Understanding Vapor Diffusion and Condensation – The Basics

By Lorne Ricketts, PEng and Marcus Dell, PEng

Building enclosure assemblies serve a variety of functions to deliver long-lasting separation of the interior building environment from the exterior, one of which is the control of vapor diffusion. Resistance to vapor diffusion is part of the environmental separation; however, vapor diffusion control is often primarily provided to avoid potentially damaging moisture accumulation within building enclosure assemblies. While resistance to vapor diffusion in wall assemblies has long been understood, ever-increasing energy code requirements have led to increased insulation levels, which in turn have altered the way assemblies perform with respect to vapor diffusion and condensation control. In particular, for construction in cold climates, these changes have led to the widespread use of exterior-insulated and split-insulated wall assemblies (see *Figure 1*).

PRINCIPLES OF VAPOR DIFFUSION

Fundamentally, vapor diffusion is the movement of water vapor molecules through porous materials (e.g., wood, insulation, drywall, etc.) as a result of differences in vapor pressure. