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Building Enclosures
Moisture-Control Fundamentals – Part 1 of 3

AIA CES Course Number: K1812T

Welcome to this continuing education seminar. This is the first of three parts of the Building Enclosure Fundamentals series.

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Course Description

Use of insulation, along with other differences in building materials and assemblies, is changing the nature of moisture risks in building enclosures in today's buildings relative to historic construction.

Underlying moisture physics and management strategies will be presented in this course to explain these changes and address them in high-performance buildings. The strategies are applied in modern building enclosure detailing, providing solutions to designers for complex challenges.

In this course, we will examine different rain-control strategies for the building enclosure in a changing construction environment for high-performance buildings.

Learning Objectives

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

1. Adapt to the changes that have been made over time to building enclosure assemblies, which have changed the nature of moisture-related issues.
2. Use the building science behind moisture control for enclosures in typical wall designs.
3. Make informed decisions about the appropriate rain-control strategies for wall assemblies in every day design.
4. Apply effective moisture management strategies to building enclosure details.

Building Enclosures
Moisture-Control Fundamentals – Part 1 of 3

What we will cover today:

- Moisture-related problems that occur within the building enclosure.
- Fundamentals of moisture and vapor control.
- Different control strategies for high-performance buildings.
- Effective detailing of moisture-control layers within the building enclosure.

Building Enclosures
Related Moisture Problems

Let’s start with the frequent **moisture-related problems** within the building enclosure.

Pre-WWII Buildings

Wetting issues due to bulk rainwater entry, but occurrence and impact limited by:

- Rainwater shedding features
  - Overhangs
  - Window and door sills and headers
  - Few duct, pipe, and wiring penetrations
- Drying capacity
  - No added insulation (or very little)
  - No vapor barriers
- Wetting-tolerant building materials
  - Masonry and old-growth solid timber

How have old buildings, built before 1940, handled moisture?

- They had a different structure and used different materials than todays buildings.
- Their outer structure was constructed primarily to shed rainwater away from the enclosure with overhangs or eaves as well as window and door headers.
- They were built out of masonry or old-growth timber, and therefore the wall assemblies were more tolerant of moisture and had a greater drying capacity than today’s buildings.
- The most crucial point was that these building were not inhibited from drying out by insulation and vapor-retardant materials.

Pre-WWII Buildings

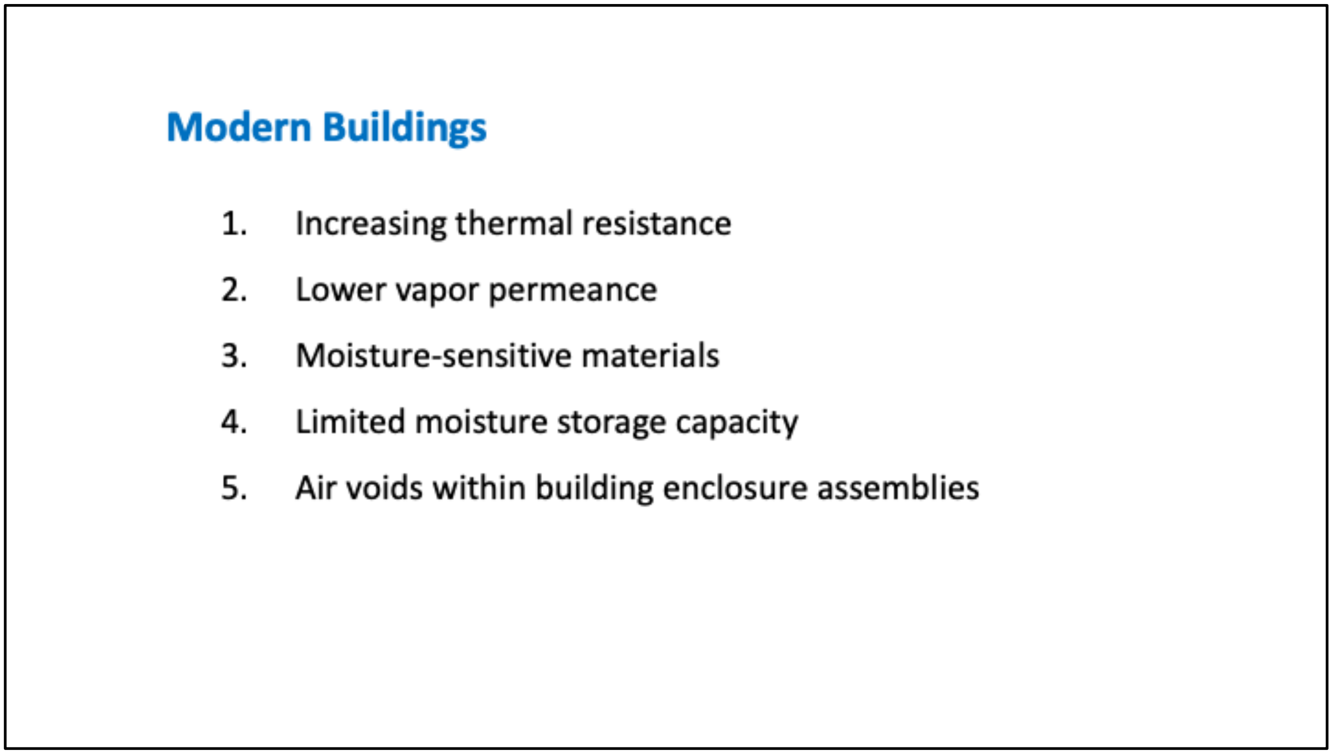
Surface condensation also an issue, but occurrence and impact limited by:

- Air-leaky buildings limit wintertime humidity
- Perimeter heating below windows
- No air conditioning
- Wetting-tolerant materials
  - Plaster and solid wood finishes

These buildings, for example, would have had surface condensation on the inside during cold winter days, because the uninsulated walls were cold.

Because they were so leaky, most of the moisture dried out quickly through convection, air leaks and other factors like perimeter heating below windows. Summertime condensation would not occur because of the lack of air-conditioning. Any damage due to condensation was mitigated by the use of moisture-tolerant materials.

Modern Buildings

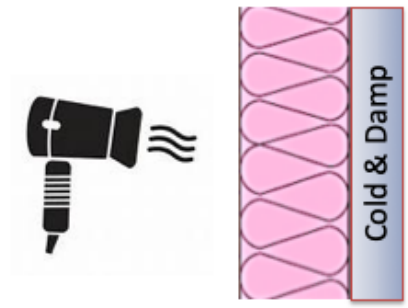


Most moisture problems are caused by our own improvements in the building sector. By using more materials that are vapor retardant and, at the same time, more moisture-sensitive, such as plywood and OSB, and by insulating our buildings to make them more energy efficient, we inhibit them from drying out.

1. Increased Thermal Resistance

- Old buildings used energy leakage (i.e., heat leaving the building) to dry materials and assemblies
- Increased insulation = less drying

Limited insulation



Interior insulation

We have dramatically increased insulation in buildings. Old buildings did not have much if any insulation, which meant all of the energy used to heat the building also dried out the building.

