets that may be applicable across British Columbia.


Door fans placed in multiple door openings with frame and fabric enclosures

TEST CONDITIONS

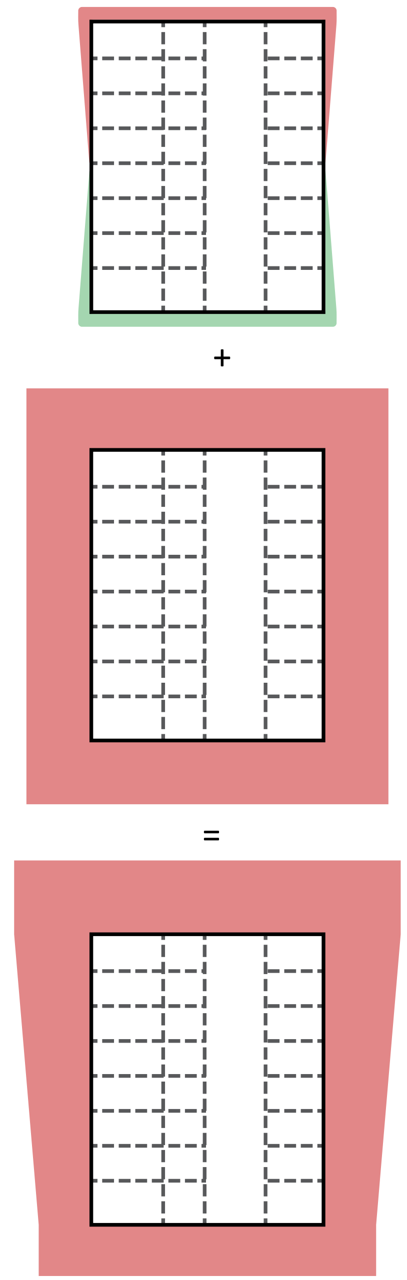
The naturally occurring forces of wind and stack effect create pressure differences that can be highly variable and often act unevenly across the building enclosure. These forces can affect the test pressure and cause inaccuracies in the measured airtightness across the building enclosure. For this reason, airtightness tests are performed at standardized test pressure differences that are designed to be of sufficient magnitude to dampen the impact of these forces. The challenge with large, tall buildings is that the magnitude of the wind and stack effect forces can be significantly higher than for smaller, shorter buildings. Test standards may place restrictions on the exterior conditions during testing in order to minimize this effect.

Exterior Conditions

Wind speed and temperature are the two climate variables of concern when performing airtightness testing. At a minimum, test standards require that the exterior conditions be reported. Some standards also limit the conditions during which testing can occur. An analysis of average environmental conditions for various Canadian cities determined that the frequency of suitable conditions for testing is quite variable and in the range of 10%-60% of the year, with mild climates like Vancouver having a higher frequency than cold climates like Whitehorse. Where challenging exterior conditions exist, it may be possible to mitigate the issue by testing for longer periods, testing at night when wind speeds are typically reduced, or testing the building while unheated to reduce stack effect.

Interior Conditions

The interior zone being tested should form a single pressure boundary. Individual test standards specify how this condition is verified, but this means that the pressure difference measured across the pressure boundary is the same throughout the building, within a specified tolerance. Achieving this condition is an integral part of the pre-test coordination.



Effect of stack effect pressure on induced test pressure

Pressurization vs. Depressurization | In addition to climatic effects, the airtightness characteristics of a building can depend on whether or not the building is pressurized or depressurized. Some leakage openings may tend to open or close depending on the pressure difference experienced across the potential leakage opening. Examples may include insufficiently secured laps in air barrier materials, or operable windows and doors pulling away from a gasketed seal. Testing under both conditions and averaging the results is required by many test standards.

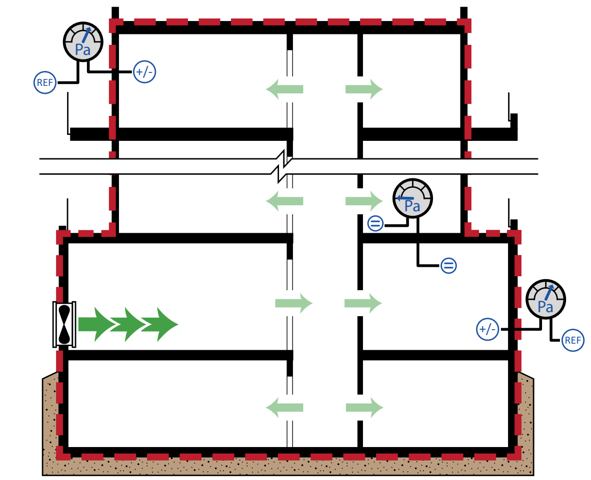
DEFINING A TEST BOUNDARY

A pressure boundary is created when an area is enclosed by a continuous air barrier. In terms of airtightness testing, the pressure boundary needs to enclose a single zone, which means that the pressure within the zone cannot differ significantly. For larger buildings, the whole building may be made up of several smaller single-zone pressure boundaries. The maximum size of a pressure boundary is generally limited by the available fan capacity.

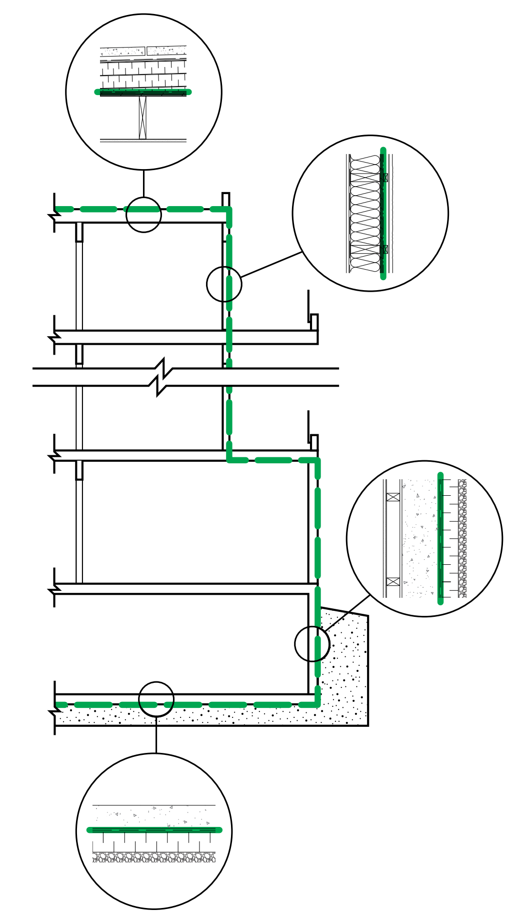
Establishing a pressure boundary that meets the single-zone condition is relatively straightforward for small, short, single-zone buildings. For most larger buildings, greater attention is required to establish and verify the single-zone condition, but the same principles apply. For very large or highly compartmentalized buildings, it may not be feasible or desirable to meet the single-zone condition for the entire building.

