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Building Enclosures

Air-Control Fundamentals – Part 3 of 3

AIA CES Course Number: K1812T2

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Course Description

The control of air infiltration and exfiltration is becoming increasingly important for modern energy-efficient buildings. This course presents the arguments for airtightness in buildings and how to detail air-barrier systems.

Because airtightness is a "whole building" characteristic that depends on the work of multiple trades, we will also look at commissioning and inspection during construction. You will come away with a stronger understanding of how air-barrier systems work and how to solve common problems in design and construction.

Learning Objectives

At the end of this course, participants will be able to:

1. Explain why airtightness is part of high-performance buildings.
2. Identify the building science behind air control for enclosures.
3. Apply building science fundamentals to air control for high-performance buildings.
4. Assess the evolving air barrier and airtightness requirements for building.

Building Enclosures

Air-Control Fundamentals – Part 3 of 3

What We'll Cover Today:

- Airtightness is good, air leakage is bad
- Fundamentals of air control
- Requirements for high-performance air barriers
- Design for air control
- Inspection and testing

Airtightness Is Good, Air Leakage Is Bad

Airtight, Ventilate Right

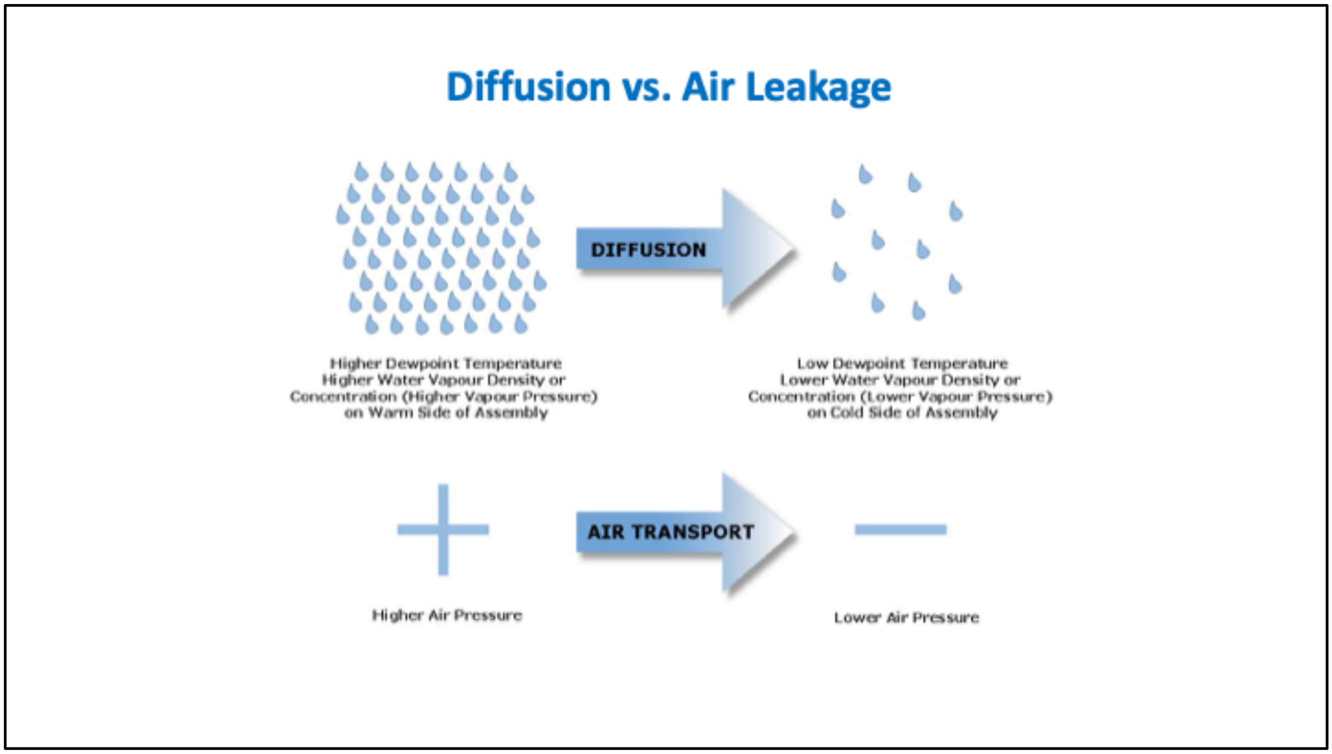
- Avoid thermal discomfort due to drafts.
- Avoid air-leakage condensation problems.
- Using HVAC to provide fresh air has a lot of advantages.

The primary reasons to build airtight buildings are to avoid drafts and air leakage condensation problems. HVAC systems work much better in airtight buildings, and the supply of fresh air has a lot of advantages.

Air-Leakage Condensation

- Moist, air-contacting, cool surfaces causes condensation
- When
  - Winter: cold outside surfaces
  - Summer: cold inside surfaces
- Damaging airflow direction:
  - Cold weather inside to outside
  - Warm weather outside to inside

When moist air comes in contact with a cool surface, condensation occurs. For building enclosures, this happens on cold outside surfaces in winter and cool inside surfaces in summer. Hence, in winter, we are concerned with humid indoor air leaking outward, while in the summer, we are concerned with humid outdoor air leaking inward. Both conditions have been found to cause material damage and mold growth in buildings.



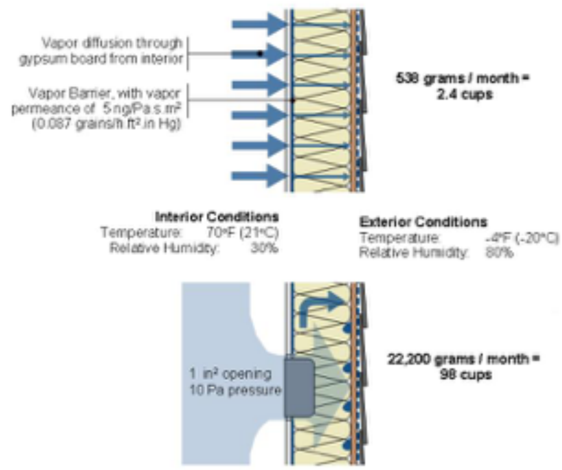
Moisture moves through diffusion from higher to lower vapor pressure.

Moisture moves through air transport from higher to lower air pressure.

Air Moves More Vapor than Diffusion!

Example #1:Vapor Diffusion
- Class III vapor control

Example #2: Air Leakage
- Class I vapor control
- 1-square-inch opening with 10 Pa driving pressure



Calculations for a single-stud bay, 8 feet tall, 16 inches wide

Air moves more vapor than diffusion.

This analysis shows the condensation predicted for a wall without a vapor barrier compared to a wall with a small 1-inch hole during severe winter conditions. The wall without the vapor barrier is shown to transport 2.4 cups of moisture per month.

Below is the analysis for air leakage through a small hole, say around a poorly sealed electrical outlet. Forty times as much water condenses. This is why condensation problems seen in the field are so much more often related to air leakage than to vapor diffusion.

* Air leakage is a much bigger risk than vapor diffusion.

HVAC Ventilation Is Better

1. Ensure fresh air is actually “fresh.”
2. Control condition of incoming air.
3. Implement energy-efficiency measures.

1. Fresh Air

- “Fresh” air from air leakage
  - Air with street-level car exhaust
  - Air with garage car exhaust
  - Air leaking through a moldy batt space
  - Air leaking past vermin remains
  - Air drawn through ground with radon gas
  - Your neighbor’s used air
- Designers can select where “fresh” comes from with HVAC and operable window design

Fresh air from air leakage is not as fresh as it is from an HVAC system. This is because leaked air can be polluted with car exhaust, mold, radon gas, and neighbors’ used air. Only with a designed and controlled fresh air supply is it ensured that the air that comes into the building is fresh.

2. Conditioning Fresh Air

- Cold drafts in winter
- Drying out spaces in winter
- Excess humidity in summer

Uncontrolled air convection can cause dry and cold drafts in the winter and excessive humidity in the summer.

3. Energy Efficiency Measures

Energy efficiency measures achievable with mechanical ventilation but not with air leakage

- Control amount of ventilation
- Control when ventilation is delivered
- Use exhaust air to preheat fresh air using heat- and energy-recovery technologies

With mechanical ventilation, energy-efficient measures are achievable, like controlling the amount and timing of the ventilation, and used exhaust air can preheat fresh air with energy-recovery technologies.

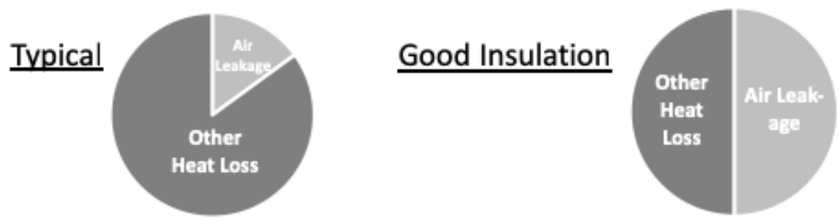
Direct Energy Impact

- Air leakage has been found to significantly increase energy use in a variety of building types.

  VanBronkhorst, D.; Persily, A.; and Emmerich, S. "Energy Impacts of Air Leakage in U.S. Office Buildings." Proceedings of the 16th AIVC Conference – Implementing the Results of Ventilation Research. 19–22 Sept. 1995.

  "Air Leakage Control Manual for Existing Multi-Unit Residential Buildings." Canada Mortgage and Housing Corporation. 2007.

- As insulation levels increase, relative contribution of air leakage to energy loss increases.



Indirect Energy Impacts

- Enable lower heating and cooling demand, low enough to make efficient HVAC systems affordable
  - Variable refrigerant flow air source heat pumps

Managing air leakage combined with increased insulation means that heating and cooling demand will be lower, making energy-efficient HVAC affordable and allowing smaller, more efficient units to be used.

What If You Don't Trust HVAC?

- Many installed HVAC systems do not work at certain times for many reasons
- The appropriate redundancy measure is operable windows
  - Control source of fresh air
  - Control fresh air rate somewhat

What if you are afraid to rely on HVAC? For example, what happens if the HVAC system fails?

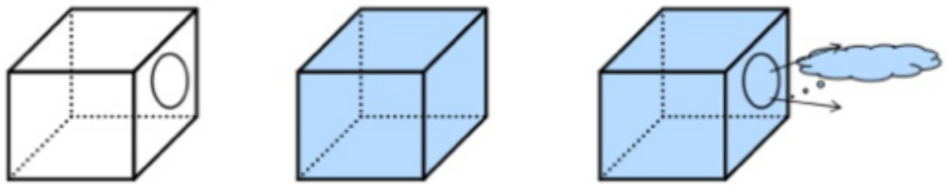
HVAC systems may not work for many reasons, including loss of electrical power, poor design, poor installation, or changing use of spaces. Air leakage is not an appropriate way of addressing the need for fresh air due to the problems we just discussed. Operable windows can present their own issues but are the appropriate redundancy measure. They also have the added bonus that most occupants will want operable windows.

* Airtightness is a necessary component of low-energy buildings and good air quality.

Fundamentals of Air Control

Air Control 101

For airflow to occur. there must be a driving force/pressure and an air-leakage path.

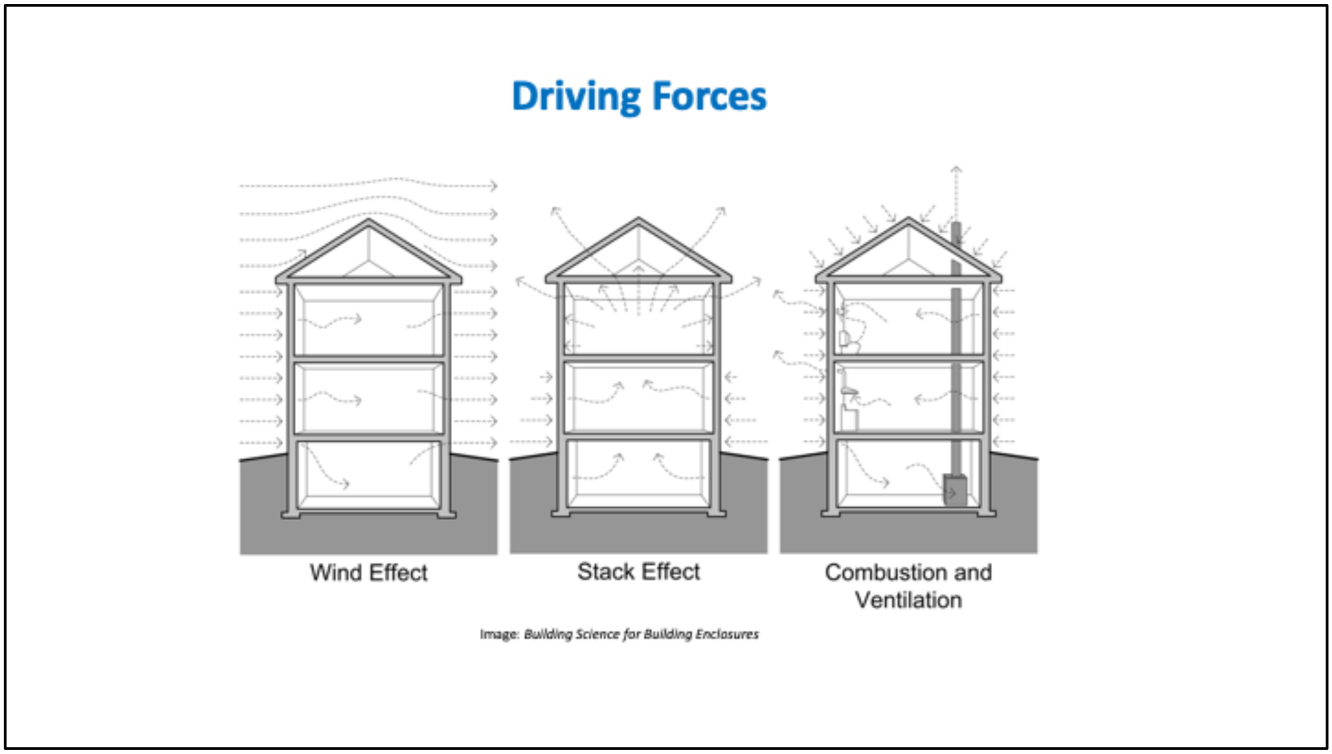


No pressure difference, no flow

No hole, no flow

It takes BOTH pressure difference and a hole for flow.

