PLAYBOOK

Planning Airtight Buildings

From ZEBx's Net-Zero Energy-Ready Playbook Series

May 2021

Overview

Why Build Airtight Buildings?

Building airtightness reduces energy consumption by minimizing heat loss via air leakage through the building enclosure. For this reason, many North American building codes have set airtightness targets as part of high-performance building standards. In addition to energy efficiency, airtight buildings experience benefits of improved moisture management, thermal comfort, indoor air quality, and quality assurance.

Less moisture transfer

Air movement is often a significant mechanism for moisture transfer in building enclosure systems. When warm and relatively moist air meets a colder surface in a building enclosure assembly it can condense, possibly leading to mould and deterioration. Airtight building enclosures reduce the risk of water vapour transport and condensation within the assembly, improving the durability of the building.

Better thermal comfort

Air leakage into buildings can also be a cause of thermal discomfort. Airtight buildings can improve occupant comfort by reducing drafts.

Better indoor environmental quality

Air movement can carry odours, noise, airborne contaminants, and pests across the building enclosure and between internal building zones. Airtight building enclosures and internal compartmentalization help to reduce the unwanted transfer of these elements, improving the indoor environmental quality for building occupants.

Improved quality assurance

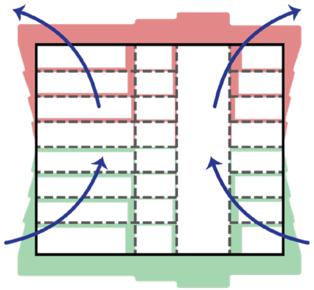
An additional benefit of airtightness is enhanced quality assurance in the construction of a building. For instance, the air barrier system often provides additional functionality such as water control, so attention to detailing the air barrier system will also benefit water penetration detailing.

Myths about airtight buildings

Airtightness does not mean a building will be stale or stuffy inside. Mechanical ventilation systems are designed to provide fresh air to a building, but it can be difficult to predict the movement of air in a leaky building. Airtight buildings allow fresh air to be more efficiently supplied by a properly sized ventilation system, and for stale air to be exhausted to the outdoors. In addition, airtight buildings also do not negate the potential to use operable windows and doors to provide natural ventilation to building spaces.

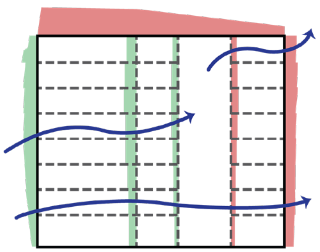
Causes of Air Leakage

Air leakage is caused by pressure differences across the building envelope and between interior zones of the building, combined with the presence of pathways for air to travel through these boundaries. These pathways are discontinuities in the air barrier system, either around the enclosure or as part of interior compartmentalization strategies. There are three primary forces which create pressure differences on and within buildings, resulting in a map of cumulative pressures.



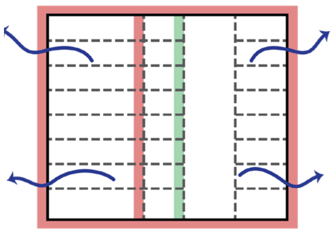
1. Stack Effect

Stack effect creates pressure differences in buildings due to a difference in air density between the interior and exterior. During colder weather, these pressure differences cause air infiltration at lower areas of the building and exfiltration at upper areas. In warm weather the pressure difference is reversed, as is the direction of air flow. As a result, exfiltrates at lower areas of the building and infiltrates at upper areas.



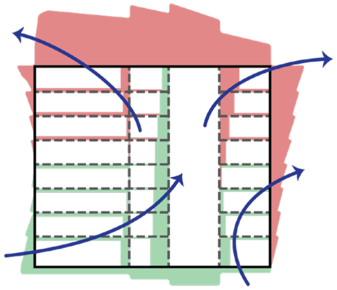
2. Wind

Wind also creates pressure difference across the building enclosure as well as between internal zones. While wind effects can be highly complex, generally, positive pressures are generated on the windward side, forcing air into the building, while negative pressures are generated on the roof and leeward sides, drawing air out of the building. Wind can create very high pressures across the building enclosure, although these pressures tend to be relatively short in duration.



3. Mechanical Systems

Mechanical systems supplying or exhausting different amounts of air from the building can create a positive or negative pressure difference. These types of systems are called unbalanced and may include designs such as corridor pressurization, or an exhaust only system such as bathroom fans or range hoods. While in some cases these pressure differences are created intentionally to control transfer of contanminants and drafts, these pressure differences can also create air leakage between zones and across the building enclosure.