A compartmentalized building is one in which there are significant internal air flow restrictions due to partitions. These can be unintentional or a by-product of the ventilation strategy and other design decisions. This condition commonly arises with mixed use buildings and with podium-based construction. Challenges in achieving the single-zone condition may arise when there are obstacles preventing air distribution within the building, large naturally occurring pressure differences, or a lack of sufficiently sized equipment. In these cases, a compartmentalized approach can often be used. The design team should consider early on how the building will be tested in order to identify and plan how the project-specific testing challenges will be overcome.

For the purpose of determining test parameters such as building volume and area, zone measurements should be taken from the plane of airtightness or as defined by the test standard. If an exterior air barrier is used, the test zone volume may include a portion of volume within the enclosure assembly. It is important to verify the location of the air barrier across all assemblies, and establish a consistent approach when completing quantity takeoffs using building drawings and field measurements.



Pressure differences and intended interior airflow required for a single pressure zone



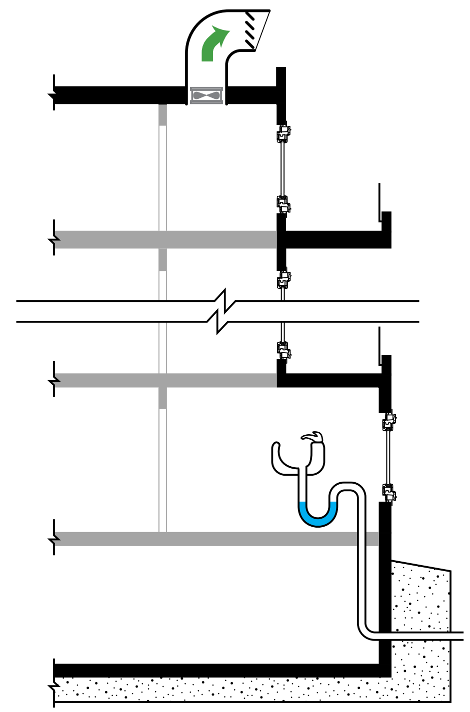
Test zone measured from the plane of airtightness at the exterior surface of the enclosure

PREPARING OPENINGS

A typical building will feature many intentional openings in the enclosure, including doors and windows, as well as mechanical penetrations like vents and louvres. During normal operation, many of these openings are closed, but others will be partially or fully open to serve their intended purpose. Whole-building airtightness results depend on how these openings are prepared prior to testing. Test standards provide schedules that indicate whether typical openings are left open, closed, or temporarily sealed. Test standards may treat continuously and intermittently operated mechanical systems differently in terms of how and if they are sealed. There are three general testing arrangements: as-is testing, sealed openings, and enclosure only.

As-Is Testing

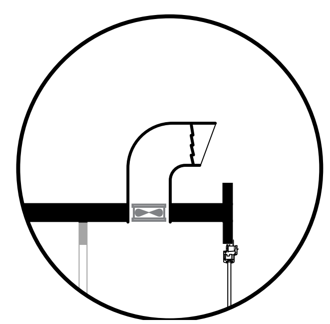
During as-is airtightness testing, doors and windows are closed, and plumbing elements such as P-traps are filled with water. However, mechanical penetrations such as ducts are left unsealed and air leakage through them is reflected in the resulting airtightness result. This type of test provides an indication of the airtightness of the building in service.



As-is testing

'Sealed' Openings

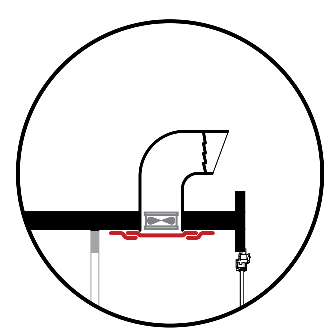
Testing with intentional openings sealed means that mechanical openings are purposely closed off. Mechanical systems that are intended to be sealed with dampers would only be sealed by closing the damper, with no additional sealing provided. Windows and doors are left in the closed and locked position. Results from this testing account for any leakage through poorly performing louvres and dampers.



'Sealed' openings - dampers closed

Enclosure-Only

Enclosure-only testing is similar to the sealed openings approach, except all mechanical penetrations are temporarily masked to completely prevent air leakage through them. Accordingly, this approach is intended to reflect the airtightness of the building enclosure only and is less dependent on the mechanical system design. The results of this type of testing are easily comparable across different buildings.



Enclosure-only - masked openings

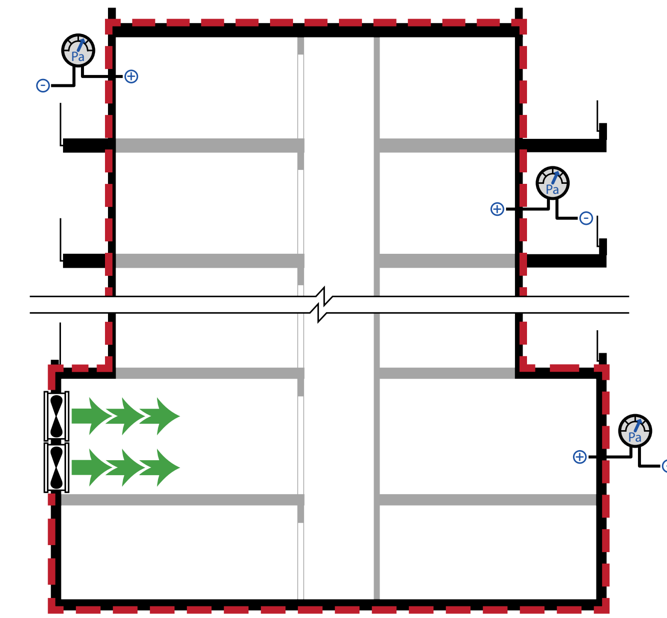
FAN REQUIREMENT & LAYOUT

The number, size and location of fans will depend on the size and specific requirements of the building or zone being tested. Consult an experienced airtightness testing professional well in advance of project completion to plan for these requirements, because airtightness testing can impact the schedule, construction sequencing, and in some cases the design. Once a layout has been selected, the testing team should verify that all the test criteria including the pressure differences and the single-zone condition are met.

Single fans providing flows in the range of 1,500-2,500 L/s (3,200-4,200 cfm) are available and sufficient for airtightness testing of single low-rise residential buildings. Tall buildings require larger or more fans to meet standard test criteria. To estimate the fan airflow requirement, measure the enclosure area from the exterior of the pressure boundary and multiply by the target Normalized Air Leakage Rate. If ACH is used, measure the building volume, multiply by the target air changes per hour, and divide by the appropriate time interval to determine airflow.

For practical reasons, it is useful to oversize the fan capacity. One of these reasons is that test pressure differences are typically measured from a non-zero baseline pressure. Multiplying by a safety factor of 1.2 is generally sufficient to ensure enough fan capacity is available.

Fans should be located to create the single-zone condition. The location of pressure taps is also important. In general, they should be located to avoid areas of high wind pressure and solar radiation, because these can effect the pressure measurements. They should also be located on both the windward and leeward sides of the building. Refer to specific test standards for more detailed guidance.



Fan Airflow Requirement Example Calculation:

$$Q_{\Delta P} = A \cdot q_{\Delta P}$$

$$A = 1{,}500 \text{ m}^2$$

Assumed $q_{75} = 2.0$ L/s·m² @ 75 Pa

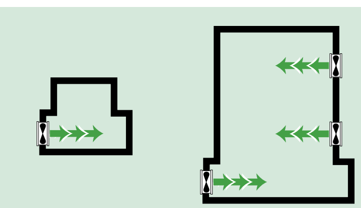
$$Q_{75} = 1{,}500 \text{ m}^2 \cdot 2.0 \text{ L/s·m}^2 = 3{,}000 \text{ L/s}$$

3,000 L/s · 1.2 = 3,600 L/s

Standard fan capacity = 2,500 L/s

Fans Required: 2

Building Size | Smaller buildings like low-rise residential buildings can often be tested with only one or two fans in one opening, while larger buildings such as mid-rise and high-rise buildings may require many more fans, positioned throughout the enclosure.



CONDUCTING THE TEST

The following section provides an overview of some considerations during testing. The requirements of the particular test standard should be reviewed carefully prior to testing.

Test Conditions

The exterior conditions should be measured before and during testing and then compared to the allowable range specified in the test standard. These conditions may be building height specific, and if they are not met, the test results may be invalid and rejected by the building authority. If the building is unoccupied, consider testing overnight and with the interior space unheated to reduce the influence of wind and stack effect.

Identifying Leaks

Quantitative testing alone does not provide the location of air leakage paths. Combining quantitative with qualitative testing to diagnose air leakage locations is helpful and often required when a building fails to meet its airtightness target. Qualitative testing is a recommended part of any airtightness test, because it might still be possible to identify meaningful or easily remedied air leaks.

Troubleshooting

A selection of common testing issues, along with potential solutions, is provided below:

- **Unstable pressure readings:** Adjust the placement of pressure taps, use longer averaging periods, and ensure all openings, especially doors, are properly sealed.
- **Unable to establish the single-zone condition:** Ensure all interior doors are in the fully open position, redefine the pressure boundary, and introduce additional fans to promote airflow between interior spaces.
- **Unable to reach the target test pressure difference:** Increase fan capacity, redefine the pressure boundary, or (if permitted) test the building to the maximum attainable pressure while maintaining the specified interval between test pressures.
- **Calculated flow exponent outside the acceptable range** ($0.5 < n < 0.85$ or as specified by the test standard): Commonly caused by a change affecting the air barrier during testing, verify the integrity of the air barrier (where possible) and of all sealed openings and re-test.

On-Site Quality Assurance

Analyzing the data as testing proceeds can reduce the need to retest by identifying if the test results are valid. This analysis may allow for changes to the test setup to correct observed deficiencies as they are discovered. The tester should check that the flow exponent is within the accepted range for the particular standard. Additional corrections or quality checks may be mandated by the applicable standard.

Safety

The large pressure difference introduced by airtightness testing can overcome the mechanical system. This is a concern when combustion appliances are present. Steps must be taken (for example, turning the system off) to ensure that these appliances are protected from back-drafting during the test procedure.

Test Pressure | When testing at multiple pressure differences, testing can proceed either from a low-to-high or a high-to-low pressure difference interval. A benefit of starting from a low pressure difference is that the air barrier system is stressed incrementally as the pressure increases, rather than all at once at the maximum pressure difference. An airtightness test will usually proceed from low pressure to high pressure.

POST-TEST ANALYSIS

Flow Coefficient & Flow Exponent

One of the purposes of multi-point testing is to permit calculation of the flow coefficient *C* and flow exponent *n*. The process is often automated by the calibrated fan software, but can also be performed quite simply using spreadsheet software such as Excel. The process is as follows:

1. Enter the measured airflows $Q_{\Delta P}$ and corresponding pressure differences ΔP into the spreadsheet program.

2. Take the log of both variables and plot $log(Q_{\Delta P})$ vs. $log(\Delta P)$, often referred to as a "log-log plot".

3. Perform a linear regression through the data points and obtain an equation for the line of best fit in the form of:

$$y = m \cdot x + b$$

$$\log(Q_{\Delta P}) = n \cdot \log(\Delta P) + \log(C)$$

4. Check the correlation of the log values using the R-squared test. The R-squared test is a measure of how accurately the line of best fit predicts the measured values. The spreadsheet software should provide this value along with the equation for the line of best fit. In general, R-squared values should be greater than 0.98.

5. The flow exponent *n* is directly equal to *m* in this formula. The flow coefficient *C* is determined using the inverse log of the *b* value.*

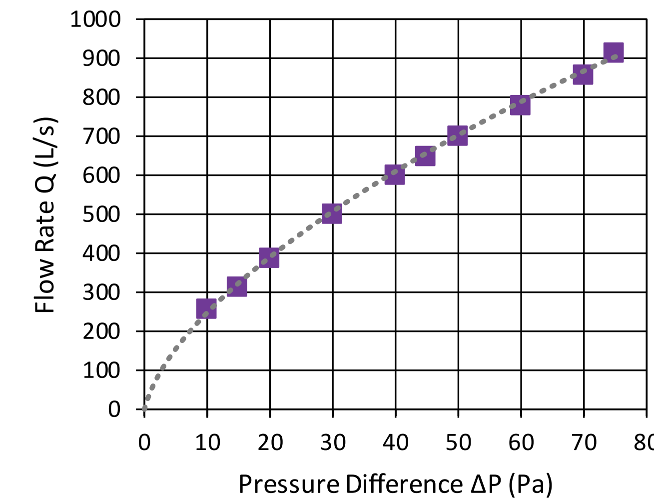
6. Various test standards may require additional statistical analysis or modification of the measured or calculated test data

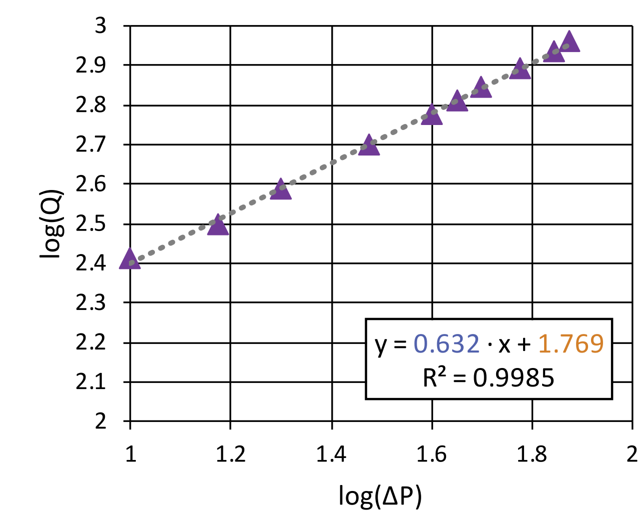
7. The reported airflows at various pressure differences can then be calculated using the calculated *C* and *n* values.

Note that test standards may include procedures to correct for air density in terms of temperature and elevation. Refer to the specific test standard for more details.

*Theoretical fluid dynamics limit the value for *n* to between 0.5 and 0.85 based on laminar and turbulent airflow. When a linear regression is not performed, such as where flow coefficient *C* must be determined from $Q_{\Delta P}$ and ΔP in a single-point test, the value for *n* can be assumed to be 0.65.