For airflow to occur, there must be a driving force or pressure and an air-leakage path. It takes a pressure difference and a hole to have airflow or leakage.



The driving forces of air leakage are: wind loads; thermal air lift, called stack effect or chimney effect; and the combustion for heat or ventilation.

Driving Forces

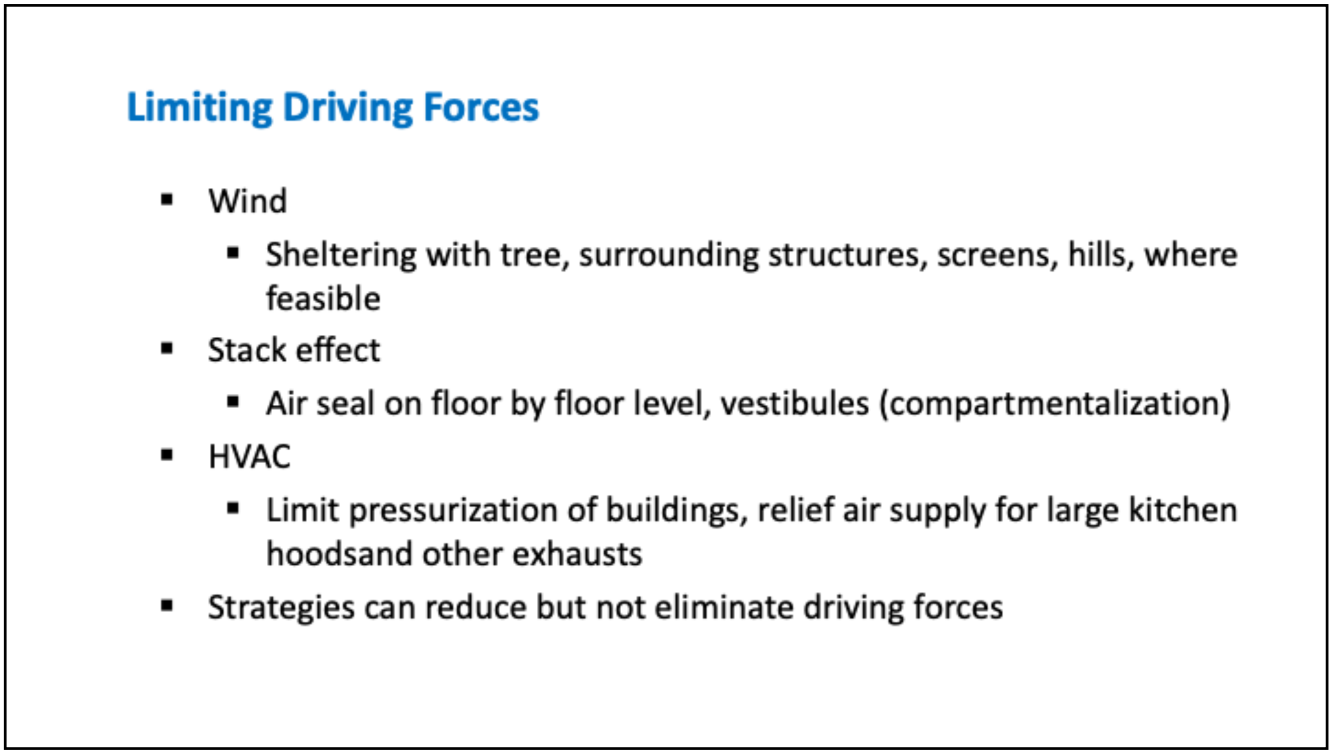
- Wind
  - Taller buildings see high pressures!
  - 2–10 Pa low buildings, 30–200+ Pa tall buildings
- Stack effect
  - Pressure increases directly with temperature difference and height
- HVAC
  - Depends on design and operation
- All can interact and often occur at the same time

Taller buildings usually see higher wind pressures.

A low building gets wind loads of up to 20 Pascal but a tall building can get wind loads of up to 200 Pascal or more.

The higher the temperature difference and the higher the building, the greater the impact of the stack effect.

The HVAC system has an influence on airflow, depending on the design and operation. Each may affect the other.

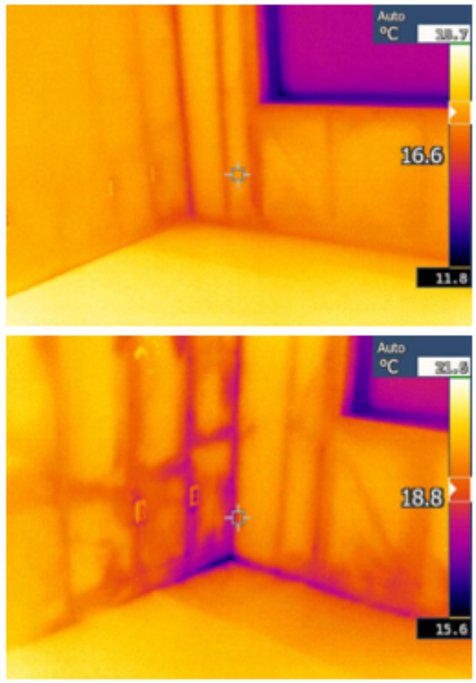


There are some strategies to reduce driving forces, but one cannot eliminate them.

Sheltering the building with trees or other structures or hills would lessen wind loads. Compartmentalizing every floor would reduce the stack effect. Balance the HVAC pressurization with a relief air supplies and exhaust.

* There are a number of forces driving airflow which can be reduced but not eliminated.

Spot the Difference…

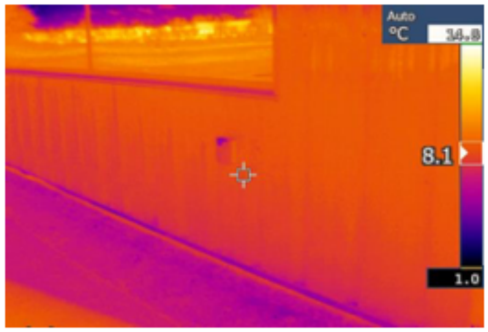


Positively Pressurized Space

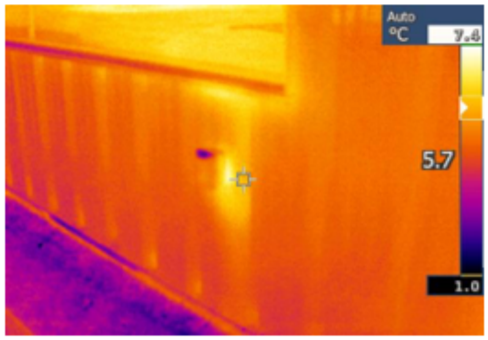
Negatively Pressurized Space

Whether a building is positively pressurized (blows) or negatively pressurized (sucks) will affect thermal bridging.