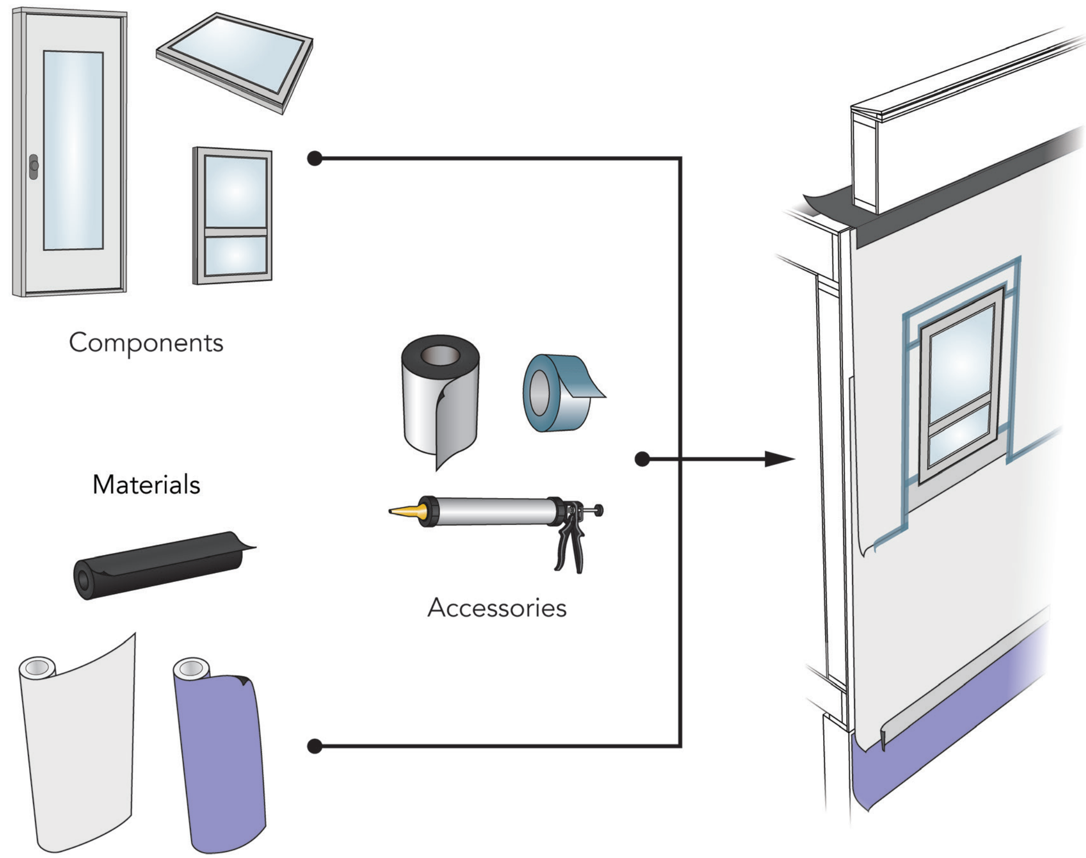


Cumulative Pressure

The pressure differences generated by the stack effect, mechanical systems, and wind add to create a cumulative pressure map across the building enclosure and between internal zones. These pressure differences, along with the presence of pathways for air movement, are the source of air leakage in buildings.

Designing Air Barrier Systems

Air barrier systems are designed to minimize air leakage into, out of, and within buildings. Air barrier systems comprise a combination of materials such as building wrap and membranes, components such as windows and doors, and accessories such as tapes and sealants. It is not enough to select airtight materials to construct an airtight building. Most air leakage occurs around penetrations and at interfaces between air barrier elements, and they must be carefully detailed to create an airtight system. To reflect this, building codes and standards have shifted from prescriptive requirements for air permeance of building materials and components towards whole-building airtightness testing and performance targets.



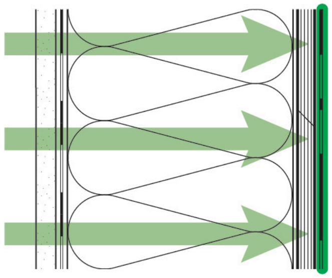
The air barrier is a system that is comprised of air barrier materials, components, and accessories. These elements must be carefully selected and detailed to achieve whole-buildings airtightness.

Airtightness testing in British Columbia

In municipalities that have adopted the BC Energy Step Code (Step Code), new buildings must be tested for airtightness. If the building design targets a Step Code level higher than the base level, the as-built airtightness test results must be incorporated into the building's energy model to determine the expected energy consumption.

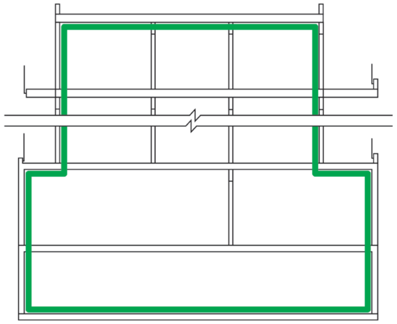
Design Principles

To perform successfully, there are five key principles to designing an effective air barrier system:



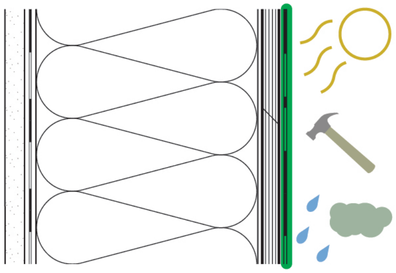
Air Impermeability

All materials, components, and accessories making up the air barrier system must resist air flow. Building codes and standards typically define performance levels depending on the type of product or system. Products such as membranes and tapes are typically orders of magnitude more airtight than the finished building air barrier system.



Continuity

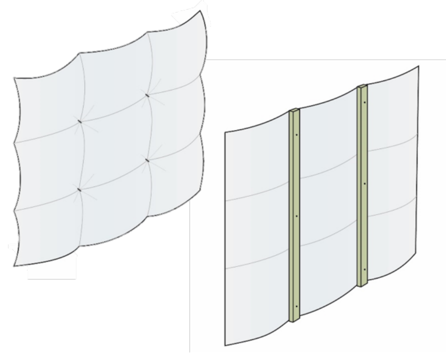
Air barrier elements must be detailed so that the air barrier system is continuous at transitions, around penetrations, and at interfaces in the enclosure. This principle is the most critical to performance and is also the most challenging to achieve.



Durability

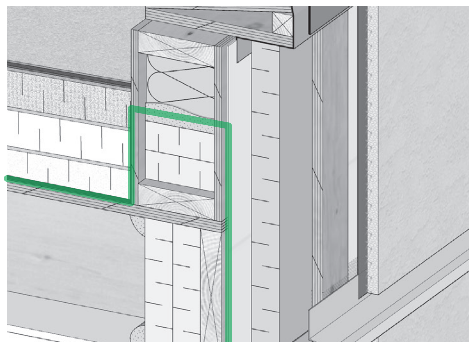
The air barrier system should be designed to last for the life of the building. Materials selected for the air barrier system must be able to withstand exposure to mechanical abrasion, wind pressures, UV light, and moisture, during construction and building operation. Further, materials that interface must be chemically compatible and not cause degradation.