Example test results and calculations





$$\mathbf{n = 0.63}$$

$$\log(C) = 1.769 \quad | \quad C = 10^{1.769}$$

$$\mathbf{C = 58.8}\ \text{L/s/Pa}^n$$

$$Q_{\Delta P} = C \cdot \Delta P^{\,n}$$

$$Q_{75} = 58.8 \cdot 75^{\,0.63}$$

$$\mathbf{Q_{75} = 893\ L/s}$$

REPORTING

Reporting is the final step in the airtightness testing process. Standards typically require documentation of more than just the airtightness results, and the specific reporting requirements of the test standard and jurisdiction should be consulted before conducting the test to ensure that all necessary parameters are captured during testing.

Common parameters to include in an airtightness testing report include (see Additional Resources on page 43):

- **Building and site details**: height, area, test boundary description, mechanical system description, as well as the locations of all test equipment.
- **Test arrangement**: test enclosure area and volume, which openings were sealed or left open, verification of the single zone condition, indoor/outdoor temperature
- **Results**: Airflow, Normalized Air Leakage Rate, pressure differences and duration of readings, as well as calculated values: *C, n*, and R-squared as required.

Checklists

Checklists can help capture all of the required information and avoid common mistakes. A checklist should either be prepared or obtained from the standard and reviewed carefully prior to testing. An example testing checklist, along with a design checklist and construction checklist, is provided in the Additional Resources on page 43.

Date:	[illegible]
Project:	[illegible]
Attendees:	[illegible]
Test Arrangement Description: Enclosure only testing; mechanical/service openings sealed off	
Test Boundary Area:	1500 m^2
Building Volume:	3857 m^3
Pressurization	
Air Leakage Coefficient (C):	58.8
Flow Exponent (n):	0.63
Air Leakage Rate @ 75 Pa (Q_{75}):	893 L/s @ 75 Pa
Normalized Air Leakage Rate @ 75 Pa (q_{75}):	0.60 L/s•m^2 @ 75 Pa
Correlation Coefficient (R^2):	0.988
Depressurization	
Air Leakage Coefficient (C):	58.1
Flow Exponent (n):	0.63
Air Leakage Rate @ 75 Pa (Q_{75}):	882 L/s•m^2
Normalized Air Leakage Rate @ 75 Pa (q_{75}):	0.59 L/s•m^2 @ 75 Pa
Correlation Coefficient (R^2):	0.986
Avg. Norm. Air Leakage Rate @ 75 Pa (q_{75})	0.60 L/s•m^2 @ 75 Pa
Pass/Fail (≤2.0 L/s•m² @ 75 Pa):	**PASS**
Equivalent Leakage Area (EqLA):	476 cm^2
Normalized Leakage Area	0.3 cm^2/m^2
Building ACH @ 50 Pa	3.3 ACH_{50}

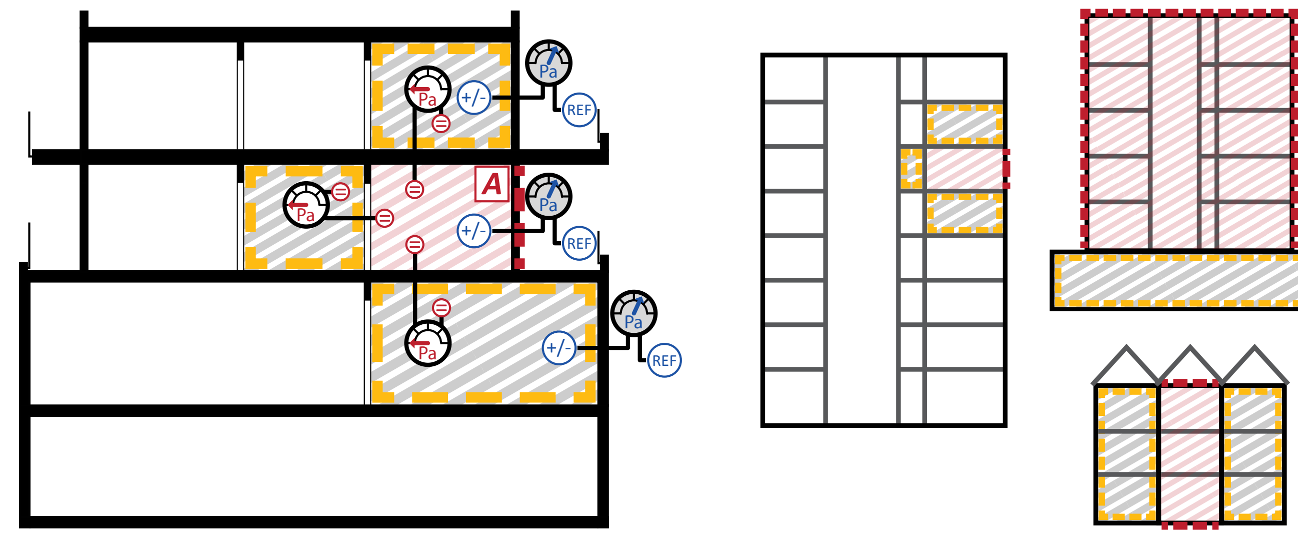
Example airtightness testing results form

Single door fan to be placed in a door opening using a solid enclosure

ALTERNATE TEST METHODS

Pressure Equalized Testing

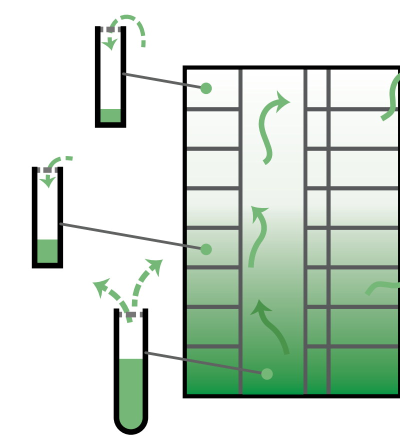
To overcome some of the challenges associated with whole-building airtightness testing (single-zone condition, fan capacity, etc.), test methods have been developed specifically to test more complicated buildings in smaller sections using zones of the building that are more manageable (i.e. floor-by-floor or suite-by-suite). As well as pressurizing the exterior boundary, compartmentalized approaches pressurize adjacent zones. By pressurizing the adjacent zones to the same pressure as the test zone (pressure equalizing), air leakage across partitions between zones is reduced and the results reflect leakage through the exterior enclosure only. Although this approach allows for additional flexibility, it is generally more time consuming and presents additional coordination challenges.