2. Lower Vapor Permeance

- Low vapor permeance of exterior layers
  - Metal panels, precast concrete
  - OSB and foam vs. wood-board sheathing
- Low vapor permeance of interior layers
  - Polyethylene
  - Vinyl wallpaper
  - Vinyl sheet flooring
- Moisture accumulates against low-vapor-permeance layer

Vapor has the need to equalize itself. If there are two adjoining environments with different vapor pressures, vapor will drive through the materials separating them, to equalize itself.

Vapor always moves from high to low pressure and from high to low temperature. When vapor hits a surface that is a certain amount cooler in temperature, a process called condensation occurs, and the moisture changes its state from gas to liquid. The place where this happens is called the dew point. In hot, humid climates the dew point will be on the interior side of your wall.

Materials that inhibit vapor from moving through the wall (vapor retarders) inhibit the wall from drying when applied to the interior side as such vinyl wall papers, etc. Many of the modern materials we now use like polyethylene, OSB, and vinyl are very low in moisture vapor permeance. These materials can change the moisture dynamics of a wall system and allow moisture to accumulate in inadvertent locations.

The photo shows mold growth behind vinyl wall paper. This picture was taken by a building scientist in his hotel room before a presentation he was about to give in Hawaii.

3. Moisture Sensitivity of Materials

- Wood products
  - New vs. old growth
  - Processing: plywood, OSB, particle board
  - Paper, veneers
- Finishes
  - Drywall, ceiling tile
- Moisture = mold growth

Processed organic materials such as plywood or OSB are much more sensitive to moisture than unprocessed wood materials or mineral materials. Therefore the impact of moisture is much higher and the risk of mold is much higher.

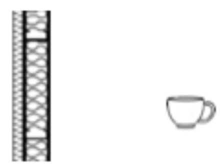
This damage is likely due to condensation from an uninsulated cold pipe but illustrates the use of water-sensitive, highly processed wood products (in this case, paper) that are now common in our construction.

4. Moisture Storage Capacity

- Old buildings
  - Concrete block/terra cotta
  - Rough cut wood/skip sheathing
- New buildings
  - Steel stud lined with gypsum board
- Orders of magnitude change in moisture storage capacity!

Safe Storage Capacity

Safe Storage Capacity



Old mass walls made of materials like masonry or rough-cut wood could store much more moisture than modern steel framed walls. This means that they are able to get wet and dry out repeatedly with little or no effect.

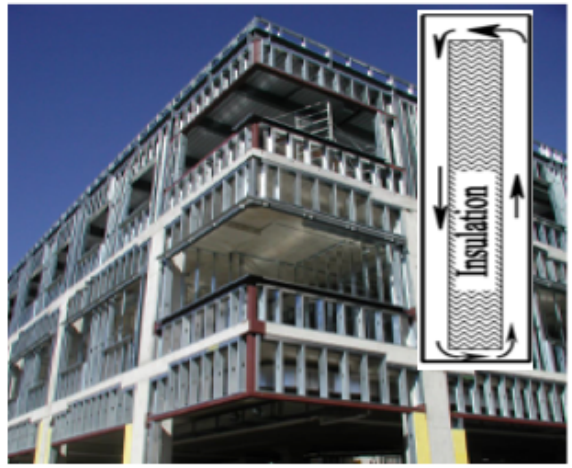
A mass wall holds a barrel of water—say 5 percent of its heavy weight safely after any wetting event.

A steel-stud assembly just holds a drop on surfaces, and even that can cause corrosion on electro-galvanized steel studs.

5. Voids within Building Enclosures

- Hollow building enclosure spaces
- Connected voids
- Airflow + complexity
- Unintended interactions with HVAC

Airflow can bring warm, humid air to cold surfaces across voids



Hollow spots within framed walls can cause air movement in the wall itself, allow convective loops in the wall, and increase the chimney or stack effect in the whole building. The air movement can bring warm, humid air to cold surfaces, resulting in condensation inside the wall.

* We can no longer rely exclusively on historical experience. We need to understand enclosure design from first principles.

Fundamentals of Moisture Control

Moisture Control

- Moisture-related problems
  1. **Moisture** must be present.
  2. There must be a **path** from the source to the susceptible material.
  3. There must be a **force** to cause movement.
  4. The material must be **susceptible** to damage.
  5. Moisture must **accumulate** beyond safe storage capacity.
- Theory:
  - Eliminate any one for complete control.
- Practice:
  - Control as many as possible.

To have moisture in a building assembly, there are five conditions that need to coexist.

In theory, if you eliminate just any one of those, there will be no moisture occurrence.

In practice, this is not possible, therefore we design to control as many of these conditions as possible.

Rain-Control Strategy

- Three possible approaches
  - Mass
  - Drained
  - Perfect Barriers
- Elements and joints can use different approach
- Mass is historical approach

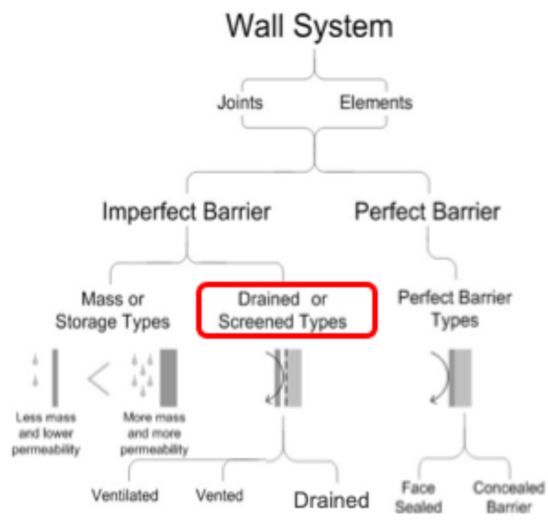


Image: *Building Science for Building Enclosures*

The most important thing to control is rainwater. There are two main strategies to control rainwater: perfect barrier and imperfect barrier.

Old walls with massive structures are an example of the imperfect barrier strategy. They follow the simple idea that "moisture penetrates the wall but can dry out again." Therefore, these walls provide more moisture storage capacity than needed by the amount of rainwater.

Thinner mass walls have less storage capacity than thicker mass walls. They compensate for their lesser storage capacity with lower perviousness to avoid greater absorption.

