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TECHNICAL ARTICLE

CONTROLLING MOISTURE BALANCE WITH WATERTIGHT VAPOR-OPEN ASSEMBLIES

by Peter Barrett and Todd Kimmel CPHD, CDT

Ever more stringent energy code requirements have necessitated increased insulation levels; in many cases, this includes adding exterior insulation. Additional insulation thickness and changes to the insulation location require reconsideration with regards to vapor diffusion and condensation control.

Varying vapor permeability of different insulation products, membranes, and other building materials introduces significant complexity to wall assembly design. Some insulation materials, like stone wool and fiberglass, are vapor permeable, while others, such as extruded polystyrene (XPS), expanded polystyrene (EPS), polyisocyanurate, and closed-cell spray foam, are relatively impermeable.

Energy codes and building codes can be confusing as they relate to exterior insulation selection and moisture control for walls. A wall works by keeping the outside out and the inside in. According to Dr. Joe Lstiburek's "Perfect Wall" principle, there is the water control layer, air control layer, vapor control layer, and thermal control layer all in the right places. Moisture to the inside of the vapor control layer dries inward while moisture to the exterior dries outward.

Selection of a particular arrangement of material layers, and the vapor permeance of those layers, will control vapor diffusion. Controlling vapor diffusion is one means of controlling condensation and the location of the dew point within the wall.

Another part of condensation management is having an airtight assembly that is vapor open in both directions. Place an airtight membrane, typically a water-resistive barrier that is also an air barrier, on the outside of the structural sheathing then cover the outside of that with another layer of vapor-open insulation. The wall can dry to the inside and outside. The term for this is a "flow-through assembly". It is airtight, but vapor open on both sides with a semi-permeable control layer in the middle and a throttle at the air control layer. In the case of the flow-through assembly, the throttle would be the lowest permeable component, such as the oriented strand board (OSB) sheathing. It should be noted the ratio of exterior insulation R-value to total insulation R-value is critical in this case to control condensation due to vapor diffusion on the sensitive layers (typically the sheathing). This ratio must be calculated based on the indoor and outdoor climates to ensure the temperature of the sheathing (or any other moisture-sensitive layer) always remains above the dew point.

This article clarifies and provides guidance on vapor diffusion and condensation control in these new wall assemblies.

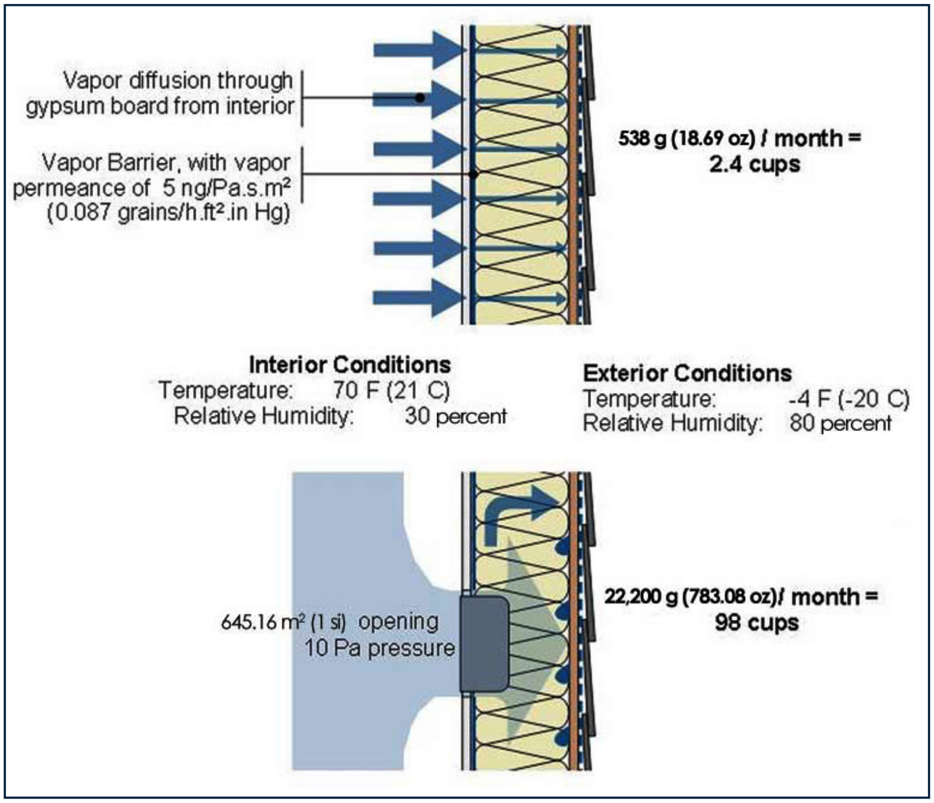
Preventing dangerous moisture from getting into buildings
requires a continuous water-, air-, and weather-tight barrier.
Photo courtesy Weis LGA Architects and Gaydon Contractors.