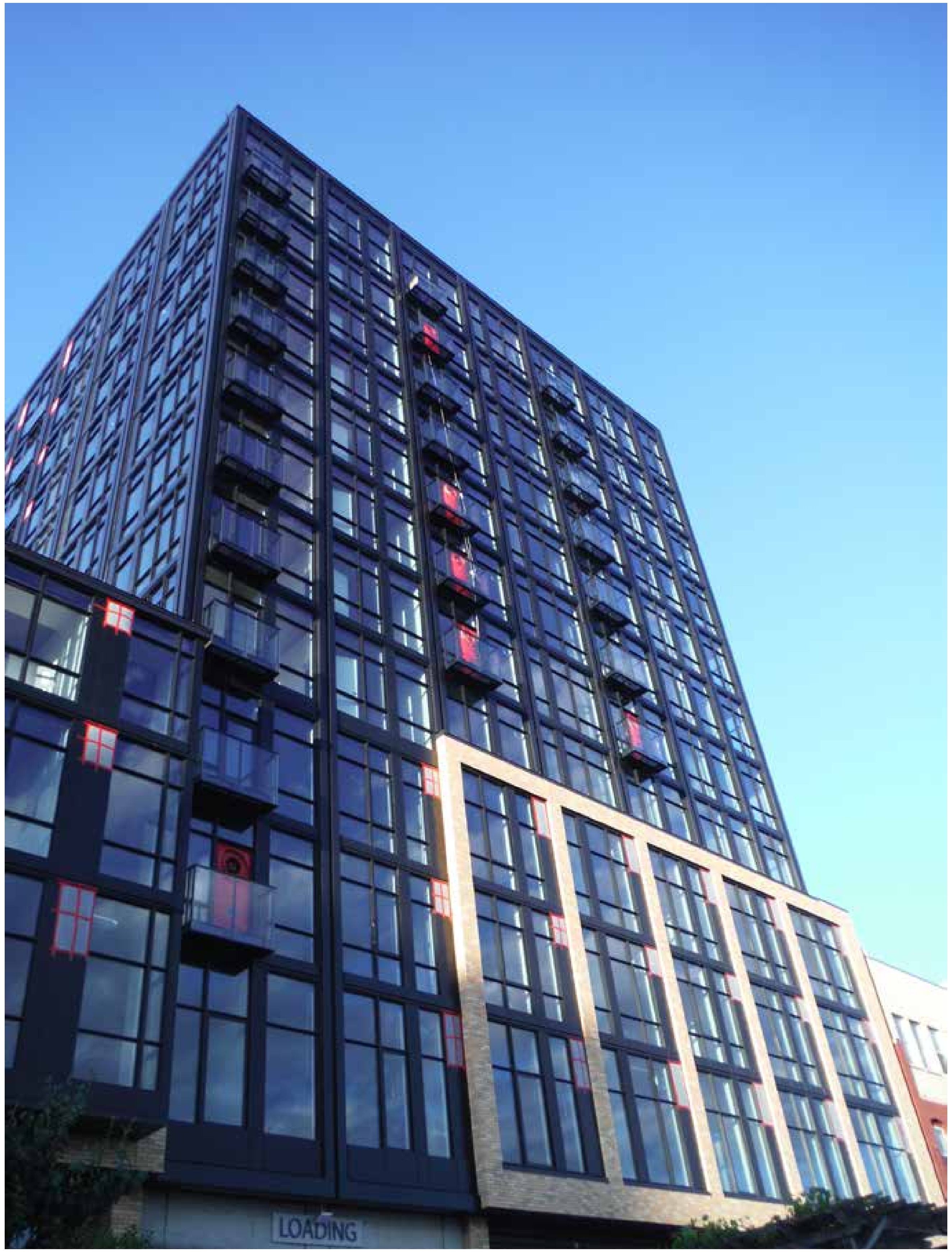
Pressure equalized testing

Tracer Gas

An alternative air leakage testing approach to using fans is tracer gas testing. Tracer gas methods measure the change in concentration of a specially chosen tracer gas. There are several variations to this approach including decay, constant injection, and constant concentration methods. The higher the air leakage, the faster the change in concentration or the higher the injection rate. To be an effective tracer, the gas should be measurable, harmless, and have no other sources during the measurement period. This approach can provide an air leakage rate at the specific operating pressure difference (including mechanical and weather forces) or at a standard fan-induced pressure difference. Tracer gas testing is far less common than testing using calibrated fans, and is more often done for research or investigation purposes following standards such as ASTM E741.



Tracer gas testing



Quantitative airtightness testing with multiple fans on a large building occurring near the end of construction

ADDITIONAL RESOURCES

AIRTIGHTNESS METRICS & UNITS

Airflow / Air Leakage (Power Law Equation):

$$Q_{\Delta P} = C \cdot \Delta P^{n}$$

Normalized Air Leakage Rate:

$$q_{\Delta P} = \frac{Q_{\Delta P}}{A}$$

Air Change Rate:

$$ACH_{\Delta P} = \frac{Q_{\Delta P}}{V} \cdot \text{(hourly airflow conversion)}$$

Equivalent/Effective Leakage Area:

$$ELA = \frac{Q_{\Delta P}}{C_D}\sqrt{\frac{p}{2 \cdot \Delta P}} \cdot 10{,}000$$

$$EqLA = \frac{Q_{10}}{0.611}\sqrt{\frac{p}{2 \cdot 10}} \cdot 10{,}000 \qquad EfLA = \frac{Q_{4}}{1.0}\sqrt{\frac{p}{2 \cdot 4}} \cdot 10{,}000$$

$$NLA_{q} = \frac{EqLA}{A}$$

Equation Parameters

$Q_{\Delta P}$	Airflow/Air Leakage at a given Pressure Difference [L/s_{Pa} or cfm_{Pa} | 1 L/s = 2.12 cfm]
$q_{\Delta P}$	Normalized Air Leakage Rate at a given Pressure Difference [$L/s{\cdot}m^2_{Pa}$ or cfm/ft^2_{Pa} | 1 L/s·m² = 0.2 cfm/ft²]
ΔP	Pressure Difference [Pascals or inH²O | 1 Pa = 0.004 in H²O]
A	Area of the Pressure Boundary [m² or ft² | 1 m² = 10.76 ft²]
V	Volume of the Pressure Boundary [m³ or ft³ | 1 m³ = 35.3 ft³]
C	Flow Coefficient [$L/s/Pa^n$ or cfm/Pa^n]
n	Flow Exponent [dimensionless]
C_D	Discharge Coefficient [dimensionless]
p	Air Density [kg/m³ or lb/ft³ | 1 kg/m³ = 0.0624 lb/ft³]
$ACH_{\Delta P}$	Air Changes/Hour at a given Pressure Difference
$EqLA$ / $EfLA$	Equivalent/Effective Leakage Area [cm² or in² | 1 cm² = 0.155 in²]
NLA	Normalized Leakage Area [cm²/m² or in²/100 ft² | 1 cm²/m² = 1.44 in²/100 ft²]

DESIGN CHECKLIST

DESIGN CHECKLIST

Date: ____________________ Design Team: ____________________

Project #: ____________________ ____________________

Building: ____________________ Building Address: ____________________

	Party Responsible	Completion Date
Air Barrier Design		
☐ Decide on the overall air barrier approach (interior/exterior/both). Consider:		
☐ Number of penetrations through the air barrier		
☐ Ease of detailing at interfaces and penetrations		
☐ Durability under the anticipated exposure conditions (UV, weather, wind pressure, etc.)		
☐ Service life of the air barrier components compared to the building		
☐ Ease of inspection, maintenance, and repair		
☐ Overall performance of the air barrier compared to target airtightness level		
☐ Material selection and compatibility of subtrates and accessories		
☐ Construction sequencing and impact on air barrier continuity (e.g., pre-stripping, etc.)		
☐ Design for resiliency in terms of accomodating larger displacement and movement at joints and interfaces		
☐ Design a continuous air barrier (i.e., without lifting the pen)		
☐ Identify critical areas for which air barrier detailing is required		
☐ Prepare 2D and 3D details to communicate the air barrier design		
☐ Consider and design for phased occupancy and compartmentalization		
☐ Coordinate/review mechanical design for ventilation and zone considerations		
Material Selection		
☐ Identify all air barrier materials and their locations		
☐ Consult manufacturer literature for compatibility, application, sequencing, etc.		
☐ Consider the five requirements of an air barrier:		
☐ Airtightness		
☐ Continuity		
☐ Strength		
☐ Rigidity		
☐ Durability		
☐ Consider the installation conditions (i.e., weather) anticipated during construction		
☐ Verify material compatibilty and adhesion at interfaces		
☐ Consider requirements for manufacturer warranties		
Preparation for Testing		
☐ Identify the test boundary or boundaries		
☐ Estimate fan sizing requirements and adjust test boundary based on equipment availability and the particular project requirements (e.g., mixed use, phased occupancy, etc.)		
☐ Include time for testing in project schedule		
☐ Contact airtightness testing firm to discuss test schedule and requirements		
☐ Consider interior coordination (i.e., access to suites, fan power requirements and layout)		
Preparation for Construction		
☐ Identify and design for penetration, detail, and interface mock-ups		

Notes:

CONSTRUCTION CHECKLIST

CONSTRUCTION CHECKLIST

Date: ____________________ Construction Team: ____________________

Project #: ____________________ ____________________

Building: ____________________ Building Address: ____________________

	Party Responsible	Completion Date
Pre-Construction Meeting		
☐ Meet with design team, contractor, and affected sub-trades to discuss air barrier strategy and details		
☐ Identify the site Air Boss or individual responsible for air barrier completeness		
☐ Ensure adequate training for Air Boss and air barrier installers		
☐ Discuss sequencing		
☐ Make clear everyone's reponsibility to report penetrations through elements of the air barrier		
☐ Discuss the quality control and assurance procedures		
Mock-ups		
☐ Prepare mock-up(s) demonstrating the air barrier details.		
☐ Perform qualitative and/or quantitative testing to verify air barrier performance and identify air leakage locations. Document any resulting design changes.		
Construction		
☐ Consult product literature prior use of all products to ensure instructions are followed		
☐ Perform adhesion pull tests at for all combinations of sealants, tapes, membranes, and substates		
☐ Involve manufacturer or certified professionals as required to establish warranty (if sought)		
☐ Ensure sub-trades (mechanical, electrical, etc.,) are aware of their responsibilty to report penetrations		
☐ Perform qualitative (smoke, infrared) testing at critical and repeated air barrier details		
☐ Notify enclosure professional when air barrier details are ready for review		
Below-Grade		
☐ Install air barrier pre-stripping before concrete work as required		
☐ Install air barrier pre-stripping before above grade framing as required		
☐ Install below-grade air barrier including tie-ins to above-grade portions and seal at all penetrations		
Above-Grade		
☐ Install air barrier pre-stripping before framing as required		
☐ Install air barrier pre-stripping as required at penetrations, details, and interfaces		
☐ Install above-grade air barrier including tie-ins to below-grade, roofs, openings and seal at all penetrations		
Services		
☐ Minimize penetrations made through the air barrier after it is installed		
☐ Communicate all air barrier penetrations, details, and interfaces not directly adressed by construction documents		
Exterior Components		
☐ Ensure all air barrier components are installed prior to installing exterior finishes		
☐ Minimize "blind" attachement through exterior finishes into air barrier		

Notes:

TESTING CHECKLIST

TESTING CHECKLIST

Date: ______________________ Testing Team: ______________________

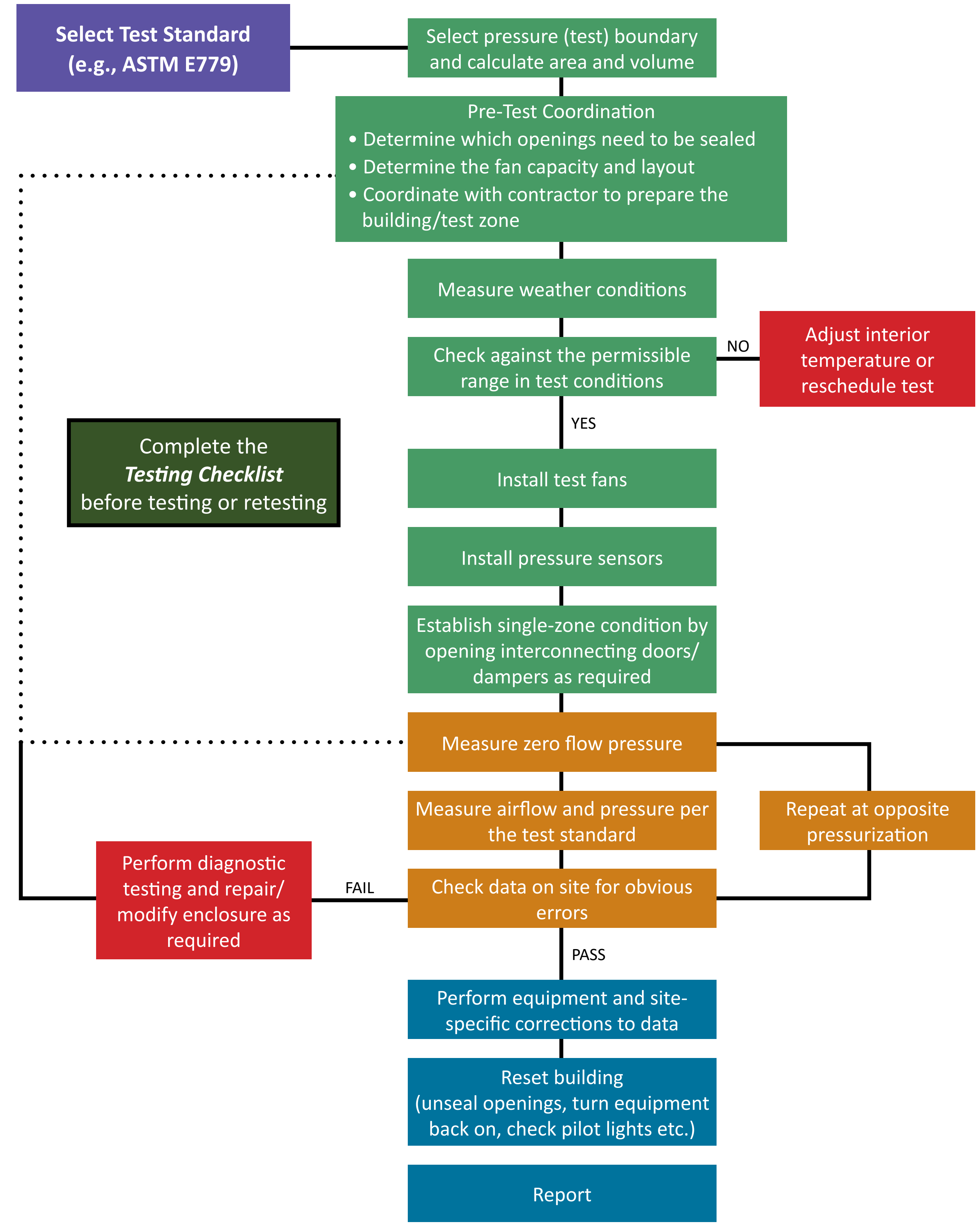
Project #: ______________________ ______________________

Building: ______________________ Building Address: ______________________

	Party Responsible	Completion Date
Qualitative Testing		
☐ Test all important penetrations, details, and interface mock-ups with smoke		
☐ Confirm air barrier continuity/repairs for all locations shown to be leaking		
☐ Document modifications/additions to original design as required		
Pre-test		
☐ Pre-test walkthrough (2 weeks prior):		
☐ Check that all air barrier components are installed and complete		
☐ Plan with contractor for sealing incomplete air barrier components as needed		
☐ Plan for sealing/pressure equalizing portions/phases of building not included in test		
☐ Confirm no work on/in building is scheduled for test day		
☐ Coordination meeting (2 days prior):		
☐ Review all temporary seals at incomplete openings and penetrations		
☐ Coordinate 120v AC 20A power supplied for each fan		
☐ Verify work on/in building is to be completely suspended during test period		
☐ Schedule site help for test days for door monitoring, general assistance, etc.		
☐ Collect keys to all doors so all areas of the building can be accessed		
Testing		
☐ Close and lock/latch exterior windows and doors or assign door monitors		
☐ Hold open all interior doors and moveable partitions		
☐ Remove at least 1% of ceiling tiles		
☐ Turn off HVAC system during test		
☐ Turn off and seal combustion equipment		
☐ Turn off and seal ventilation system equipment per test standard		
☐ Fill plumbing traps with water, including sinks, showers, toilets, floor drains, washing machines, etc.		
☐ Close and seal all vents including range hoods, dryers, fireplaces, trickle vents per test standard		
☐ Change fire alarm off or to test mode (if smoke testing)		
☐ Turn off elevators		
☐ Clean areas around fans to prevent dirt/debris from being blown around		
☐ Monitor enclosure during testing for blown open doors/windows/temperary seals		
Post-test		
☐ Complete limited qualitative testing if initial test results indicate missed target		
☐ Restore building to its original condition after test (remove temporary seals, turn on HVAC, etc.)		
☐ Complete testing report including notes/important findings and provide to design/construction team		
☐ Assist in coordination/planning for follow-up testing if needed		

Notes:

EXAMPLE AIRTIGHTNESS TEST PROCEDURE



EXAMPLE TEST RESULTS REPORTING FORM

AIRTIGHTNESS TEST REPORTING FORM

Normalized Air Leakage Rate

______ [L/s·m² @ 75Pa]

Project Address ______ Building Name ______ Submission Date ______

Related Building Permit ______ ☐ Pass ☐ Did Not Pass* Test Date ______

*Attach supporting documentation outling steps to correct deficiencies

TESTING ORGANIZATION INFORMATION

Name: ______

Company: ______

Address: ______

Phone: ______ Fax: ______ Email: ______

TEST BOUNDARY

☐ Whole Building ☐ Partial

Floor Area [m²]: ______

Enclosure Area [m²]: ______

Elevation [m]: ______

Height [m]: ______

TEST #1 ☐ Pressurize ☐ Depressurize

Test Pressure [Pa]	Corrected Flow Rate [L/s]

Wind Speed [m/s]: ______ Direction: ______
Temperature [°C] Pre: ______ Post: ______
Baseline Pressure [Pa] Pre: ______ Post: ______

TEST #2 ☐ Pressurize ☐ Depressurize

Test Pressure [Pa]	Corrected Flow Rate [L/s]

Wind Speed [m/s]: ______ Direction: ______
Temperature [°C] Pre: ______ Post: ______
Baseline Pressure [Pa] Pre: ______ Post: ______

TEST STANDARD

Standard: ______

Target: ______ L/s·m² @ ____ Pa

RESULTS

Flow Coefficient (C): ______

Flow Exponent (*n*): ______

Coefficient of Determination (R^2): ______

Air Leakage Rate: ______ L/s @ ____ Pa

Normalized Air Leakage Rate:

______ L/s·m² @ ____ Pa

Equivalent Leakage Area (EqLA): ____ cm²

Building ACH: ______ @ ____ Pa

NOTES

By submitting this form, the applicant declares that all requirements of the applicable test standard have been met, unless otherwise noted.

TEST STANDARDS COMPARISON

	CGSB 149.10 - M86	CGSB 149.15 - 96	ASTM E 779 - 10	ASTM E 1827 - 11	ISO 9972:2012	USACE	ABAA
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	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	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 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 "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	> 10
Preferred Test Direction	Depressurize	Either	Both	Either	Both	Both	Either
Acceptable Test Direction	Depressurize	Either	Both Required	Either	Either	Both (either for very large	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	
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. $R^2 > 0.98$	0.45 ≤ 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 to ensure that the interior pressure differs by no greater than 10% of the measured test pressure.

FURTHER READING

Whole-Building Airtightness Standards

CAN/CGSB 149.10 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method"

CAN/CGSB 149.15 "Determination of the Overall Envelope Airtightness of Buildings by the Fan Pressurization Method Using the Building's Air Handling Systems"

ASTM E779 "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization"

ASTM E1827 "Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door"

US Army Corps of Engineers (USACE) "Air Leakage Test Protocol for Building Envelopes"

Airtightness Testing and Measurements Association (ATTMA) TSL2 (UK) "Air testing standard for non-dwellings"

National Environmental Balancing Bureau (NEBB) "Procedural Standards for Building Enclosure Testing"

ASTM E741 "Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution"

Air Leakage Detection

ASTM E1186 "Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems"

Material Airtightness Standards

ASTM E283 "Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen"

AAMA/WDMA/CSA 101/I.S.2/A440 "NAFS – North American Fenestration Standard/Specification for windows, doors, and skylights"

NFRC 400 "Procedure for Determining Fenestration Product Air Leakage"

ANSI/DASMA 105 "Test Method for Thermal Transmittance and Air Infiltration of Garage Doors"

Additional Material Resources

Canadian Construction Materials Centre (CCMC) Registry

Organizations

US Army Corps of Engineers (USACE)

Air Barrier Association of America (ABAA)

National Environmental Balancing Bureau (NEBB)

Airtightness Testing and Measurements Association (ATTMA) in the UK

Design Guides and Other Resources

Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings published by FPInnovations, BC Housing, and the Canadian Wood Council

Building Enclosure Design Guide published by BC Housing

Illustrated Guide-Energy Efficiency Requirements for Houses in British Columbia published by BC Housing

Canadian Home Builder's Association Builders' Manual published by the Canadian Home Builders' Association

Residential Construction Performance Guide published by BC Housing

Builder's Guide to Cold Climates published by Building Science Corporation

Pathways to High-Performance Housing in British Columbia published by FPInnovations

Air Leakage Control in Multi-Unit Residential Buildings published by CMHC

Study of Part 3 Building Airtightness published by the National Research Council of Canada

Building Science Digest-014: Air Flow Control in Buildings published by Building Science Corporation

Building Science Digest-104: Understanding Air Barriers published by Building Science Corporation

Towards Airtightness - The Contractor's Role in Designing and Constructing the Air Barrier System published from the Building Enclosure Science & Technology 3 conference

Retrotec testing equipment supplier website: www.retrotec.com

The Energy Conservatory equipment supplier website: www.energyconservatory.com

See Also Appendix A | Building Airtightness Targets in Codes and Standards Across B.C.