Because maintenance and renewal of the air barrier system will likely be required during the life of the building, it is important to consider the ease of access when designing the building enclosure. Air barrier materials should be selected that are intended to last as long as the materials that cover them, for example by choosing a durable air barrier membrane and sealants when using a cladding with a longer service-life.



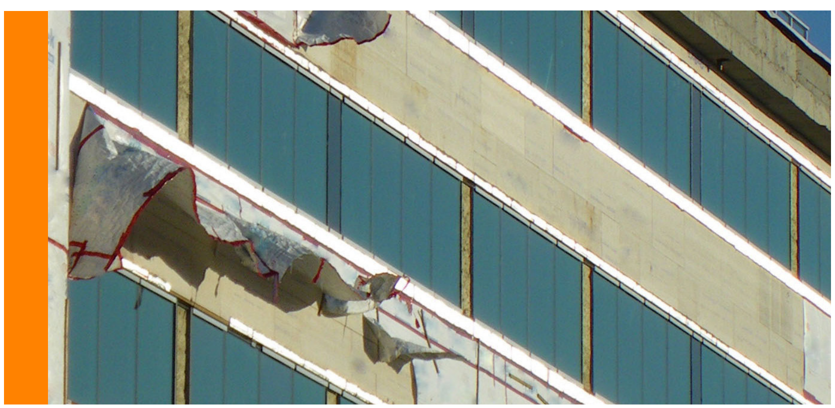
Strength and Stiffness

Wind, thermal expansion, and building deflections may create stresses that the air barrier should accommodate without significant damage to the air barrier system. Interfacing materials in the air barrier system must also be compatible so that they adhere where intended.

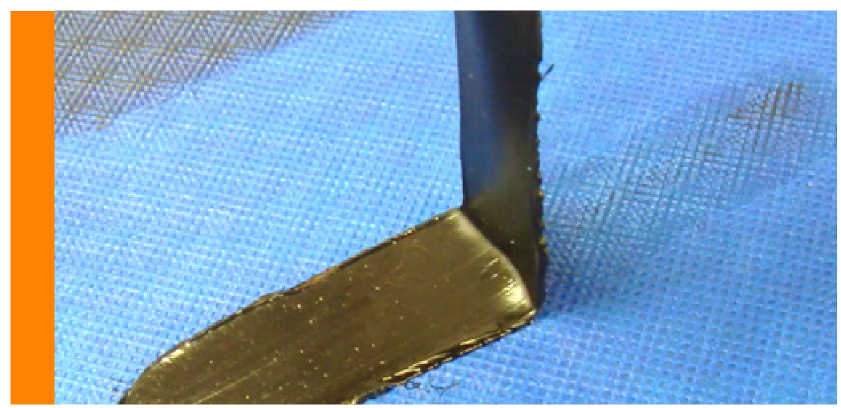


Constructability

Performance of the air barrier system is highly dependent on the quality of construction. Air barrier system design must consider installation requirements when selecting materials, such as the need for primers, application temperatures, adhesion to wet substrates, and substrate preparation. Materials should be readily available and familiar to the local industry. The design of transitions in the air barrier system should consider how construction will be coordinated and sequenced.



Exterior air barrier system damaged during construction.



Incompatible air barrier materials fail adhesion test.

Design Approaches

There are a wide range of design approaches for air barrier systems which apply the key design principles using various combinations of air barrier materials, components, and accessories. Four basic steps can be followed to develop a design. The air barrier design process is iterative and may require revisiting earlier steps.

1 Choose the location of the air barrier system

Air barrier systems for opaque enclosure assemblies can be grouped into two types: **interior** and **exterior** systems. These types describe where the primary air barrier components are located within the enclosure assembly. Both approaches must be designed with airtight details around penetrations and at transitions such as walls to roofs and balcony slabs. Exterior air barrier systems are often simpler to construct, as there are fewer interfaces and penetrations at the exterior of assemblies. Materials used for exterior systems are also generally more robust.

2 Select primary air barrier materials

Air barrier systems for opaque enclosure assemblies often use a combination of membranes, impermeable rigid materials, and tapes as the primary materials and accessories. Mass concrete can be part of an air barrier system, as can some types of air impermeable insulation, including extruded polystyrene boards with taped joints and some spray foams. In transparent assemblies, glazing systems are part of the air barrier system. Key design principles to consider when selecting air barrier materials are air impermeability, durability, strength, and stiffness.

3 Consider other functions of air barrier materials

The design of the air barrier system should consider its integration with other functions of the building enclosure system. For example, another function of the building enclosure is moisture management, including water control, vapour control, and drying capacity. Some air barrier elements can also be designed to serve as the water resistive barrier in an assembly. When choosing the vapour permeability of air barrier materials, vapour movement within the system should be considered to avoid condensation risks and associated durability concerns.

4 Design air barrier details

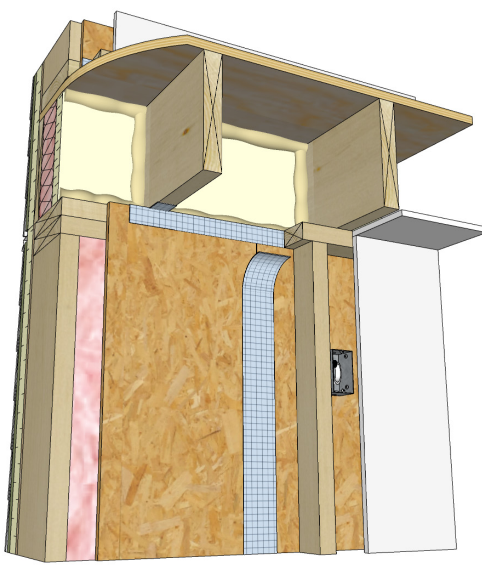
Air barrier details are crucial to air barrier system performance. Details should be designed to create a continuous air barrier system around openings, penetrations, and transitions in the building enclosure. In addition to continuity, air barrier details should integrate the other four key design principles for air barrier systems. Details must utilize air impermeable materials and be constructable within the constraints of available construction techniques and project sequencing. Thoughtful use of reinforcing materials and transition membranes can help achieve strength, stiffness, and durability in the air barrier system. Detailing techniques are discussed later in this playbook.

Design Examples

Interior Air Barrier Systems

Sealed Polyethylene Approach

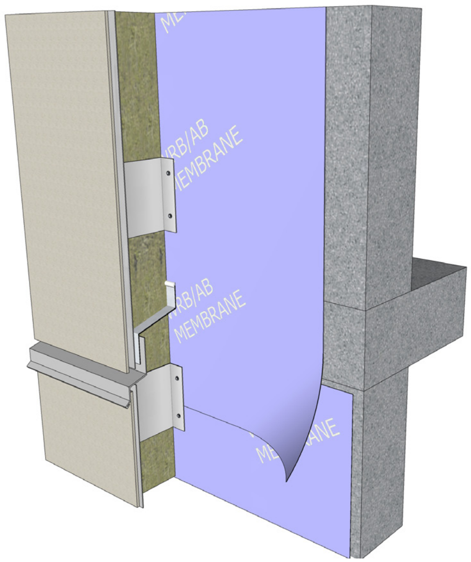
In this system, polyethylene sheets (typically used for vapour control in wood-frame construction) are sealed to the interior framing. The sheets must be taped or sealed around interior service penetrations, and accessories like spray foam may be used where it is difficult to install the polyethylene. Interfaces between elements such as floors, interior walls, and staircases make this approach difficult to implement successfully, especially in large buildings or where high-performance airtightness is required.



Taped Interior Sheathing Approach

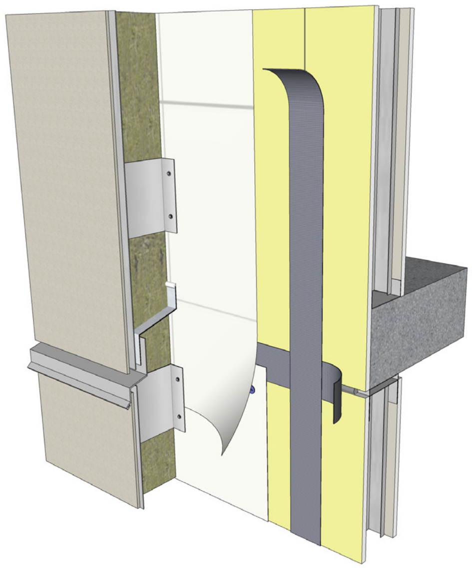
In this approach, oriented strand board (OSB) or plywood sheathing is fastened to the interior framing and joints between the sheets are sealed with an air impermeable tape. Like the sealed polyethylene approach, continuity must be maintained at elements that interface with exterior walls. In this approach, a service wall can be constructed interior of the wood sheathing to accommodate utilities.

Exterior Air Barrier Systems



Sheathing Membrane Approach

This system utilizes mechanically fastened, self-adhered, or liquid-applied airtight membranes on the exterior sheathing. Sealant, tape, and strips of self-adhered membrane are used to seal around penetrations and transitions. Mechanically fastened membranes must be adequately attached and supported to prevent tearing. Exterior membranes often also serve as the water resistive barrier in the building enclosure assembly and must be designed and constructed as such.