Spot the Difference…



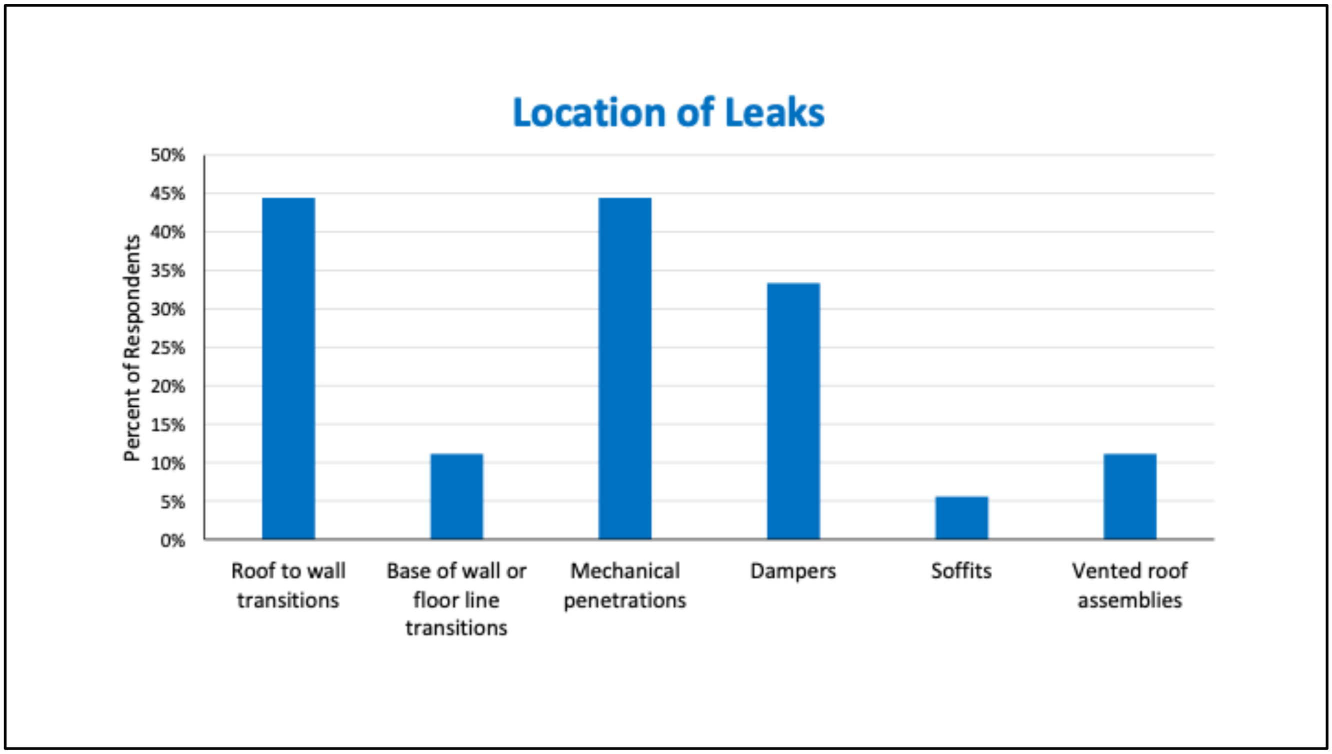
Negatively Pressurized Space



Positively Pressurized Space

Note the changing cold spots.

In a smoke test, the areas of leakage or unintentional openings become quite apparent.



This graph shows the locations where leaks are most likely to occur. The greatest number of leaks are at wall roof transitions and through mechanical penetrations.

Requirements for
High-Performance Air Barriers

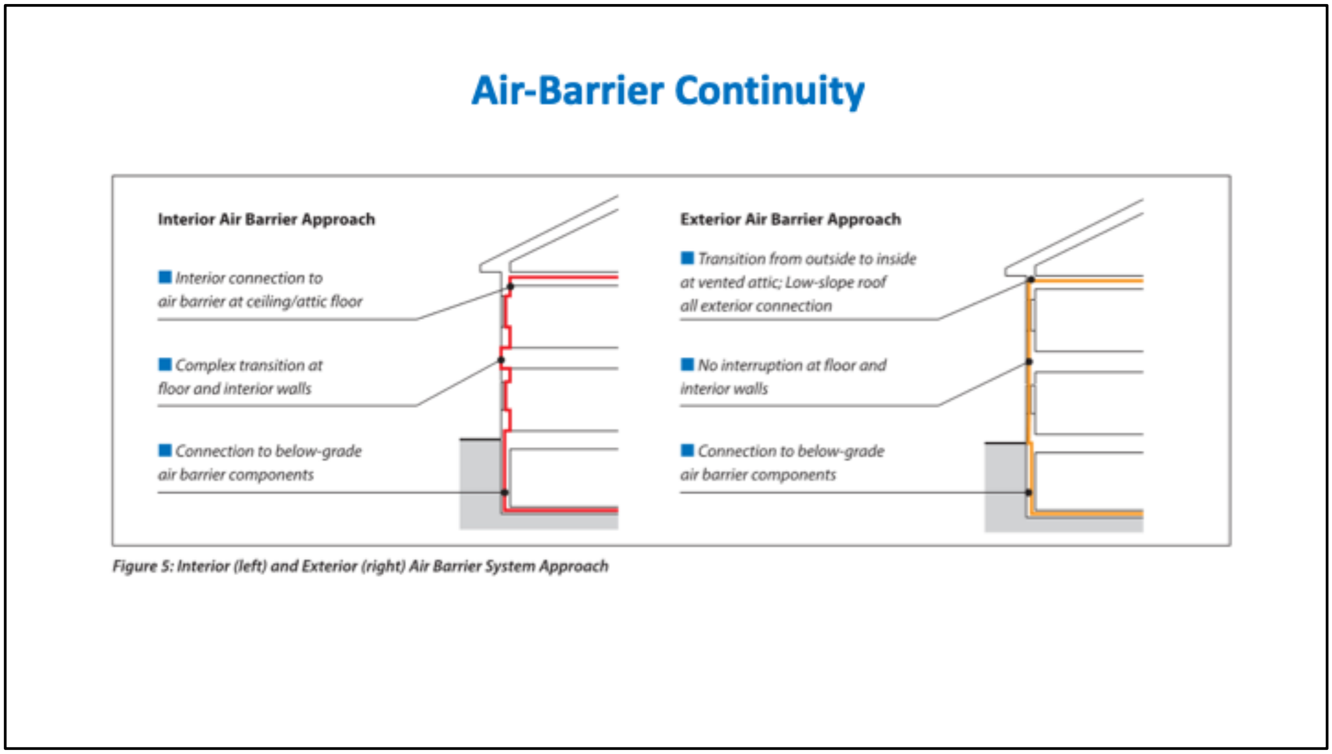
Air-Barrier Requirements

- Use barrier to block air-leakage paths
- Requirements for an effective air-barrier system
  - **Continuous (most important)**
  - **Strong**
  - **Durable**
  - **Stiff**
  - **Air impermeable (least important)**
  - **Correct location (sometimes important)**