Understanding Vapor Diffusion

Vapor diffusion is the movement of water vapor molecules through porous materials (e.g. wood, insulation, drywall, concrete, etc.) driven by vapor pressure differences. Vapor pressure differences occur as a result of temperature and water vapor content differences in the air. Vapor diffusion flow always occurs through an assembly from the high- to the low-vapor-pressure side, which is often from the warm side to the cold side, as warm air can hold more water than cold air.

In cold climates, this means vapor diffuses primarily from the heated interior to the colder outdoors, whereas in hot climates, the vapor drive is reversed and instead flows primarily from the warm, humid exterior to the air-conditioned interior. The direction of vapor diffusion can also be reversed when the sun heats up damp, absorptive wall claddings like masonry, driving water vapor inward.

Overall, the direction of the vapor drive has important implications on the placement of materials within a wall assembly. The best tool for calculating vapor pressure differentials is the **psychrometric chart**.



Controlling the flow of air is more important than controlling vapor diffusion. During a heating season, air leakage through gypsum board with a hole in the middle will result in 28.4 L (7.5 gal) of water. However, vapor diffusion through a solid sheet of gypsum board with no hole, will only result in 0.3 L (0.08 gal) of water.

Vapor Barriers and Vapor Retarders Defined

While the goal is to limit the air flow through walls, the air that does make it into the walls (from the conditioned or unconditioned side) may leave condensation behind when it goes from warm to cold. Making a wall or building as airtight as possible makes sense at first. However, the wall assembly should, preferably, be water vapor permeable to allow incidental moisture to escape or diffuse, instead of being trapped and forced into the wall materials. This is not always as easy as it sounds.

A vapor retarder, according to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), is designed and installed in an assembly to retard the movement of water by vapor diffusion. There are several classes of vapor retarders from which to choose. The International Building Code (IBC) uses ASTM E96 Method A to categorize materials as vapor retarders. For example, according to the 2018 IBC, the Vapor Retarder Classifications are:

- Class I: 0.1 perm or less
- Class II: 1.0 perm or less and greater than 0.1 perm
- Class III: 10 perm or less and greater than 1.0 perm

Colloquially, what one typically refers to as a vapor barrier is a Class I vapor retarder. To be classified as vapor permeable, a membrane needs to have a permeance of 10 perms or greater, per the ASHRAE Journal. However, the higher the perms, the better vapor can diffuse through.

When designing a well-performing wall assembly, specifiers should consider:

- using a water-resistive barrier to keep bulk water out of the wall;
- using an air barrier to prevent air movement through the wall, which could cause condensation; and
- using vapor control appropriate for the type of wall and climate zone.

In many assemblies, vapor barriers can be placed on the warm side of the insulation without being sealed airtight if there is an uninterrupted air barrier somewhere else in the wall and ceiling assemblies. However, the best practice is to fully tape and seal the vapor barrier so it is airtight. The reason for this is simple: diffusion of moisture vapor is slow, relative to much quicker air movement, which carries more moisture vapor quicker. However, a single material may perform more than one control function. For example, some materials may act as both the air- and the water-resistive barrier.

Designing a building to be as airtight as possible is an important first step when determining which barriers to use; the more airtight the building, the fewer vapor issues will crop up. Contrary to common belief, a building cannot be "too airtight," which is not to say a building does not need air exchanges. For proper air exchange, one should have a correctly sized and calibrated HVAC system.

A design can eliminate the risk of mold and rot by also allowing existing moisture to escape. The vapor permeability and airtightness of a good air and water-resistive barrier makes it ideal for building and helping to maintaining healthy and comfortable interiors while letting moisture out and improving energy efficiency.