Mass/Storage/Reservoir Walls

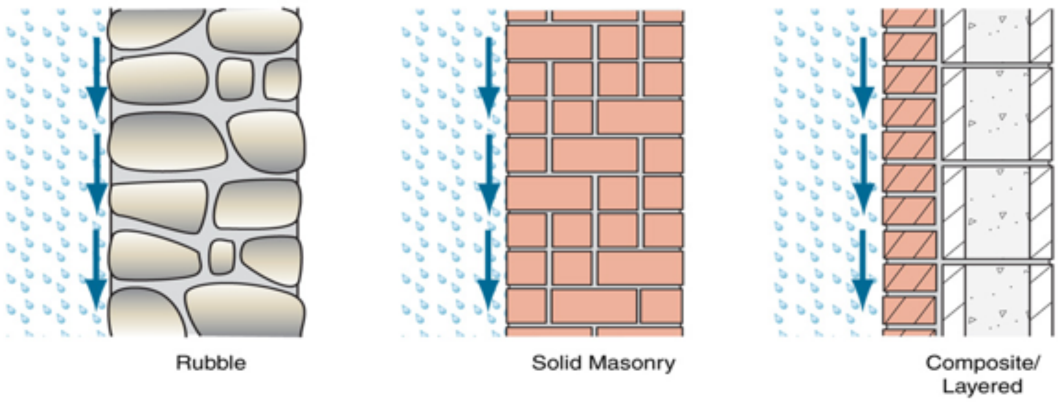


Image: *High-Performance Enclosures*

Three common examples of a mass, storage, and reservoir walls are the rubble wall, a solid masonry wall, and a composite layered wall.

No Building Paper, Flashing, Weep Holes

Old buildings like the one shown here are good examples of the simple (imperfect barrier) storage strategy to control rainwater and has been proven over decades. Moisture penetrates the wall structure but can dry out again.

Rain-Control Strategy

"Perfect" barriers are inherently risky.

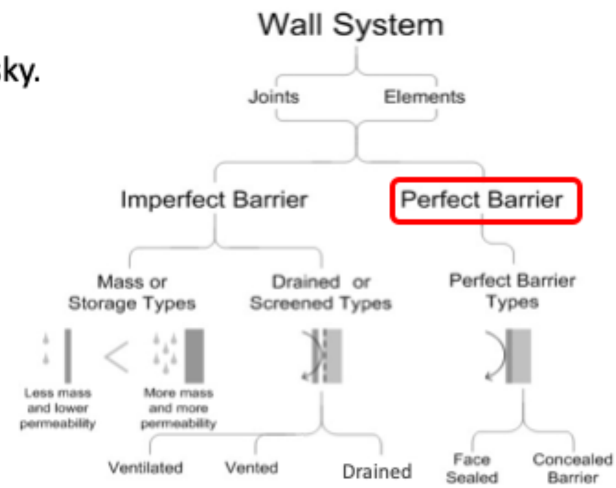


Image: *Building Science for Building Enclosures*

The second strategy when it comes to rain control is the perfect barrier. However, nothing in life is perfect, and certainly not in construction.

The materials used as a perfect barrier, like glass or metal, could be perfect in the field when installed continuously without interruptions. But each connection point, like seams, transitions, and joints, is an interruption of the perfect barrier. The interfaces or connections are the weak points in any perfect barrier strategy.

Perfect Barrier/Face Sealed

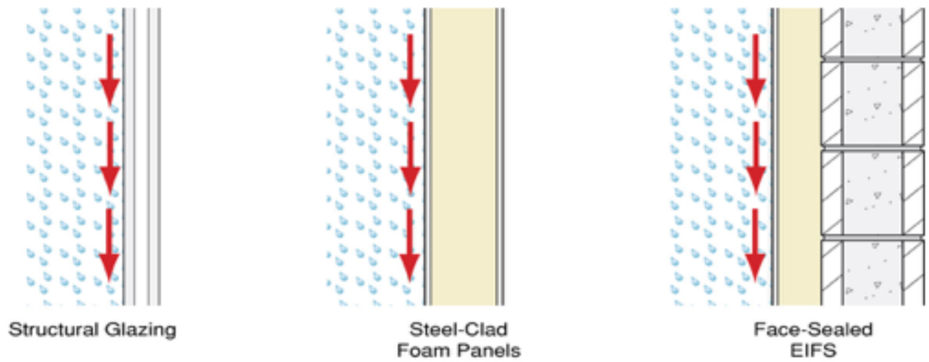


Image: *High-Performance Enclosures*

Shown here are three examples of perfect barrier systems: structural glazing, steel-cladded foam panels, and a face-sealed exterior insulated and finish system.

All about Joints, Transitions, Penetrations

Glass is a perfect barrier. We don’t worry about water migrating through the middle of a window. However, there are a lot of rainwater entry problems where the glass interfaces with framing and where those systems interface with floor slabs and other elements. In fact, the lifespan of these systems is typically limited by excessive rainwater leakage, which gets worse and worse over time. It’s hard to make perfect in the first place and impossible to keep perfect forever.

Rain-Control Strategy

AKA Rainscreen

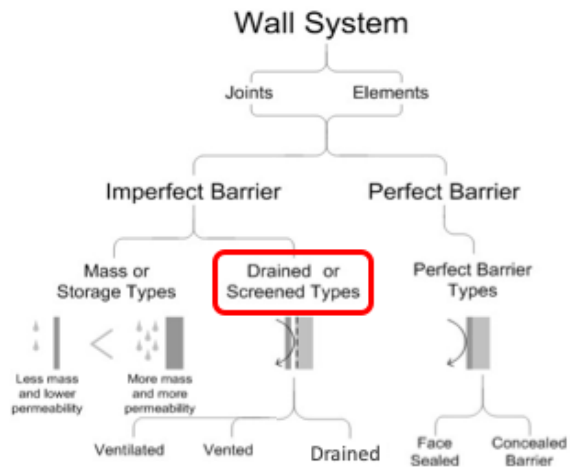


Image: *Building Science for Building Enclosures*

There are three different types of rainscreens: vented, ventilated, and drained. A rainscreen always has a cavity where moisture is controlled either by air or by drainage (or both), depending on the system. The drainage approach is the most successful one when it comes to moisture control.

Drained Walls

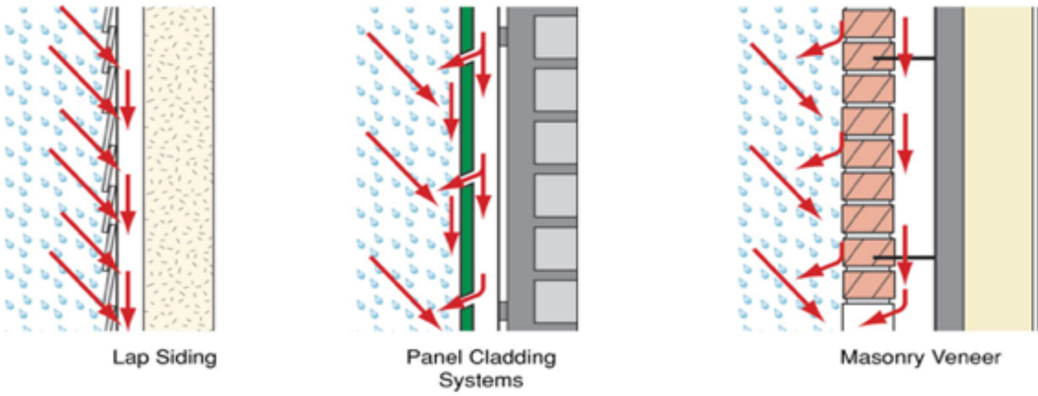


Image: *High-Performance Enclosures*

Different drained wall systems follow a similar strategy: draining the water in the cavity behind the first moisture-control layer (also known as the cladding). Three examples of drained wall systems are lap siding, panel cladding, and masonry veneer.

Advantage of Drained Walls

- The cladding manages most of the rain but has a secondary rain-control layer underneath, providing redundancy.
- The most exposed (abused) layer, the cladding, can deteriorate safely without jeopardizing major building enclosure function of rain control.
- The rain-control layer is protected from the elements and hence more durable.

The advantage of this system is its redundancy. There are two moisture-control layers spatially separated from each other. The first one shields and protects the second one from most of the environmental influences like rainwater, heat, and ultraviolet rays.

* A drained screen assembly is the best strategy for new buildings to control rain penetration in most climate zones.

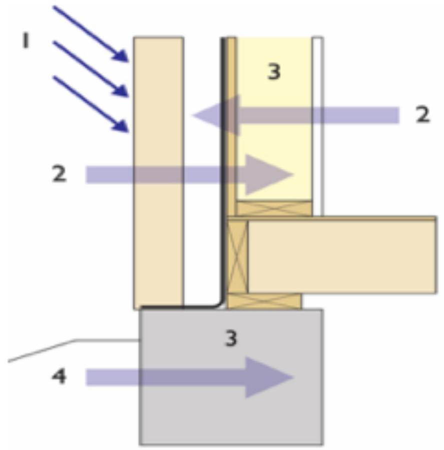
A drained screen assembly is the best strategy for new buildings to control rain penetration in most climate zones.

Water Vapor Control Recommendations

Wall + Roof Wetting

Sources/Mechanisms

1. **Rain**
   - Absorption
   - Penetration
   - Splash and drips
2. **Water Vapor Movement**
   - Diffusion
   - Convection (air leaks)
3. **Built in**
4. **Ground**
   - Capillary (wicking)
   - Gravity
   - Diffusion



There are several mechanisms of moisture movement within wall systems.

Building codes tend to focus on vapor diffusion, which is important but tends to be small in terms of actual mass of moisture movement relative to other mechanisms. This means that as a wetting mechanism, it is not the most significant.

Problems do arise due to poor water vapor diffusion strategies.

Vapor-Control Recommendations

Types of Vapor Retarders

- **Class I:** 0.1 perm or less (impermeable); includes polyethylene film, foil-faced insulated sheathing and non-perforated aluminum foil
- **Class II:** 0.1 to 1 perm (semi-impermeable); includes unfaced expanded polystyrene, fiber faced polyisocyanurate, and asphalt-backed kraft paper facing on fiberglass batt insulation
- **Class III:** 1 to 10 perms (semi-permeable); includes latex paints over gypsum board, #30 building paper and plywood

Reference 2006 International Energy Conservation Code (IECC)

Materials to retard vapor are classified in three classes.

Each class is defined by a range of perms. Perms are the way to measure how much vapor can move through a material. The higher the perm rating, the more vapor can move through.

Class 1 is the most impermeable, and materials that fall under this class are often called vapor barriers.

Vapor-Control Recommendations

Climate-Based Recommendations

- Balance of vapor diffusion inward and outward in winter vs. summer.

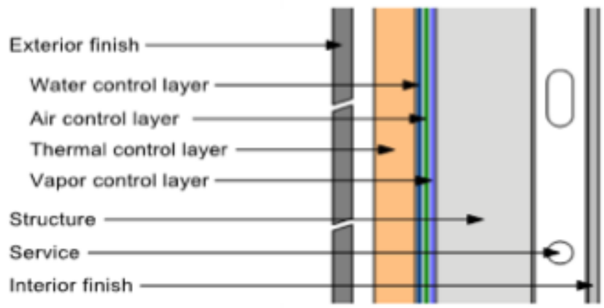
In colder environments, the vapor drive is generally from the inside out. In warmer environments, the vapor drive is generally from the outside in. The method and strategy of vapor control will vary according to the climate zone.

Vapor-Control Recommendations

The "perfect wall" works in all climates.

Assemblies with all or most (more than 75 percent of the total) of the insulation value located outboard of the structure (framing or solid).

- A Class I or II vapor-control layer on the inside of all or most of the insulation

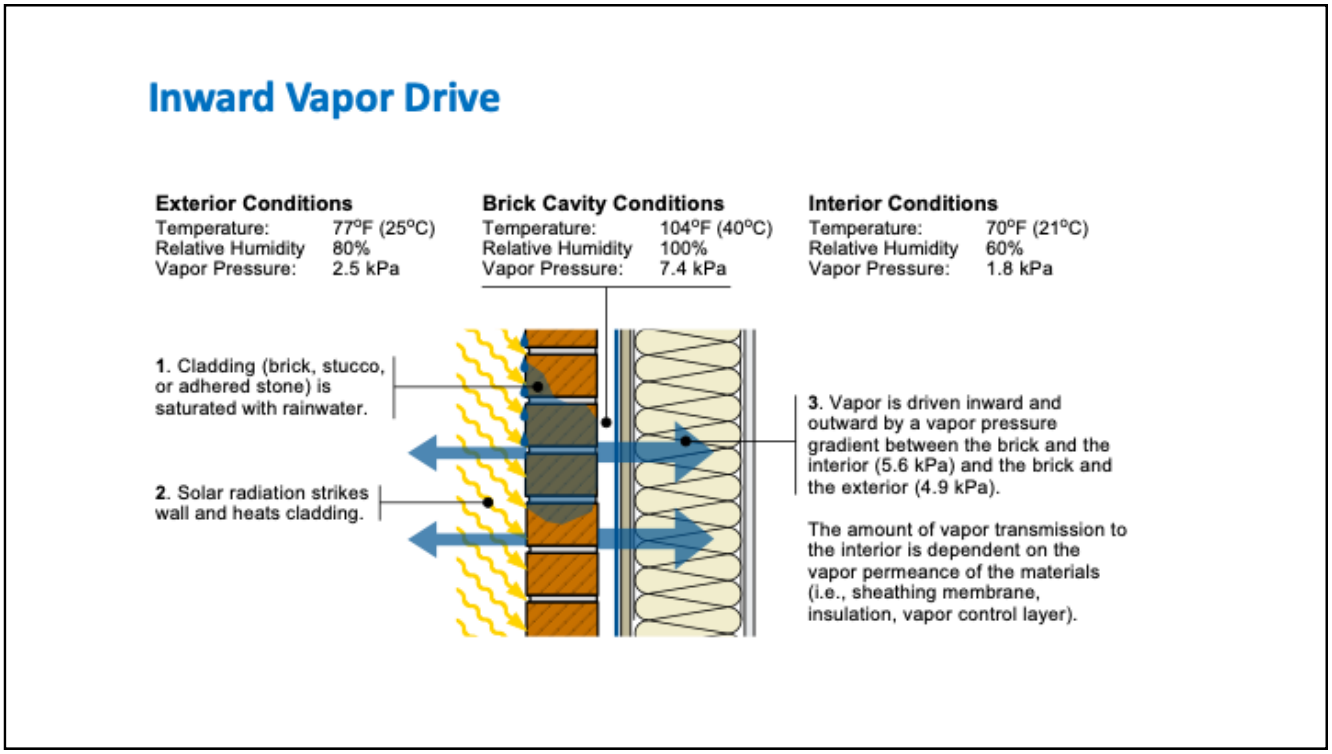


The perfect wall is conceptional. More than 75 percent of the total insulation is located outboard of the structure. This concept works in all climates because all control layers, including the air-, moisture-, and vapor-control layers, are outboard of the structure. Therefore, the structure is mainly unaffected by thermal-, air-, and moisture-control loads. If using a Class I or II vapor-control layer, it must be located to the inside of the insulation.

Vapor-Control Recommendations

A Class III vapor-control layer on the interface of a high-permeance (more than 10 perms) insulation layer outboard of a moisture-sensitive structure should only be used if warm weather and inward vapor drive condensation are not an issue or are controlled by interior drying, ventilation of the cladding, or other means.

Warm climates and sunshine can cause inward vapor drive. The moisture can be handled in different ways, either by placing a vapor-retarding material on the outboard of the insulation, using a vapor-retardant insulation itself, or providing interior drying capacity such as air-conditioning.



Inward vapor drive happens when reservoir claddings are saturated with rainwater, then hit by solar radiation. The cladding absorbs and holds water. When the sun hits the cladding, it heats up, creating a layer of high moisture-vapor pressure on the surface of the cladding. The cooler interior is at a lower moisture-vapor pressure since moisture-vapor always moves from high to low pressure. The moisture will drive inward away from the high-pressure layer on the surface. The amount of moisture vapor driven through will depend on the moisture-vapor permeability of the various system components.

Inward vapor drive can cause condensation inside the wall structure, as seen in this example.

Vapor-Control Recommendations

- **Framed assemblies with some insulation value outside of the framing or structure**
- A Class III vapor-control layer may be used on the interior of framed walls if any of the following criteria are met:
  - **Zone 1–3** (e.g., Miami to Atlanta)
    - No requirements

The following slides describe the use of a Class III vapor retarder in a framed wall assembly, including placement and amount of insulation, by climate zone.

This describes the flow-through assembly with excellent drying capacity.

Vapor-Control Recommendations

- **Framed assemblies with some insulation value outside of the framing or structure**
- A Class III vapor-control layer may be used on the interior of framed walls if any of the following criteria are met:
  - **Zone 4c** (e.g., Vancouver, Seattle, or Portland)
    - Sheathing-to-cavity R-value ratio of >0.20
    - Insulated sheathing with an R-value ≥ 2.5 on a 2x4 insulated framed wall
    - Insulated sheathing with an R-value ≥ 3.75 on a 2x6 insulated framed wall

Vapor-Control Recommendations

- **Framed assemblies with some insulation value outside of the framing or structure**
- A Class III vapor-control layer may be used on the interior of framed walls if any of the following criteria are met:
  - **Zone 5** (e.g. Chicago, Windsor, Boston)
    - Sheathing-to-cavity R-value ratio of >0.35
    - Insulated sheathing with an R-value ≥ 5 on a 2x4 insulated framed wall
    - Insulated sheathing with an R-value ≥ 7.5 on a 2x6 insulated framed wall

Vapor-Control Recommendations

- **Framed assemblies with some insulation value outside of the framing or structure**
- A Class III vapor-control layer may be used on the interior of framed walls if any of the following criteria are met:
  - **Zone 6** (e.g., Toronto, Ottawa, Montreal, Halifax, Minneapolis)
    - Sheathing-to-cavity R-value ratio of >0.50
    - Insulated sheathing with an R-value ≥ 7.5 on a 2x4 insulated framed wall
    - Insulated sheathing with an R-value ≥ 11.25 on a 2x6 insulated framed wall

Vapor-Control Recommendations

- **Framed assemblies with some insulation value outside of the framing or structure**
- A Class III vapor-control layer may be used on the interior of framed walls if any of the following criteria are met:
  - **Zones 7 and 8** (e.g. Calgary, Edmonton, Whitehorse, Anchorage, Fairbanks)
    - Sheathing-to-cavity R-value ratio of >0.70
    - Insulated sheathing with an R-value ≥ 10 on a 2x4 insulated framed wall
    - Insulated sheathing with an R-value ≥ 15 on a 2x6 insulated framed wall

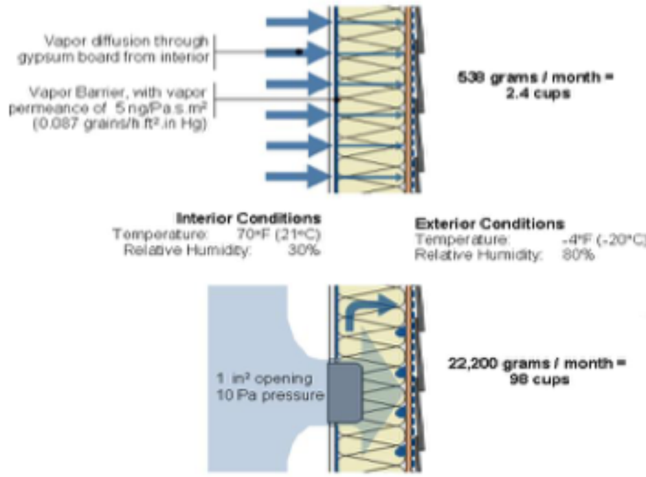
Air moves more Vapor than Diffusion!

Vapor Diffusion Only

- Class III vapor control
- 1 to 10 U.S. perms

Air Leakage Only

- Class I vapor control
- Less than 0.1 U.S. perms



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

Diffusion is just one component that moves vapor through a structure. The much bigger factor that needs to be considered is air movement.

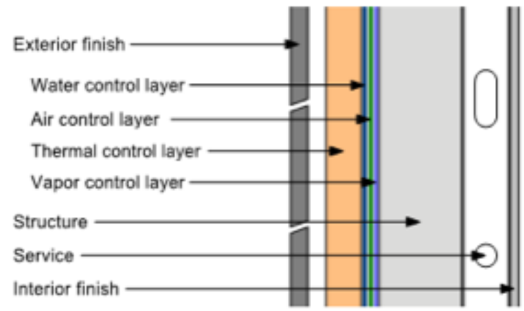
The first assembly has an airtight Class III vapor-control layer on the interior side. The second assembly has a leaky Class I vapor-control layer to the interior side. Even if the second assembly Class I vapor-control layer retards more vapor diffusion, the condensation caused by air leakage through a 1-inch opening is 40 times higher.

* Diffusion is rarely a big deal, but air leakage almost always is!

Moisture-Control Strategies
for High-performance Buildings

The Perfect Wall Concept

- Support
  - Structure is anything that works
- Control continuity
  - Rain-control layer
    - Perfect barrier,
    - Drained with gap, or
    - Storage



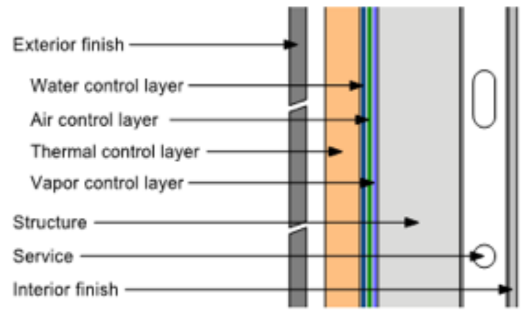
The perfect wall consists of four layers: support, control, service, and finish layers.

The support layer is the load-bearing structure of the wall assembly, such as the framing.

The control layer category contains four different layers itself. Each controls one moisture source like water, air, thermal, and vapor. Each control layer is important and necessary for a fully functional wall.

The Perfect Wall Concept

- Control continuity
  - Air-control layer
    - Air barrier
  - Thermal-control layer
    - AKA insulation, radiant barriers
  - Vapor-control layer
    - Retarders, barriers, etc.
  - Fire, sound, pest, etc.
- Finish
  - Interior and exterior



Placing the thermal-control layer as well as the air- and vapor-control layers outboard of the structure has many advantages when it comes to moisture control.

Continuity is the most important property for all control layers to avoid moisture problems.

The details of air, vapor, and thermal-control layers are part of the next courses. We will continue with the most important layer when it comes to moisture control: the rain-control layer.

Rainwater Control

- Now, industry is using mostly a rainscreen approach to cladding
- Performance of “rain-control layer” is key
  - Needs to drain down and out
  - Needs to be continuous
  - Different approaches available

To control rainwater, the construction industry today mostly uses the rainscreen approach. To perform properly, the rain-control layer needs to be continuous, draining rainwater down and out. There are different approaches being used for this control layer.

Sheet Membranes

- Products available for any substrate and application condition
- Shingling works!

One approach is to use sheet membranes as the rain-control layer. There are products for any substrate or condition available, and the membranes are fastened either by mechanical attachment or adhering to the substrate. Either approach has advantages and disadvantages, but every membrane follows the golden rule of rainwater control: positive shingling, the upper layer lapping on the lower layer.

Sheet Membranes

- Inadequately secured during construction
- Shingling often botched/installed incorrectly
- Beware of wrinkles

Common problems with the installation of sheet membranes are that membranes are secured inadequately during construction, torn apart by wind loads, or just a botched installation with a lot wrinkles and/or shingled in the wrong direction.

Liquid Applied

- Avoids laps

Another approach to control rainwater is to use a liquid-applied membrane. With liquid-applied membranes, the risk of wrinkles and negative shingling can be avoided as well as tearing by heavy wind loads.

Liquid-Applied Barriers

- Challenges with thickness control
- Limitations on application conditions

But liquid-applied layers have their own issues.

- They must be applied with adequate thickness to be sufficiently water impermeable.
- To spray on the right thickness is often difficult and complicated to verify.
- Liquid-applied materials have limitations on weather conditions such as wind, rain, and cold as well as on substrate conditions like dirt. This often leads to construction delays or poor performance.

Mixed Liquid & Membranes

- Often use mix for transitions

Depending on the installation, a mixed use of sheet membrane and liquid-applied membrane can be a successful combination.

* A drained screen assembly is the best strategy to control rain penetration in most climate zones.

Effective Detailing for Moisture Control

Water-Control Layer

Air barrier application in residential construction

Surface preparation

If the rain-control layer is self-adhered, then dirty surfaces should be prepared through cleaning or priming to ensure that it sticks to the substrate, not to the dust or dirt.

Water-Control Layer

A continuous rain-control layer includes every affected component, such as windows, dormers, valleys, and connections between the roof and wall assemblies at the eaves.

Subsill Flashing

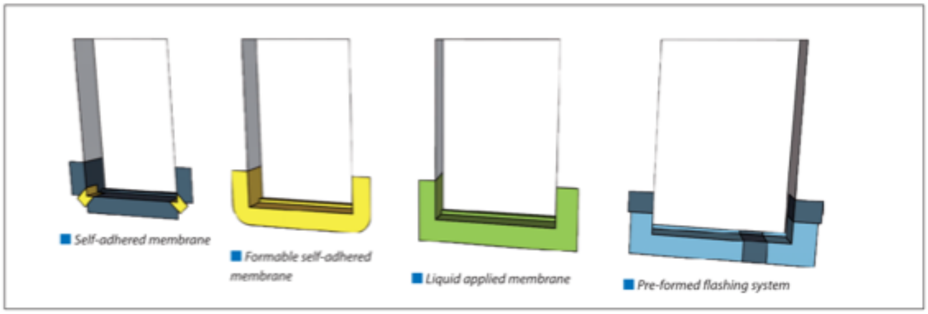
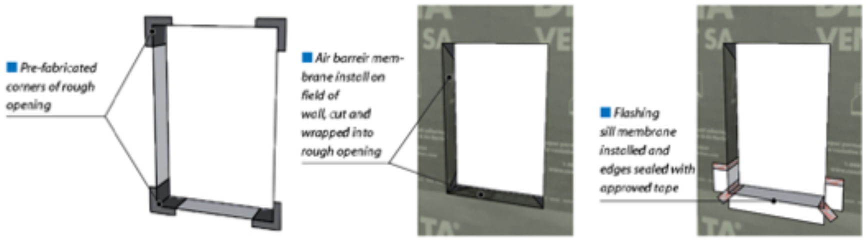


Figure 3: Sub-sill flashing below all window and door openings is a critical component to ensure resistance to rain penetration.

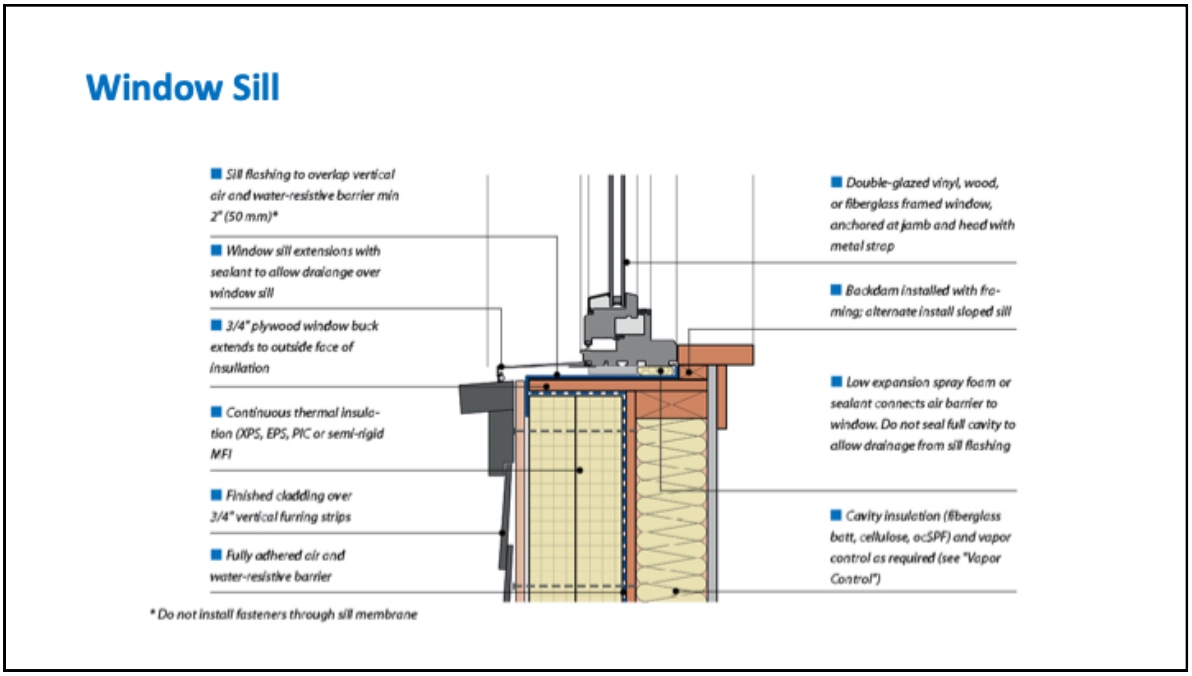
The sub-sill flashing below all window and door openings is a critical component to ensure resistance to rain penetration. Different approaches can be used to adequately address this detail, from self-adhesive and formable self-adhesive membranes to liquid-applied membranes and preformed flashing systems.