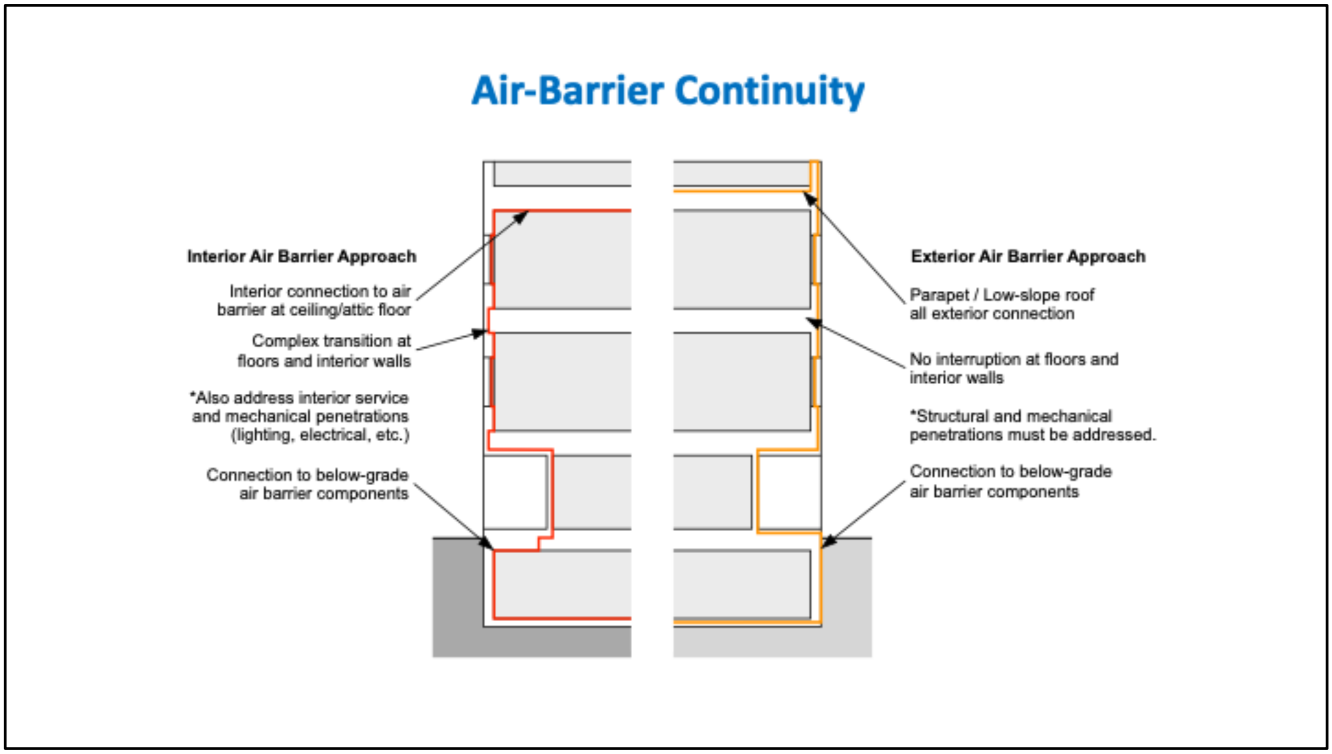
Use barrier to block air leakage paths in a system.

The requirement for an effective air-barrier system are that the system is continuous, strong, durable, stiff, and correctly located.

The air impermeability of the membrane itself is considered least important because most air-barrier materials are air impermeable. What counts is that the entire system is designed and installed in an airtight manner, which can only be achieved through continuity.



An air barrier can be located anywhere in the wall system. However, it should be installed at the location where it is most easily made continuous. In general, it is most easily made continuous when installed to the exterior of the wall rather than to the interior, where there are many more details to manage.



There are two general approaches for where to locate the air-barrier system. But whether the system is located on the interior or exterior, continuity is key.

Commercial Buildings: Often Exterior Air Barrier Is Only Practical Solution

Because buildings today tend to be quite complex, often the only solution is to use an exterior air-barrier approach.

Air-Barrier Strength and Durability

Typically not easy to replace, hence they must:

- withstand design wind loads
- be durable through construction
- be durable for life of the building

Air-barrier strength and durability are important because the system is not easy to replace and must withstand wind loads and be durable through construction and the service life of the building.

Air-Barrier Stiffness

Unsupported flexible air barriers can billow in the wind, leading to air-pumping and air-barrier damage

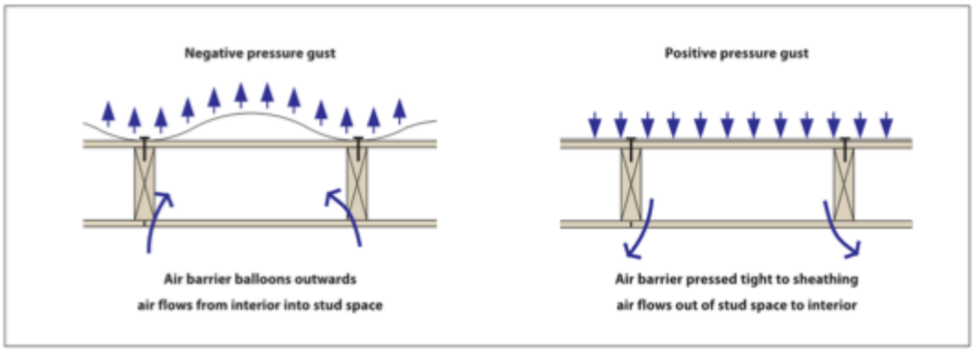


Figure 6: Wind-induced "pumping" of mechanically attached air barrier

Unsupported flexible air barriers can billow in the wind, leading to air-pumping and air-barrier damage by not only allowing air movement paths but also driving the air through them. Therefore, stiffness is very important to minimize this.

Air-Barrier Permeability

- Air impermeability Requirements (ABAA)
  - Material: 0.02 lps/m^2 @75 Pa (0.004 cfm / ft^2 @0.3”) wg
  - Component: 0.2 lps/m^2 @75 Pa (0.04 cfm / ft^2 @0.3” wg)
  - Building: $\boxed{\text{2.0 lps/m}^2\text{ @75 Pa (0.4 cfm / ft}^2\text{ @0.3” wg)}}$

- **Building** requirement most important for energy, interior RH, IAQ
- **Component** requirement may matter for air-leakage condensation control
- **Materials** less important, system is!

There are different requirements for the material and its components as well as for the entire building.

The requirement for the materials is 0.02 liters per second per square meters at 75 Pascal pressure differential.

The requirement for components is 0.2 liters per second per square meters at 75 Pascal pressure differential.

The requirement for the building (or system) is 2 liters per second per square meters at 75 Pascal pressure differential.

System performance is most important because that is the performance of the building.

Air-Barrier Location

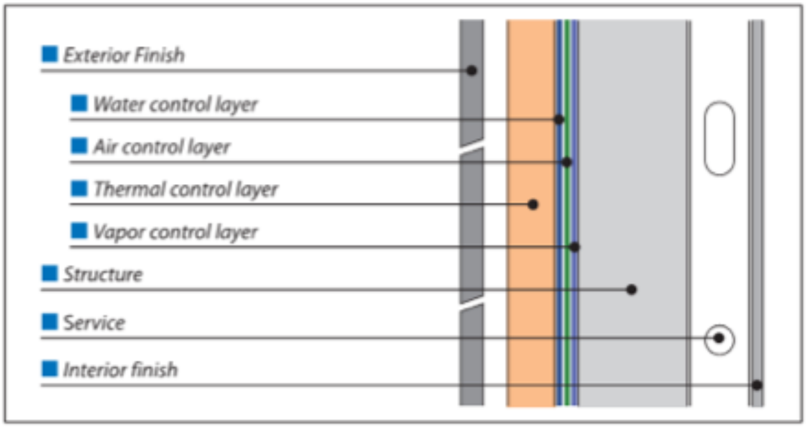


Figure 1: Diagram of the "Perfect" Wall showing ideal sequence of assembly layers

(From John Straube, High Performance Enclosures, Building Science Press)

The air-barrier in the perfect wall approach is best located outside of the structure between the wall sheathing and protected through the exterior insulation.