APPENDIX A | BUILDING AIRTIGHTNESS TARGETS IN CODES AND STANDARDS ACROSS B.C.

This appendix outlines the current whole-building airtightness performance targets that may be applicable across British Columbia. **Refer to the *Illustrated Guide – Achieving Airtight Buildings*, published by BC Housing, for information and guidance on designing, constructing, and testing airtight buildings.**

An airtight building enclosure is an important part of a modern building. It can increase energy efficiency, improve durability, and allow greater control over occupant comfort and indoor air quality. Airtightness requirements in building codes and energy performance standards are becoming increasingly stringent across North America. Historically, many codes and standards have included only requirements for the air permeance of materials and components in building enclosure assemblies, but experience has shown that this approach is often insufficient to achieve higher levels of airtightness. More recent codes and standards have now begun to also include targets for whole-building airtightness as a way of achieving consistently higher levels of performance.

To achieve these targets, airtightness must be considered through all phases of a building project, from design through construction to completion. To confirm these targets have been met, whole-building airtightness testing is performed.

Codes and standards typically specify airtightness performance targets using either of two metrics: Air Changes per Hour (ACH) or Normalized Air Leakage Rate (in L/s per m^2 of building enclosure area). Both metrics are reported at a specific pressure difference, usually 50 or 75 Pascals (Pa). The following table summarizes the mandatory and non-mandatory target maximum air leakage rates found in the various codes and standards that may be applicable across British Columbia. It is important to note that the table does not represent all available codes and standards in North America and is not able to capture specific intricacies which may be relevant to a given project. For more information on specific testing requirements and performance targets, always refer directly to the referenced code or standard.

The following building code and energy performance standards are not listed in the following table and do not currently include whole building airtightness requirements or targets.

- BC Building Code Part 9.36 current base prescriptive air barrier requirements
- 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

Air Changes per Hour versus Air Leakage Rate | Codes and standards may specify airtightness targets using an air change rate or an air leakage rate. While it is possible to convert from one airtightness metric to the other for a specific building, it is not possible to provide a single conversion factor that applies to all buildings. This is because the conversion is a function of the volume to enclosure area ratio which varies with building height, shape, etc.

Standard	Buildings Where Testing is Required	Mandatory Target?	Airtightness Performance Target	Referenced Test Standard
ASHRAE 90.1-2016	All (except low-rise residential) for possible compliance path	Yes[1]	2.0 L/s·m^2 @ 75 Pa	ASTM E779, ASTM E1827
BC Building Code Energy Step Code (2017)	Part 9 Residential	Yes (except Step 1)	Varies[2]	CAN/CGSB 149.10, ASTM E779, USACE
	Part 3 buildings	No[3]	Max TEDI/EUI[4]	ASTM E779, USACE
Vancouver Building By-Law (2014)	Part 9 Residential (1- & 2-family dwellings)	Yes[5]	3.5 ACH_{50}	None
Vancouver Green Building Policy for Rezonings (2017)	Near Zero Emission Buildings (Passive House)	No	0.6 ACH_{50} (if Passive House)	EN 13829 / ISO 9972
	Low Emission Green Buildings	No	2.0 L/s·m^2 @ 75 Pa	ASTM E779 or equivalent
EnerGuide 15.1 (2015)	Part 9 Residential	No	None	CAN/CGSB 149.10-M86
Energy Star® Homes 12.6 (2015)	Part 9 Residential Attached	Yes	3.0 ACH_{50} or 1.32 L/s·m^2 @ 50 Pa	CAN/CGSB 149.10-M86
	Part 9 Residential Detached	Yes	2.5 ACH_{50} or 0.93 L/s·m^2 @ 50 Pa	CAN/CGSB 149.10-M86
Energy Star® MFHR 1.0 (2015)	Part 3 Residential (Suite)	Yes	1.5 L/s·m^2 @ 50 Pa[6]	ASTM E779 2010, ASTM E1827
IECC (2012)	Part 3 Commercial[7,8] for possible compliance path	Yes[1]	2.0 L/s·m^2 @ 75 Pa	ASTM E779 or equivalent
	Part 9 Residential[9]	Yes	3.0 ACH_{50}	None
IGCC (2012)	All buildings	Yes	1.25 L/s·m^2 at 75 Pa	None
LEED BD+C	Seeking Residential Air Infiltration Credit	Yes	Varies[10]	None
	Seeking Environmental Tobacco Smoke Control Credit	Yes	1.17 L/s·m^2 @ 50 Pa[6]	None
Net Zero Energy	All (testing recommended)	No[11]	1.0 ACH_{50}	None
Passive House	All	Yes	0.6 ACH_{50}	EN 13829 / ISO 9972
R-2000 Standard (2012)	Part 9 Residential	Yes	1.5 ACH_{50} or 0.7 cm^2/m^2 @ 10 Pa	CAN/CGSB 149.10-M86
PHIUS+ 2015	Non-combustible 5+ Storeys	Yes	0.4 L/s·m^2 @ 50 Pa or 0.5 L/s·m^2 @ 75 Pa	None
	All other buildings	Yes	0.25 L/s·m^2 @ 50 Pa or 0.4 L/s·m^2 @ 75 Pa	None

1. *Further testing and remedial measures required to reduce air leakage when target is exceeded.*
2. *Targets based on the performance level (Step) and Climate Zone.*
3. *Measured airtightness to be reflected in energy model.*
4. *TEDI, Thermal Energy Demand Intensity; EUI, Energy Use Intensity (kWh/m^2 per year).*
5. *Training required when target is exceeded, remedial measures required to reduce air leakage if greater than 5.5 ACH_{50}.*
6. *Air leakage testing only required for a specific subset of individual units, not the entire building.*
7. *Commercial buildings under the IECC includes nearly all large buildings, including multi-unit residential buildings over 3 stories*
8. *Target applies only to ASHRAE/IECC Zones 4-8.*
9. *Target applies only to ASHRAE/IECC Zones 3-8.*
10. *Target varies based on Climate Zone and desired LEED points.*
11. *Voluntary target set on a case-by-case basis to meet net zero energy use.*

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NOTES

BC HOUSING

Research Centre
1701 – 4555 Kingsway
Burnaby, BC V5H 4V8
Phone: 778 452 6454
Toll-free: 1 866 465 6873
Email: technicalresearch@bchousing.org
www.bchousing.org