It is expensive to install moisture control measures after a building is complete. It is much cheaper to do correctly at the time of initial construction. A building must emphasize air and vapor control as part of its design, rather than attempting a retrofit, so it will be much more secure against mold, mildew, and other problems. This also ensures there will be fewer issues and expenses down the road.

Controlling Vapor Diffusion

Assemblies do not always require vapor barriers. Historically, they dried both outward and inward, could manage leaky windows without flashing, and could be rained on during construction. The key to this superior moisture management in older buildings was poorly insulated or uninsulated walls. The heat that flowed through helped dry the assembly of any moisture.

A trend toward tighter and more highly insulated enclosures led to higher levels of interior moisture. This, coupled with continuous exterior insulation, which resists the flow of heat through the assembly, reduces the wall's drying potential. Therefore, interior moisture should be handled at the source using ventilation fans, and through the proper design, installation, and operation of the building's heating and cooling system. The interior moisture that cannot be eliminated needs to be controlled by an air and vapor barrier.

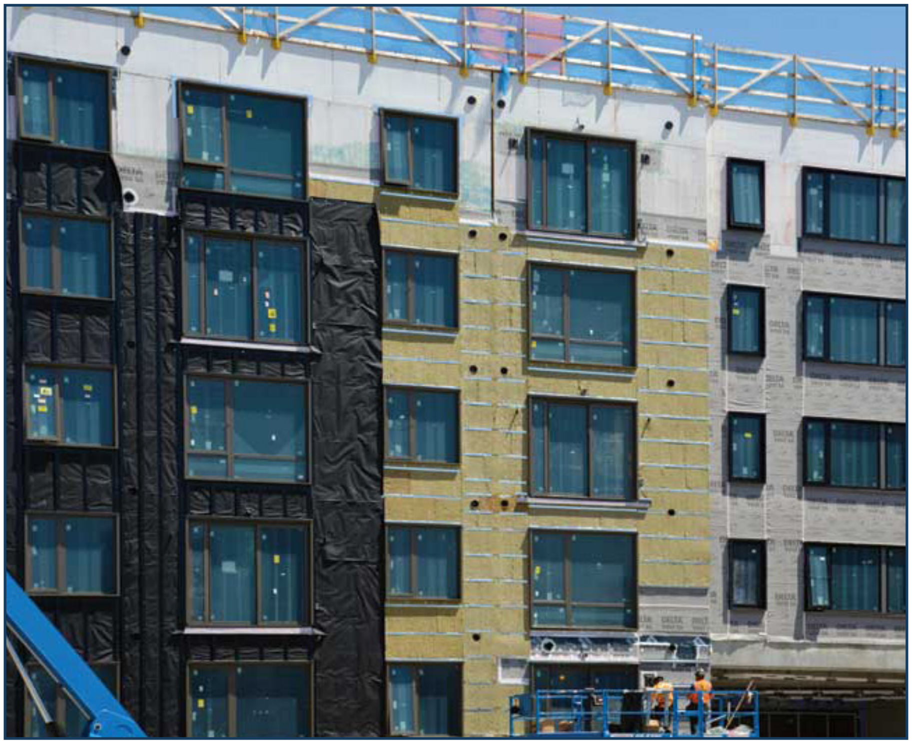
Controlling the flow of air is more important than controlling vapor diffusion. During a heating season, air leakage through gypsum board with a hole in the middle will result in 28.4 L (7.5 gal) of water. However, vapor diffusion through a solid sheet of gypsum board with no hole will only result in 0.3 L (0.08 gal) of water.

Vapor-open Assemblies

Although vapor barriers (where required) are intended to prevent assemblies from getting wet, they also often prevent them from drying. Vapor barriers installed on the interior side of assemblies impede drying toward the interior (e.g. vinyl wallpaper, white boards, etc.)—this is a problem for air-conditioned spaces and can be an issue when there is also a vapor-impermeable material on the assembly's exterior, creating a double-vapor-barrier wall assembly (i.e. impermeable continuous exterior insulations such as polyisocyanurate or extruded polystyrene boards). Therefore, it is practical to encourage drying mechanisms over wetting prevention mechanisms—meaning one should avoid using vapor barriers if vapor retarders will work and avoid using vapor retarders when vapor-permeable materials suffice. Additionally, some flow-through assemblies need a ventilated cladding system to cover the continuous insulation (ci) or exterior sheathing to let the passing moisture get around the wall assembly. Most claddings do not need a significant amount of space. Dr. Joe Lstiburek recommends a minimum of 9.5 mm (0.38 in.).