What about Wind Washing?

Air-pressure differences on either side of corner can create flow paths:

- through stud cavity
- between sheathing and exterior insulation, and
- through exterior insulation

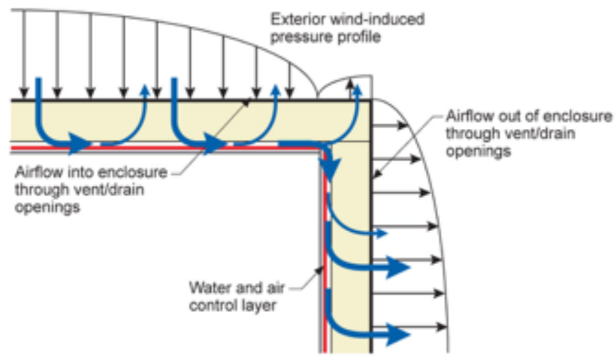
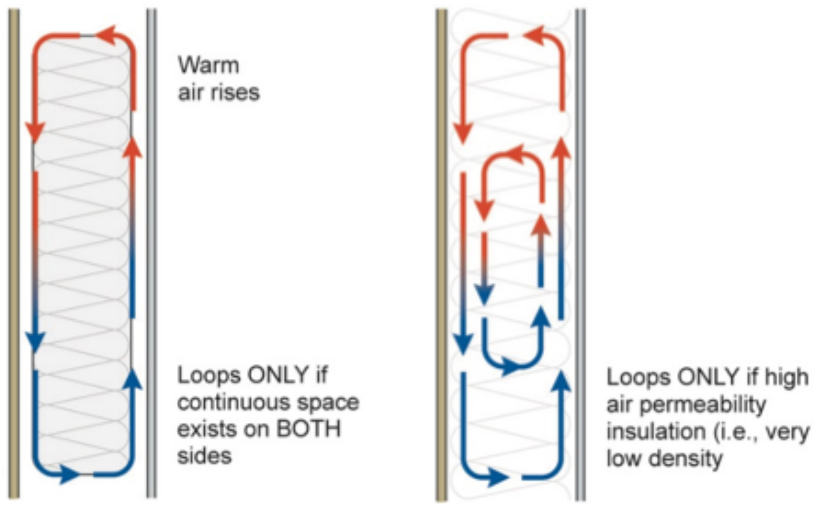


Image: *Building Science for Building Enclosures*

Another good reason for an external air barrier is to avoid the reduction of R-value of the insulation by wind washing.

What about Convective Looping?



But even in an airtight wall cavity, convection can happen.

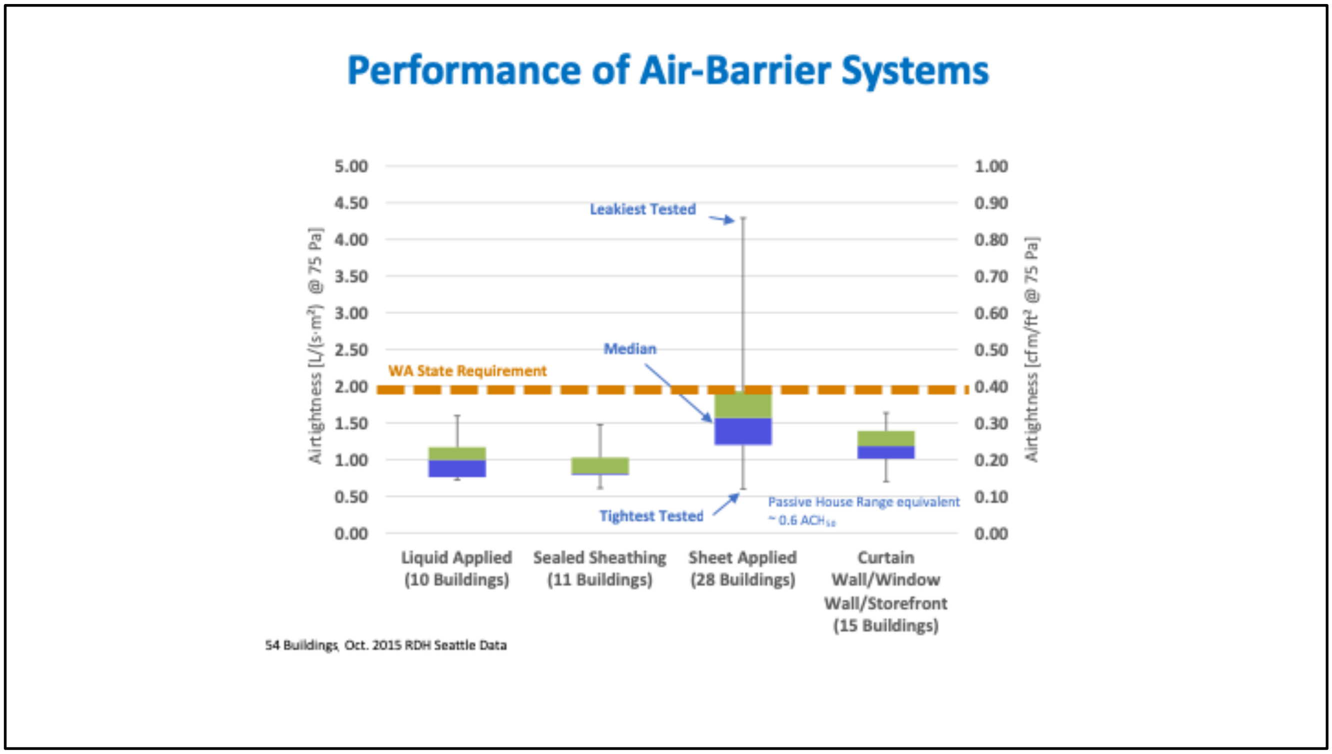
* A fully supported air barrier outside of the structure is most likely to meet performance criteria.

Quality Assurance for Air-Barrier System

- Design
- Inspection
- Testing

To assure quality for air-barrier systems, three things are necessary: the air-barrier system should be properly designed, inspected, and tested.