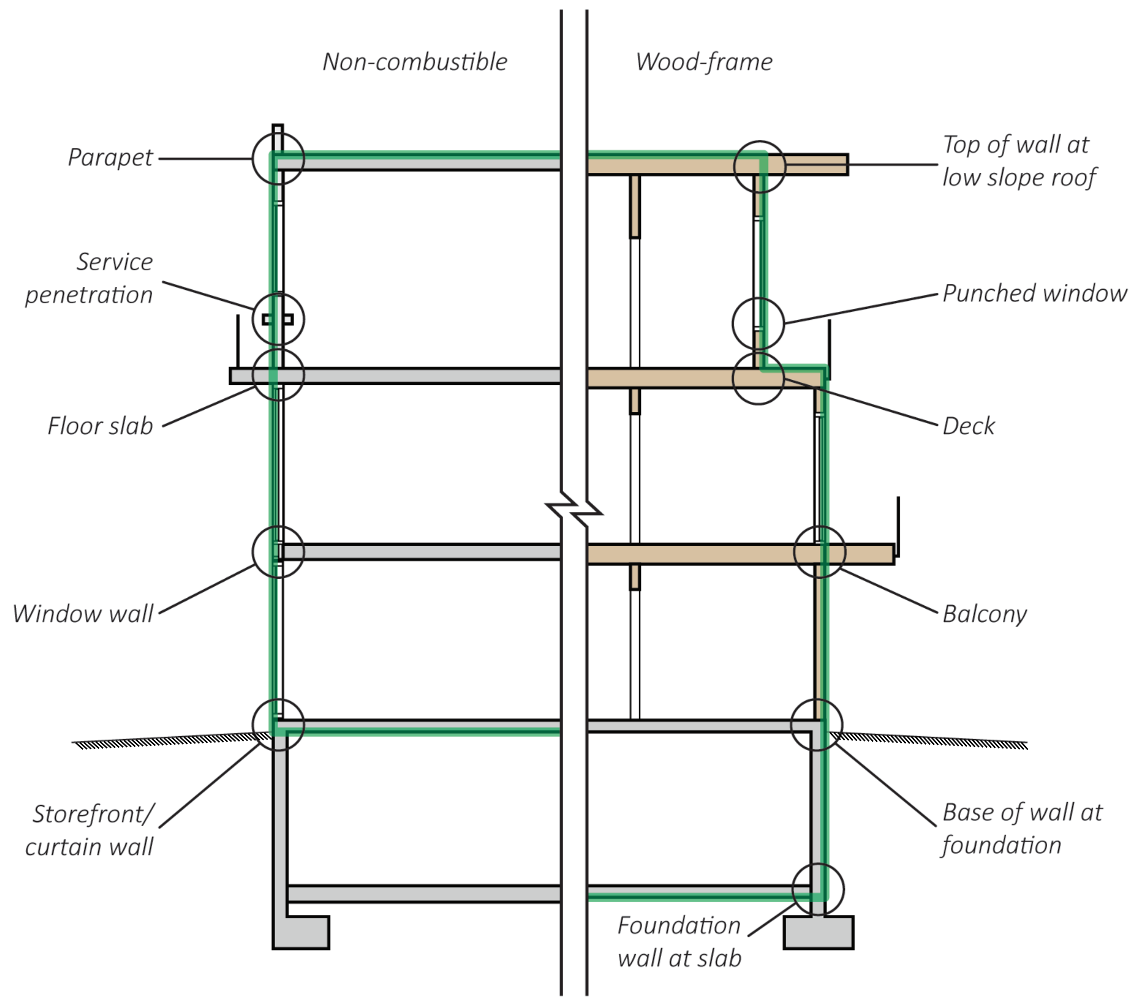
Sealed Exterior Sheathing Approach

In this system, exterior sheathing is taped at the joints to act as the air barrier. Like the sheathing membrane approach, air barrier accessories must be used to seal around penetrations and transitions.

Detailing Techniques

Interfaces and penetrations in the building enclosure are locations where discontinuities in the air barrier system are most likely to occur. As such, detailing how the system will be constructed at these enclosure details is often the most important aspect of designing an airtight building enclosure. Enclosures have numerous locations that require attentive detailing, including above-grade to below-grade transitions, service penetrations, windows and doors, roof-to-wall interfaces, and balconies. Even a relatively straightforward project can have many details that need to be designed.

It is important to consider the constructability of building enclosure details in addition to their airtightness performance. Details may need to be constructed in several steps, and these tasks should be coordinated between different trades. For example, air barrier system transitions in wood-frame construction may involve installing pre-striped membrane between framing members, requiring coordination of the framing and membrane installers. An easily constructed detail is much more likely to be built successfully.

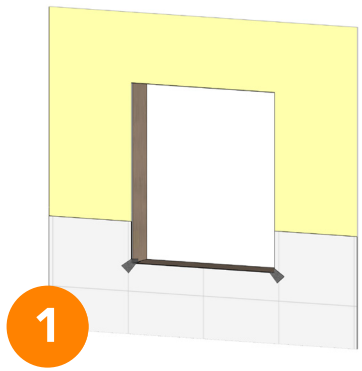


The building enclosure has many interfaces and penetrations that intersect the air barrier. These are areas where discontinuities are likely to occur, and should be detailed to ensure continuity.

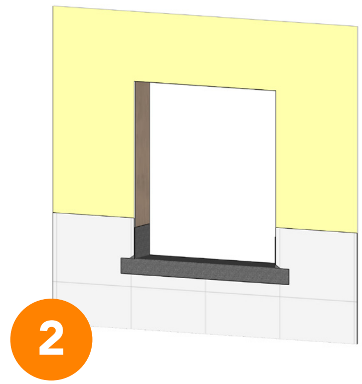
3D Sequence Drawings

Air barrier system details must be effectively communicated to several designers and builders on a given project, both during design development and as part of the construction documents. 3D sequence drawings help communicate how details are constructed by showing each step of their assembly. These drawings illustrate air barrier system installation details better than 2D drawings and provide instruction to the relevant trades.

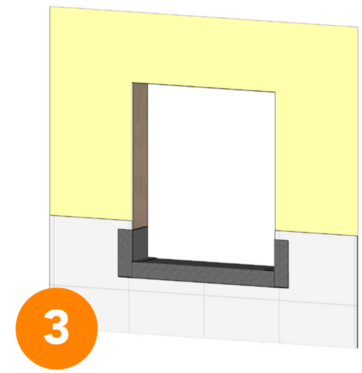
This set of 3D installation sequence drawings illustrates how an air barrier and water resistive barrier should be installed around a punched window.



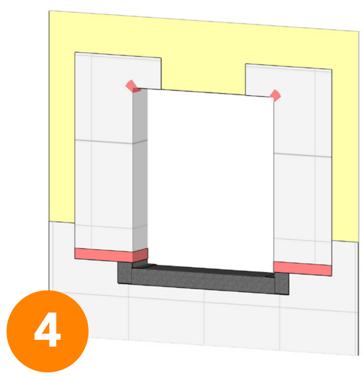
Lower membrane and self-adhered gussets at corners



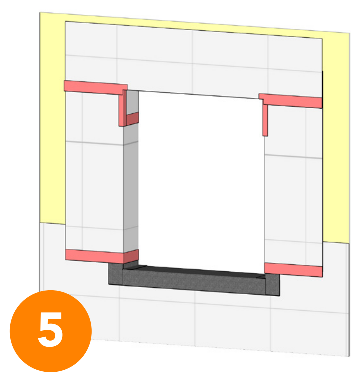
Self-adjered sill membrane with upturn at jambs