Subsill Flashing



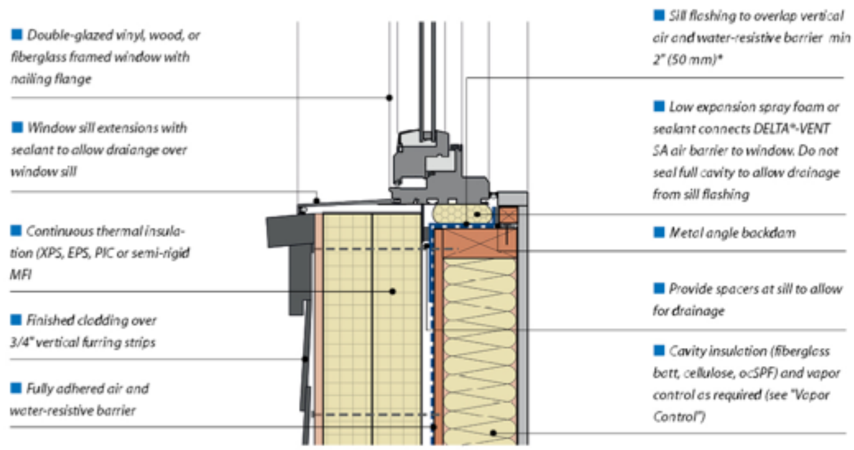
- Sub-sill flashing system

A combination of preformed corners, a self-adhesive sheet membrane, and optimally matched adhesive tape ensures a perfect rain-control layer.

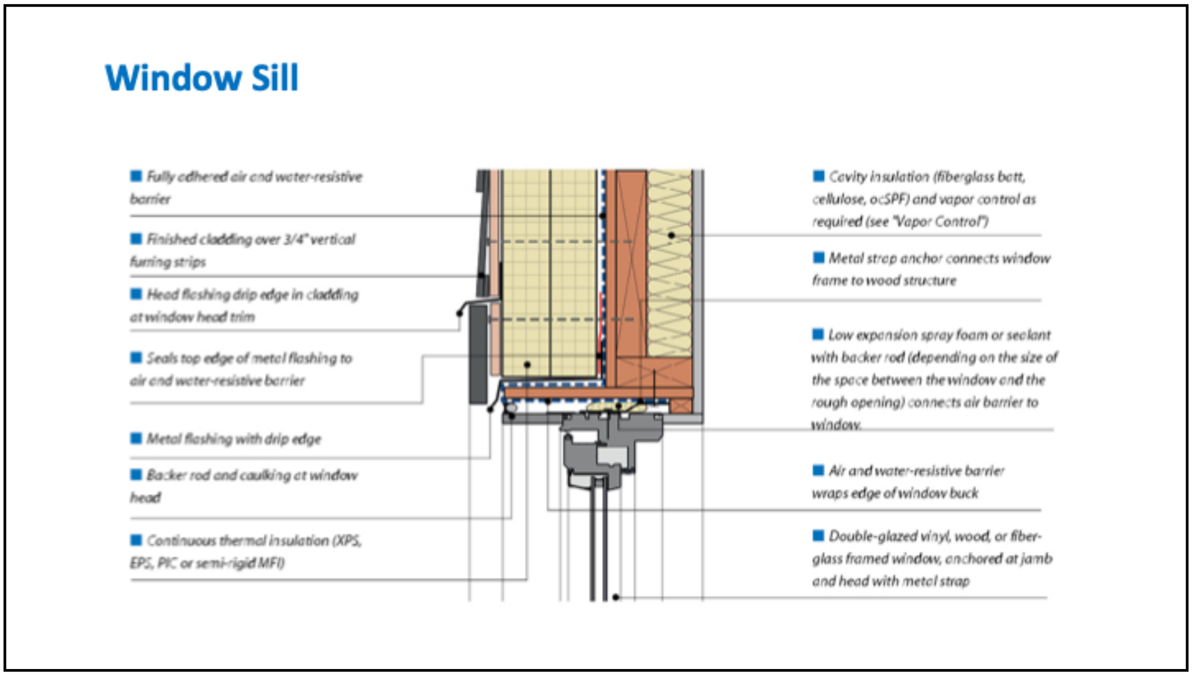


A window sill detail shows that every control layer needs to be addressed within every detail to avoid thermal bridging and ensure proper moisture control. But the specific material selection for this detail is critical. The expected water occurrence in the window sill section requires a vapor impermeable flashing material even in an otherwise vapor-permeable wall assembly.

Window Sill

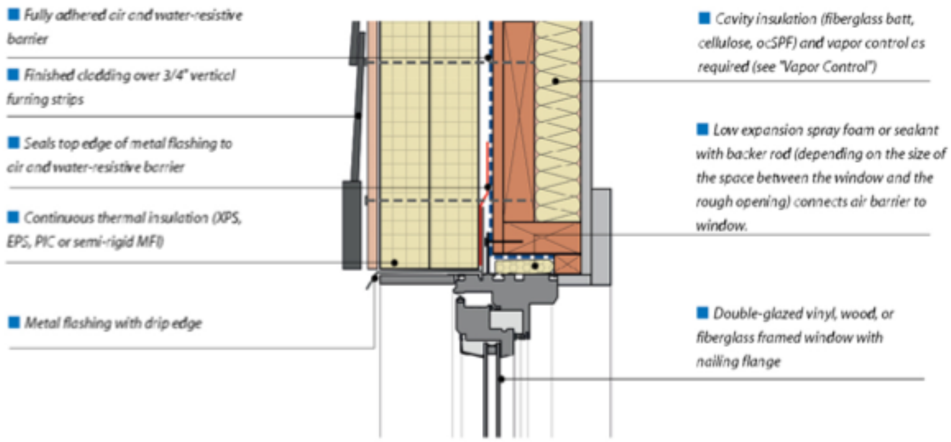


A simpler solution is to connect the rain-control layer directly to the window sill without running the continuous exterior insulation into the window sill flashing. This option is simpler, but it limits options for positioning the window, and potential moisture will not be drained outboard of the wall cladding.

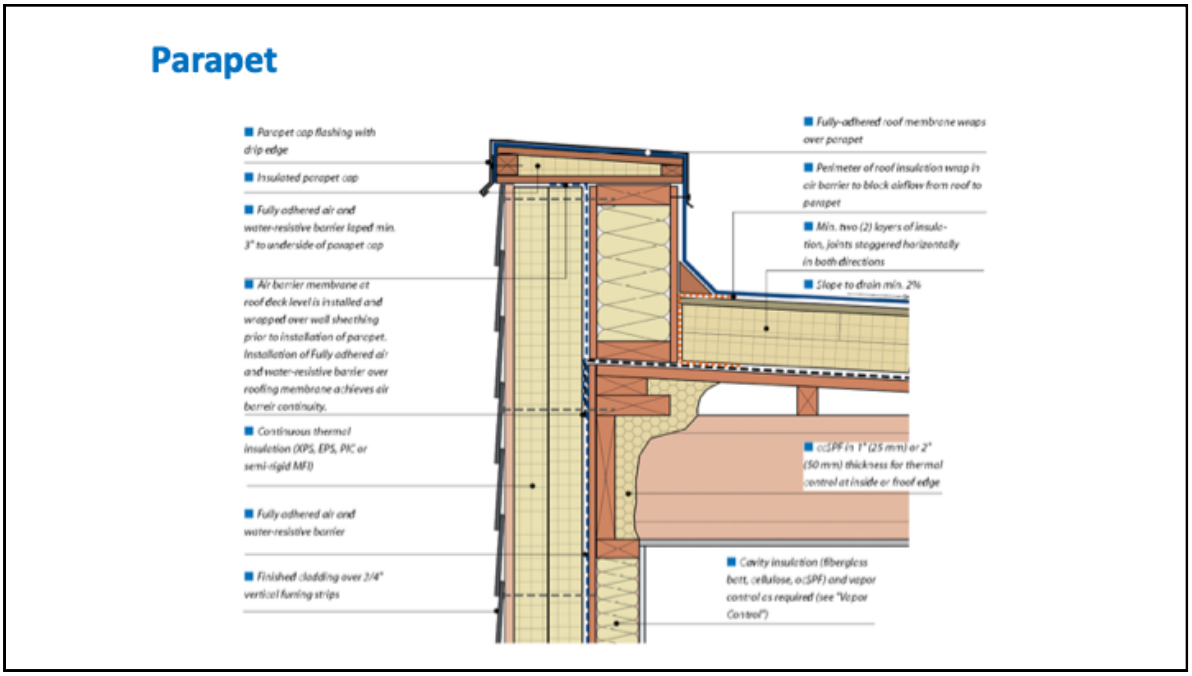


As in every detail, it is critical to connect the rain-control layer to every component. At the window lintel, the flashing can be wrapped around the exterior insulation to protect the wood construction.

Window Sill



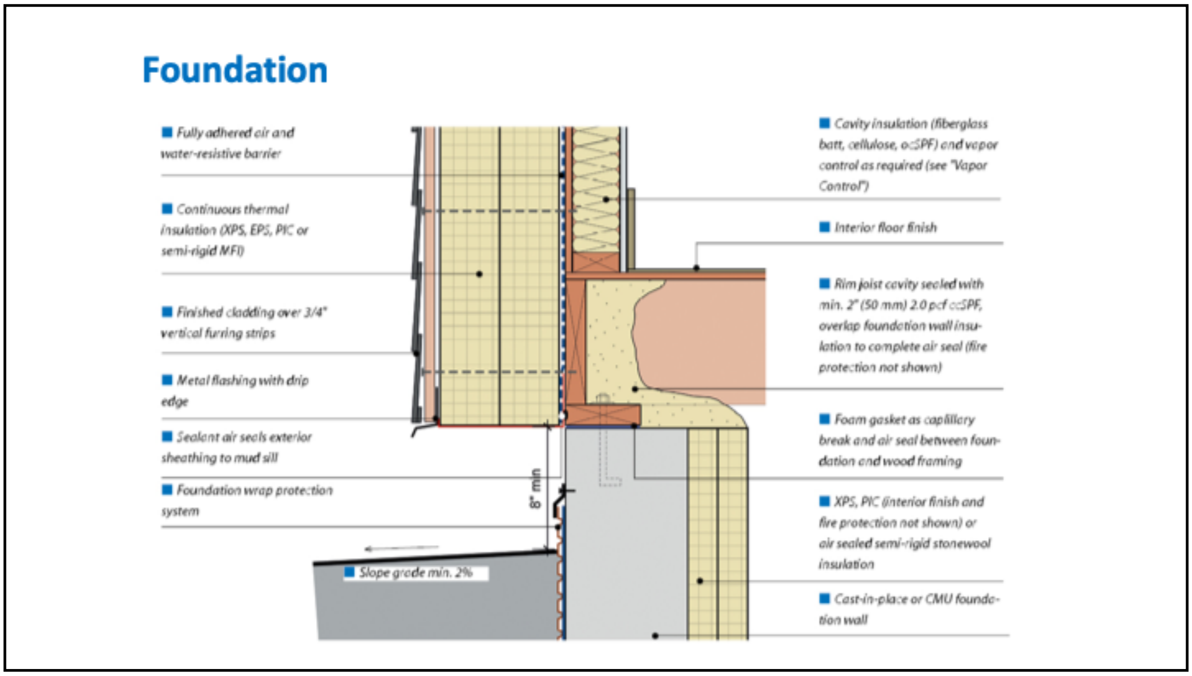
This window lintel detail is a little bit easier, but it limits the option for positioning the window.



A parapet detail can be very difficult to solve if not addressed correctly.

The connection between the rain-control layer and the parapet cap flashing is critical to ensure proper rain control. When the rain-control layer, as shown in this detail, also functions as the air-control layer, it is important for continuity to establish a connection to the roof air-control layer.

When a material is performing more than one control function, the placement and detailing in the system becomes more critical to ensure each of the control functions is properly addressed. A detailed description of every connection point is extremely important to ensure proper installation and performance.



No less complex is the foundation detail where the floor and basement structures are connecting to the wall assembly. Same rule: when one material covers different tasks, it is even more important to address every control function in the detail drawings.

* Do not rely on caulking for perfect barrier rainwater control in details.

Summary

- We can no longer rely exclusively on historical experience. We need to understand enclosure design from first principles.
- A drained screen assembly is the best strategy to control rain penetration in most climate zones.
- Diffusion is rarely a big deal, but air leakage almost always is.
- Do not rely on caulking for perfect barrier rainwater control in details.

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.