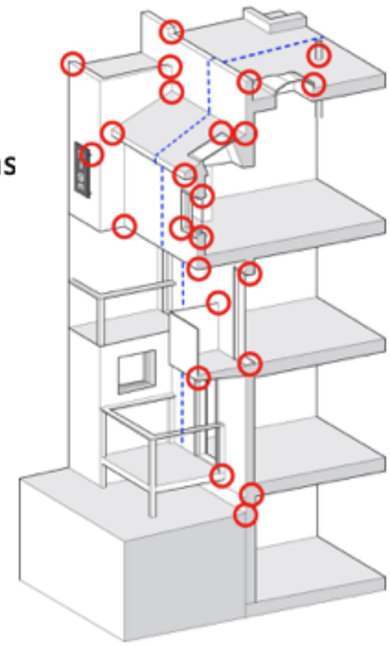
Design for Air Control



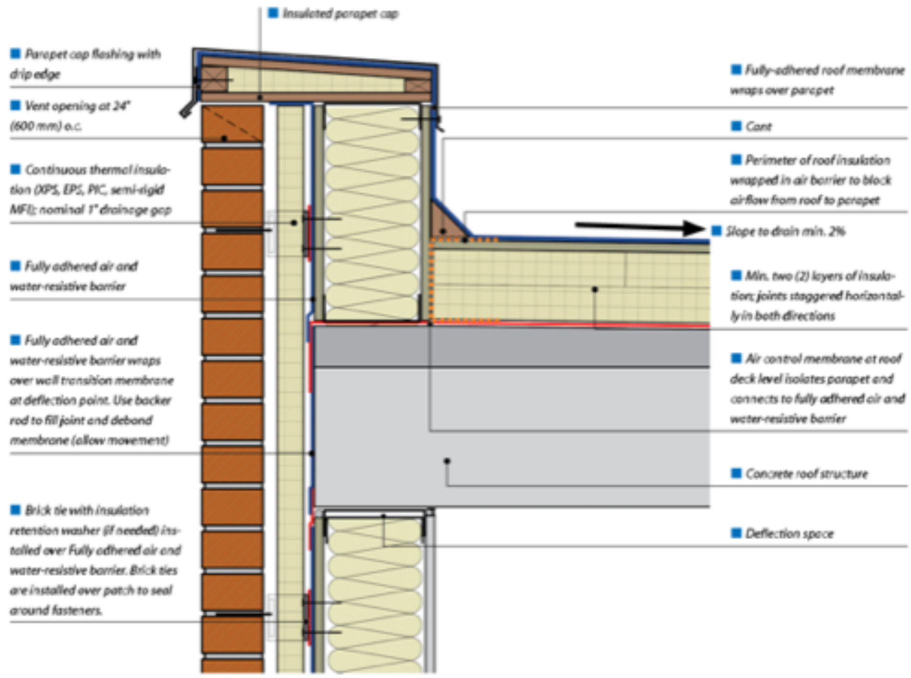
A comparison of air-barrier system performances showed that the sheet-applied systems, tested on 28 buildings, were the tightest of all tested air-barrier systems.

Enclosure Details

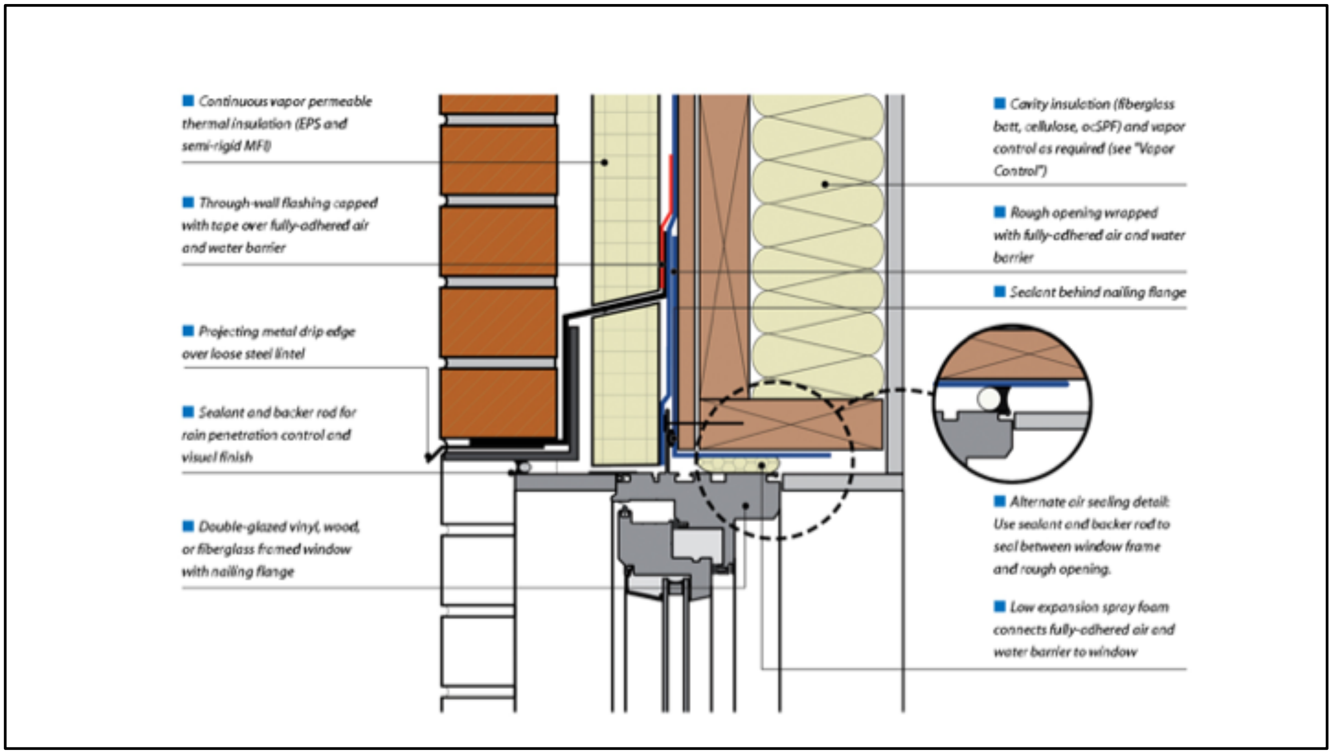
- Details demand the same approach as the typical enclosure assemblies:
  - Support
  - Control
  - Finish
- Scaled drawings required at



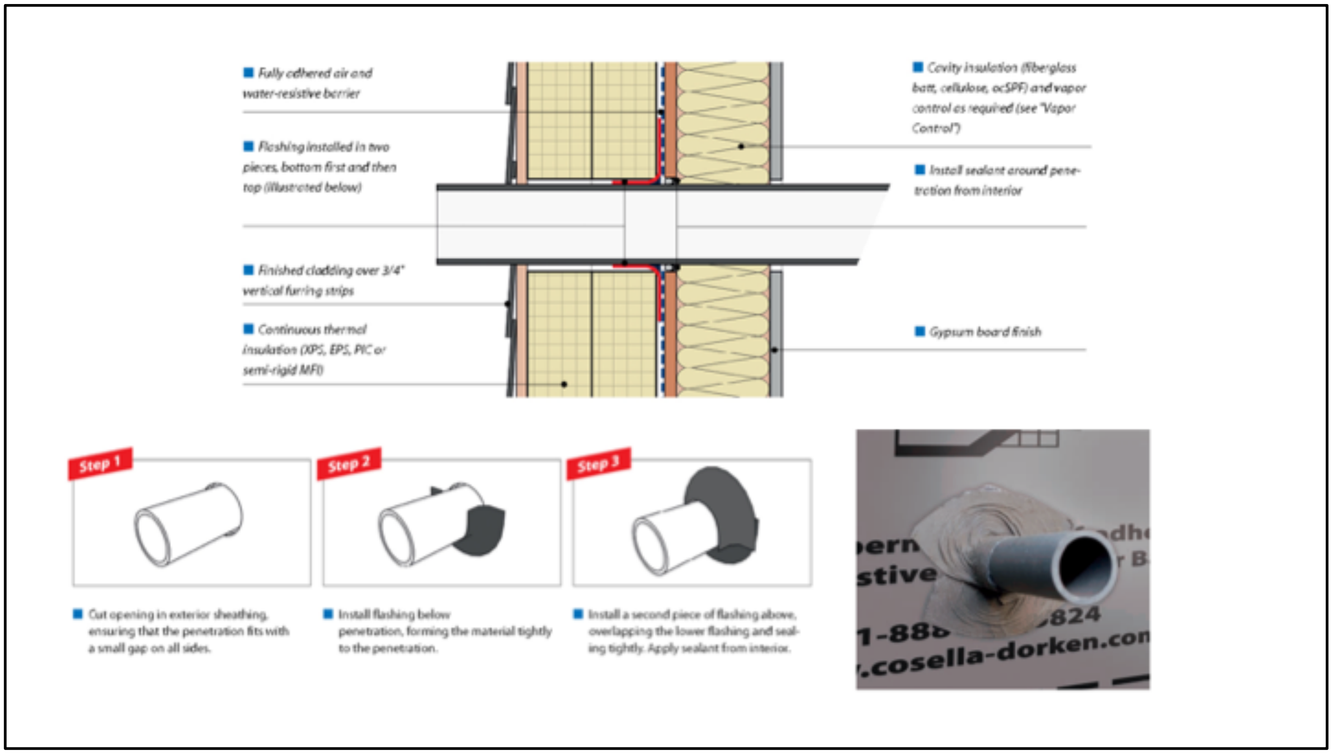
Every detail should be addressed and follow the same approach as the whole assembly. The red circles represent critical transition areas often not fully detailed by the designer, leaving it to the contractor to guess, and representing areas that then risk failure.