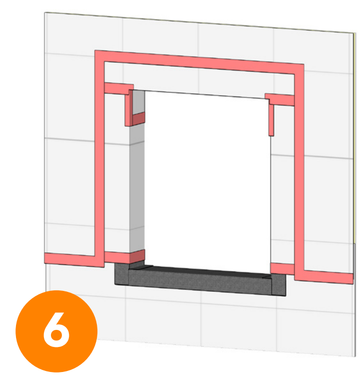
Self-adhered jamb membrane



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

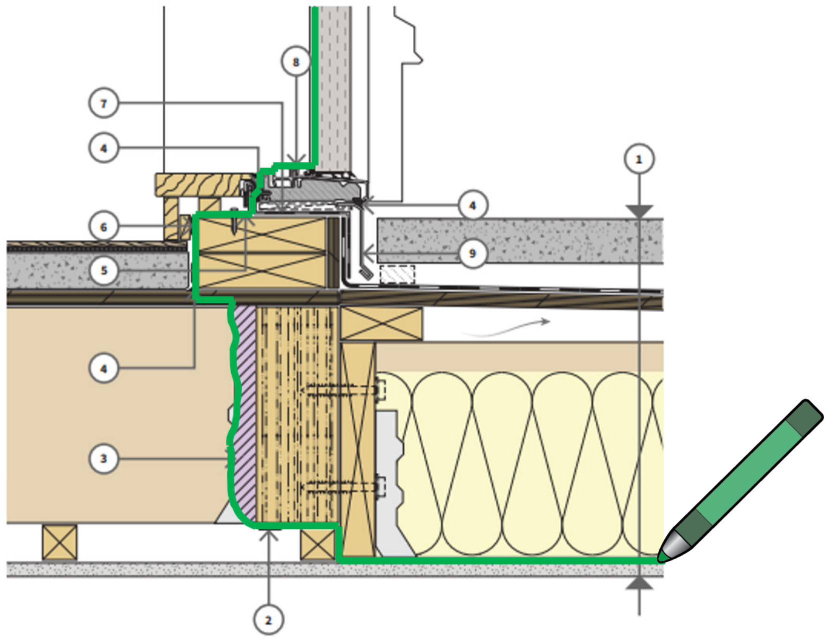
Detailing and Documentation

The "Pen Test"

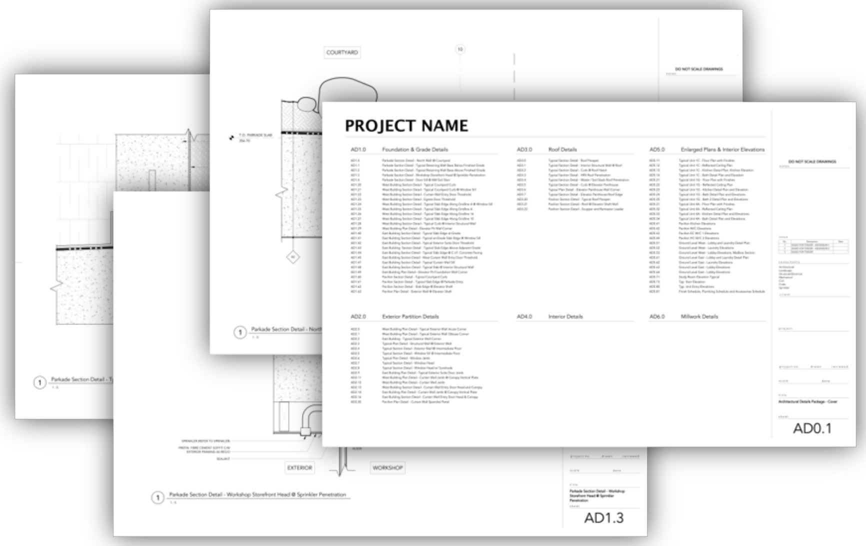
A technique to assess the continuity of the air barrier system is the "pen test." A designer should be able to trace the air barrier system on building plans, sections, and details without lifting their pen off the page as a way of demonstrating continuity. It is also important to remember that the continuity shown in 2D drawings must be translated into 3D on site.

Documenting the Air Barrier System

The air barrier system should be shown in architectural details and be easily identifiable to the reader. This helps avoid oversight during construction that could result in discontinuities. Additionally, airtightness testing specifications should be included in the construction documents. These specifications should outline the preparatory work required for airtightness testing, what zones of the building will be included in the test, and what submittals and performance targets are required for the test.



The pen test is used to ensure continuity of the air barrier at transitions like this one, located between a roof deck to door sill.



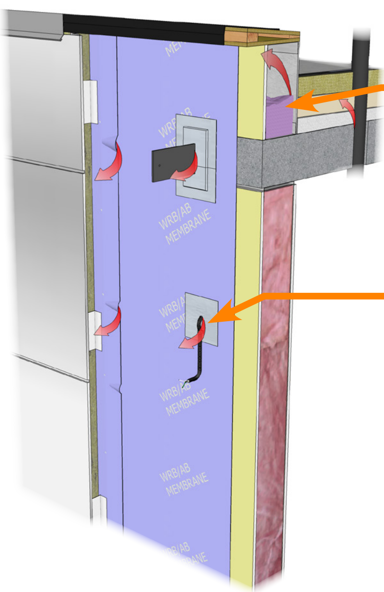
Archtectural details should identify the location of the air barrier system in enclosure assemblies.

Quality in Construction

The performance of the air barrier system ultimately depends on the quality of construction on-site. Thoughtful coordination and sequencing, quality assurance and quality control, and skilled trades are required to achieve an airtight building. Construction mock-ups, mid-construction airtightness testing, a construction stage plan, and designating an “air boss” are strategies that can help communicate construction requirements and ensure quality throughout the process.