However, when it comes to reservoir claddings, such as brick veneers, and very vapor-open sheathings (coupled with very vapor-open water and air control layers), a building will require larger space for ventilation to handle higher moisture loads. For stucco or adhered stone over a wood-based sheathing, the 2021 IBC (Section 2510.6.2, Moist or marine climates) requires a minimum space of 4.8 mm (0.19 in.) to the exterior of a Grade D 60-minute equivalent water-resistive barrier. The 2021 International Residential Code (IRC) uses the same language.

The inward motion (known as solar-driven moisture) occurs with a rain-wetted reservoir cladding, coupled with solar radiation and air conditioning. This inward motion should be "throttled" down and



The exterior of Clippership Wharf in Boston incorporated a prefabricated wood frame construction with fire-rated OSB sheathing. This approach, coupled with the city's climate zone and unique location challenges, called for the use of a vapor permeable air- and water-resistive barrier. No matter how moisture entered the system, through construction or intense wind-driven rain and snow, the team needed to be confident that any incidental moisture could escape and not cause serious damage to the building enclosure. Photo courtesy The Architectural Team and Lendlease the cladding should be uncoupled with a ventilated air space, or the size of the reservoir might need to be reduced by painting the cladding or by using additives with the ability to reduce water absorption.

Vapor-open Insulation

The primary reason to choose vapor-open insulation is to allow for superior drying. Wall assemblies will almost always leak, so plan ahead and use a vapor-open insulation product to facilitate the drying of that moisture when it inevitably happens. But the wall assembly itself and the strategy for vapor permeability will depend on the type of application. The plan will vary if it is a retrofit versus a new construction.

Regardless of the assembly, material selection is critical. Vapor permeable insulation such as stone wool will allow for greater drying than can be achieved with vapor impermeable insulation such as foam plastics: XPS, polyisocyanurate, and spray polyurethane foam insulation. This greater drying ability generally results in improved durability of the wall assembly.

Wall Assembly Design

Whether the construction is new or a retrofit, there are three typical approaches to insulating walls: all interior cavity insulation, all exterior continuous insulation, or split insulation between the interior and the exterior side of the wall. The selection depends on several factors, such as construction type and climate. Climate will dictate the direction of the vapor drive as well as the dew point and, consequently, where to install the vapor barrier in relation to the insulation. In the south, for example, the priority is preventing moisture from coming in from the exterior; in the north, the opposite is true.

Stud Cavity-insulated Walls

Exterior rigid insulations may be used as the exterior vapor retarder; however, their permeability is relatively low, which restricts drying to the exterior. A vapor-open exterior insulation, such as stone wool, used in conjunction with a vapor permeable membrane of at least 10 perms, provides a forgiving assembly with increased exterior drying. Additionally, this assembly can tolerate leaks and construction moisture to a certain degree. The 5 to 10 perm (semi-permeable) vapor control can be achieved by selecting an appropriate fluid-applied, self-adhered, or mechanically fastened water control membrane applied over the sheathing or concrete masonry unit (CMU) back-up wall. Alternately, when using plywood or OSB sheathing, a more vapor-open water control layer is permissible, since the plywood or OSB itself provides the vapor control.

In colder climates, where only stud cavity insulation is usable in a building, thermal bridging in walls can increase the risk of condensation by causing increased heat loss, resulting in colder surfaces where condensation may form if the temperature of the surface falls below the dew point. Builders may install continuous insulation on the exterior of a building to reduce this risk.

For warm climates, installing an interior vapor retarder can create a substantial risk of condensation within the wall assembly. A common, unintentional example of this is the use of vinyl wallpaper. The vinyl wallpaper acts as an interior vapor retarder and, in combination with inward vapor drive, can lead to moisture accumulation within the wall assembly. Alternatively, in warm and humid climates where air conditioning is provided, diffusion occurs primarily from the exterior to the interior and an exterior vapor retarder should be provided.

Exterior-insulated Walls

Instead of insulating walls within the stud cavity, exterior continuous insulation can be used in any climate, and this approach to insulating wall assemblies can also be effective for concrete or CMU walls. In these walls, insulation goes on the exterior of the wall back-up.

Exterior continuous insulation is an effective way of achieving highly insulated wall assemblies and can substantially reduce thermal bridging. In addition to these thermal benefits, exterior insulation can also provide a robust assembly with respect to vapor diffusion and condensation.