The transition details between wall and roof assemblies are always critical. Continuity is the key and should be addressed properly as shown on this detail.



Windows are part of the air-barrier system. As shown on this detail, the air-barrier system is connected to the window frame in an airtight and watertight way. The window becomes part of the water-resistive barrier. Therefore, it is also connected to a drip edge through a through-wall flashing membrane.



Best practice for pipe penetrations is to use a flexible membrane to ensure an easy installation with airtightness and watertightness.

* Continuity is key to good air-barrier design.

Inspection & Testing

Inspection & Testing for Air-Barrier System

- Inspection
  - Confirmation of materials and assemblies
  - Confirmation of assembly sequence
  - Visually confirm continuity
- Testing
  - Testing of mockup(s) common for midsize and large buildings (quantitative)
  - Smoke testing (qualitative)
  - Moving toward whole building testing for all buildings

Part of the inspection is the confirmation of the proper materials and assemblies as well as the construction sequence and visual confirmation of the air barrier system continuity.

The testing of a mockup wall is common for mid-size and large buildings. This forms the basis of understanding for all parties as to the expectations.

The smoke test is used to make even the smallest leaky spots visible and ensure quality.

The movement is toward whole building testing.

Evolving Requirements for Airtightness

- Changing building code requirements
  - IECC/IRC likely to require airtightness testing soon for residential buildings
    - Measured at 50 Pa in residential buildings
  - Coming for commercial buildings
    - GSA and Army Corps requiring testing to tightness targets now
    - 0.40 and 0.25 cfm/sf@75 Pa respectively
- Requirements for measurable airtightness levels is likely to spread

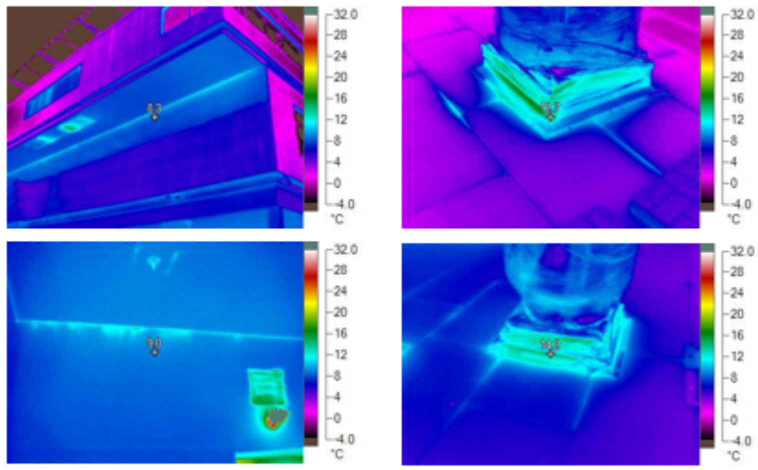
Airtightness requirements are evolving.

The IECC and the IRC are likely to require testing for residential buildings measured at 50 Pascal.

The new targets according to the GSA and Army Corps for commercial buildings are 0.4 and 0.25 cubic feet per minute per square foot at 75 Pascal, respectively.

Finding the Leaks – Qualitative Testing

Infrared Photography



Infrared photography can be used to make leaks visible.

Finding the Leaks – Qualitative Testing

Smoke Tracer Testing

The smoke test is also a good method to make leaks visible.

Whole-Building Testing

- Demonstrate target exceeded
  - Accuracy, clarity of target
- Diagnose cause of problems
  - Location of leak
- Quality control
  - Quantity and location of leaks
- Structural integrity or watertightness
  - Special, different, testing protocols

Whole-building testing should include a clear objective, a diagnosis of the problem if any occur, location of leaks, count of leaky spots, and the structural integrity or watertightness. To capture the results, testing protocols should be created.

Test Equipment Setup in Exterior Door or Opening

Whole-building airtightness is tested with a blower door test.

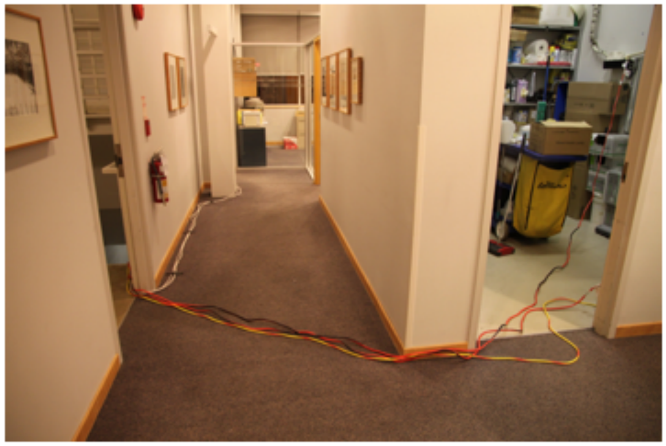
A big fan to depressurize (blow out) or pressurized (suck in) air is installed into the main door of the building.

Here is an external view of a blower door testing system.

Exterior Setup: Intentional Mechanical Openings Closed

All enclosure openings, including mechanical openings, must be sealed to properly test the enclosure.

Interior Setup: All Doors Opened, Control and Power Installed



All interior doors should be opened to allow airflow inside the building.

* Whole building airtightness testing is now available for most new buildings.

Summary

- Air leakage is a much bigger risk than vapor diffusion.
- Airtightness is a necessary component of low-energy buildings and good air quality.
- There are a number of forces driving airflow which can be reduced, but not eliminated.
- A fully supported air barrier outside of the structure is most likely to meet performance criteria.
- Continuity is key to good air-barrier design.
- Whole building airtightness testing is now available for most new buildings.

This concludes the American Institute of Architects Continuing Education Systems Course.

Thank you for completing this educational course by Dörken Systems.

Dörken Systems is the first to have Health Product Declaration (HPD) v2.0 or HPD with LEED v4 for our air-barrier systems; the first air- and moisture-barrier manufacturer to provide files for AutoDesk Revit; and our data is available on BSD SpecLink™-E and Avitru MasterSpec™ software platforms.