Coordination and Sequencing

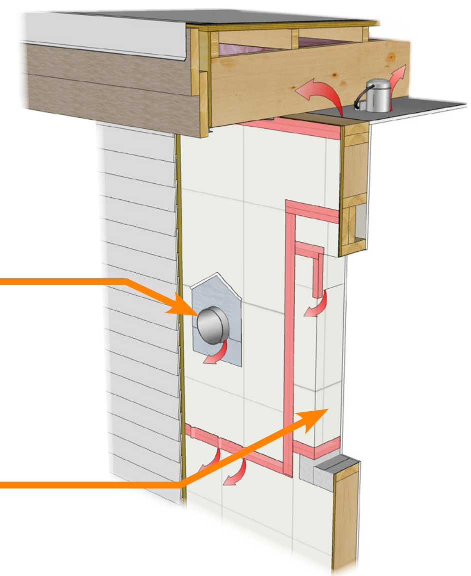
During construction, tasks associated with the installation of the air barrier system will happen at different times. It is important to coordinate and sequence these tasks to ensure they integrate properly with the air barrier system.



Building components outside the air barrier system, such as parapets and balconies, are often constructed at the same time as the primary structure. Allowances should be made to ensure continuity of the system through these elements.

Service penetrations through the exterior wall may occur at any time throughout construction, and coordination is required to ensure these holes in the air barrier system are adequately sealed.

Rough openings and window installation are other tasks that are often completed before the air barrier system is in place. They should be detailed so that they can be tied in with the system at a later stage.



Importance of QA & QC

It is important to have quality assurance (QA) performed by the building enclosure consultant and on-site quality control (QC) of air barrier system construction. It is the responsibility of the trades to successfully install the system by carefully referencing details and descriptions provided in the design documents. Regular field reviews of the air barrier system during construction, as well as mid-construction airtightness testing, will provide feedback in a timely and efficient manner so that deficiencies can be resolved before the air barrier system is no longer accessible.

Trade Familiarity and Training

Successful installation of the air barrier system is skilled work. Trades must be knowledgeable on how to apply membranes, tapes, and sealants, including how weather constraints and requirements for substrate preparation can impact these materials. They should also understand installation sequencing to efficiently and effectively complete details. Hiring skilled trades, providing training on materials, and demonstrating construction techniques can make a crucial difference in achieving airtight construction.

Air Barrier System Mock-Ups

Air barrier system mock-ups can be valuable to achieving the airtightness requirements of a project. Mock-ups involve completing a sample portion of the building enclosure detailing before the main installation, either as a part of the building or a separate temporary structure. They provide an opportunity for the design team to ensure the installation meets the project requirements, and they also allow the construction team to become familiar with detailing techniques and test material compatibility. Any required changes to the design or construction of the air barrier system can be made before a larger portion of the work is completed. Mock-ups can also serve as a training opportunity if trades change or if trades need a reminder on certain critical installation procedures or details. In some cases, mock-ups can also be tested to confirm performance.

Air barrier system mock-up with penetrations and cladding attachment system.

Mid-Construction Airtightness Testing

Mid-constructing airtightness testing is a good opportunity to identify deficiencies in the air barrier system before it is covered by exterior finishes. Mid-construction tests can include testing isolated elements of the air barrier system, such as a window installation, or could include an entire zone of the building where construction is complete. Testing can identify issues on a macro scale and may give an early indication of the building's performance relative to the performance targets.

It is much easier to make repairs to the air barrier system during construction while most of the air barrier components are exposed. Repairs after construction is complete can be expensive as they may require interior and exterior finishes to be removed.

Trades training at a prefabrication facility.

Construction Stage Services Plan

A construction stage services plan should be developed for the air barrier system to help establish roles and responsibilities of the project team with respect to airtightness. The plan provides written guidelines to coordinate the quality assurance process for the air barrier system between different trades, designers, and consultants. It should outline:

- Lines of communication for construction and review of the air barrier system
- Any trades training that will occur before installation of the air barrier system
- When field reviews of the air barrier system will occur
- Which elements of the air barrier system will be constructed as mock-ups before installation
- Which elements of the air barrier system will be reviewed
- The extent and timing of the mid-construction airtightness test
- The extent and timing of the as-built airtightness test

Designating an "Air Boss"

A useful approach to support the successful implementation of the air barrier system is to designate an on-site "air boss." This person should have a good understanding of the air barrier system and detailing for the project, requirements for airtightness testing, and a general understanding of the principles and approaches to air barrier system design. The air boss takes on responsibility for regularly reviewing system installation and offers immediate guidance and instructions where needed. They also coordinate tasks between different trades to ensure the air barrier is completed without damage and will take the lead on coordinating the airtightness testing.

Airtightness Testing

Once the air barrier system is complete, the final step of quality assurance is an as-built airtightness test. All new buildings constructed in municipalities that have adopted the British Columbia Energy Step Code are required to undertake quantitative airtightness testing for code compliance. Part 3 buildings targeting Step 2 or higher are required to update the airtightness value in the building energy model with the as-built airtightness measurement to show compliance with the Step Code target. Individual authorities having jurisdiction (AHJs) may require different steps to be taken if an airtightness target is not met. This test must be accommodated by other on-site activities as it may require access to all areas of the building, depending on the type of test.

Blower Door Testing

The most common way to test airtightness is blower door testing. These tests use calibrated high-power fans to pressurize or depressurize the building relative to the exterior conditions and measure the rate of air leakage from the building.

- Fans are installed in doors or other suitable openings to supply or exhaust air from the building.
- For large buildings, multiple fans at multiple locations may be required to attain a uniform pressure across the entire test zone.
- Building openings must be prepared according to the type of test and compliance standard. The building may be tested in an "as-operated" condition with doors and windows closed and mechanical dampers closed, or it can be tested as "enclosure only" with mechanical penetrations entirely sealed.