The use of exterior continuous insulation changes the temperature profile through the wall assembly and, consequently, the back-up wall—be it sheathed steel stud, concrete, or CMU—is maintained at a temperature relatively close to interior conditions. Additionally, since a water-resistive barrier is applied to the back-up wall behind the insulation in these assemblies, moisture-sensitive materials are generally all located on the interior side of the insulation and water-resistive barrier where they remain both warm and dry, resulting in a very durable wall assembly in all climates.

Split-insulated Walls

In some cases, it can be advantageous to use split-insulated wall assemblies; that is, assemblies where insulation is provided both in the stud cavity and on the exterior of the sheathing. Usually these are used as they can provide the necessary R-value in a relatively compact (i.e. thinner) assembly. As one might guess, these walls essentially provide a mixture of the performance of stud cavity insulated and exterior insulated wall assembly.

Given that split-insulated walls fall somewhere between stud cavity-insulated walls and exterior-insulated walls with respect to performance, there are important considerations to make with respect to vapor diffusion. Generally, the exterior insulation will be enough to keep the sheathing closer to interior conditions, but if it is a relatively small fraction of the overall insulation in the wall, the sheathing will remain at temperatures close to the exterior. In this situation, the vapor permeability of the insulation should be considered.

When vapor permeable stone wool insulation goes outboard of the sheathing, it has the effect of warming the stud space and exterior sheathing—the more exterior insulation, the warmer the cavity and sheathing. An interior or exterior Class I vapor retarder may not be required; a Class II or III vapor retarder may be necessary to prevent condensation or high relative humidity (RH) levels from occurring. This will depend on the thickness of exterior insulation and the vapor pressure gradient (expected interior and exterior conditions). It ultimately depends on ensuring a proper ratio of exterior air permeable insulation R-value to total insulation R-value. For moderately cold climates and most indoor conditions within commercial buildings, the installation of a thin layer of stone wool outboard of an insulated (152 mm [6 in.]) stud wall is sufficient to ensure good performance when applying Class III vapor retarder (e.g. latex paint) on the drywall's interior. Because wood is hygroscopic, keeping RH in the wall low is critical to preventing mold and decay.

Detailing and Roof Assemblies

In flat commercial roofs, vapor-open insulation does not provide any value in relation to vapor control, as they will always require a roofing membrane which is vapor permeable, but do not disqualify it as a good choice in this application, as stone wool insulation provides several other benefits. In fact, in comparison to other roofing insulation materials, stone wool's complete performance (i.e. thermal stability [the R-value of some foam insulation will decrease over time due to blowing agent off-gassing], dimensional stability [e.g. foam shrinks, creating gap], acoustic performance, and fire resistance) makes it an ideal solution.

Cladding Selection

While most cladding materials and assemblies do not contribute to controlling vapor—stucco is one such exception—considerations necessary in regard to the use of sandwich wall panels (SWP), precast tilt up, and curtain wall systems, or in areas where rainscreen systems may not be used. Additional considerations will also be necessary if using a vapor-open insulation. SWP are not different from foam in that they are vapor impermeable; however, mass walls are if they are insulated from the interior. In this case, it is logical to allow for a high drying potential, so the wall can dry while ensuring moisture does not penetrate the wall (at least from the interior side). Here, it is common to use a smart membrane—a variable permeance vapor barrier on the interior side of the assembly.

Curtain wall systems are another story. They typically include a vapor barrier on the interior side (foil or back pan) and a vapor barrier on the exterior side (glazing). The bottom line? These assemblies need to be tightly water and air sealed to prevent moisture from penetrating, and to allow them to drain and dry out.

Conclusion

Controlling moisture vapor within walls is a balance between minimizing wetting and maximizing drying ability. Correct selection and placement of vapor retarders can prevent excessive moisture vapor and potential condensation in wall assemblies. Using vapor permeable materials allows moisture to diffuse both inward and outward, and is beneficial to drying performance. Stone wool vapor-open insulation with a vapor permeable, airtight, and watertight barrier is a smart choice.

The strategy is simple: ensure that drying capacity exceeds wetting potential. A flow-through wall design provides the greatest freedom in construction design and building location, while providing benefits beyond thermal and moisture performance; occupant safety and comfort are all improved with a well-designed and durable wall.

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