Blower door tests start with establishing testing zones. Airtightness testing zones are areas in which the pressure does not vary significantly and are generally enclosed by a continuous air barrier system.

- For small buildings, it is relatively straightforward to establish the whole building as a single test zone.
- For large buildings or buildings with isolated zones (such as commercial retail units in a mixed-use building), the building may be divided into multiple zones due to building geometry.
- Buildings with multiple zones may develop alternate test methods with approval from the AHJ, such as:
  - *For tall buildings, a sampling of floors can be isolated and tested.*
  - *For large buildings, or buildings with phased occupancy, the building can be tested in portions.*
  - *For buildings with compartmentalization or isolated zones, openings may be installed in interior partitions or zones may be sealed and tested separately.*

Airtightness Testing Conditions

Environmental conditions will affect when testing can occur. Wind and stack pressures, and mechanical systems that have not been turned off (e.g. continuous exhaust fans) can affect the test pressure and cause inaccuracies in the measured airtightness of the building. Standardized test pressure differences are often large enough to overcome these building pressures; however, some testing standards provide limits for wind speed and indoor/outdoor temperature differences when testing to ensure accuracy of the results. The applicable building code will outline the acceptable airtightness testing standards for a project.

Airtightness Metrics

Airtightness is often quantified with one of two metrics:

1. **Normalized air leakage rate**: describes the volumetric airflow through the building enclosure per unit of enclosure surface area, at a given test pressure. In Canada, this is usually measured as *L/(s•m*^{2}*) @ Pa*. Normalizing leakage by the enclosure area allows for comparison with benchmarks and performance requirements. This is the most common metric for whole-building airtightness measurements of larger buildings , and is used to specify targets for Part 3 buildings under the Step Code.

2. **Air change rate**: describes the volumetric airflow at a given test pressure divided by the building volume, and is typically indicated in air changes per hour (*ACH @ Pa*). This metric describes how frequently the air in the building is completely replaced due to air leakage at a given pressure difference. This metric is commonly used for smaller buildings and is used to specify targets for Part 9 buildings under the Step Code and for Passive House compliance.

Blower door setup with two fans.

Qualitative Airtightness Testing

Qualitative testing methods help identify air leakage locations. Similar to quantitative tests, they generally require that the buildings are pressurized or depressurized to increase the rate of air leakage. Instead of aiming to reach a specific air leakage rate the qualitative tests are used as a diagnostic tool to identify deficiencies. They are helpful for locating leakage areas but do not provide an air leakage rate for the purposes of compliance.

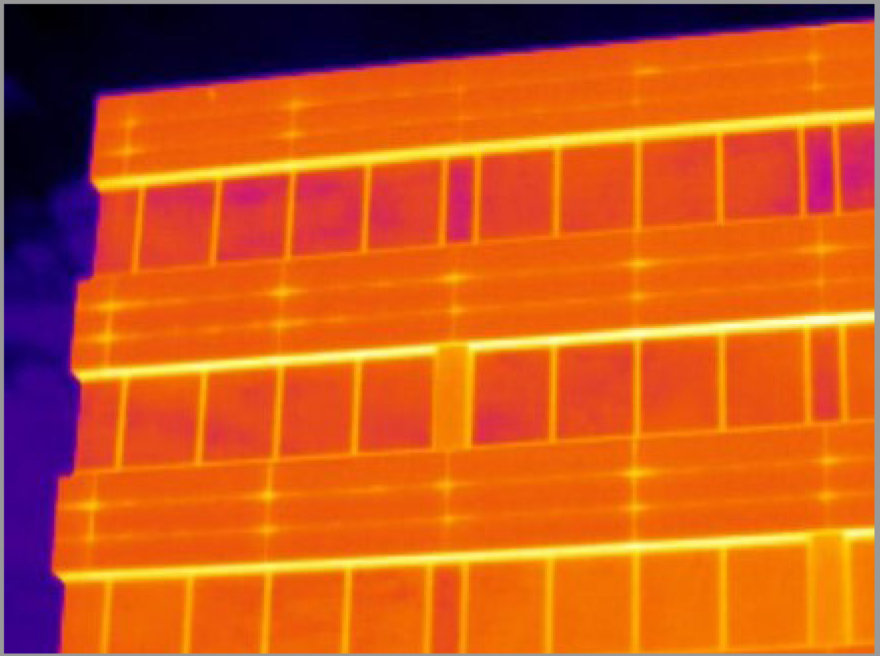
Smoke Tracer Testing

This test method uses theatrical fog released on the high-pressure side of the enclosure. Typically, the smoke is released on the interior of a pressurized building. Air leakage pushes the smoke through the enclosure and it is visually observed from the exterior at leakage locations.

Smoke tracer testing at night shows where air is exfiltrating from the building under pressurized conditions.

Infrared Thermography

This test method identifies anomalies in the thermal profile of the building enclosure to spot potential areas of air leakage. Usually thermal images are taken under pressurized and depressurized scenarios to differentiate between areas of thermal bridging and air leakage. Infrared thermography is best carried out when outdoor conditions are colder than indoors.



Infrared thermography reveals where air is exfiltrating through penetrations in the enclosure under pressurized conditions.

Additional Resources

To learn more about the topics covered in this playbook, please consult the following publications:

- Illustrated Guide – Achieving Airtight Buildings. BC Housing. September 2017.
- Building Enclosure Design Guide. BC Housing. 2019.
- Air Leakage Control in Multi-Unit Residential Buildings. CMHC. December 2007.
- Study of Part 3 Building Airtightness. National Research Council of Canada,. December 2015.
- Building Science Digest-014: Air Flow Control in Buildings. Building Science Corporation. October 2007.
- Building Science Digest-104: Understanding Air Barriers. Building Science Corporation. October 2006.

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

Net-Zero Energy-Ready Playbook Series

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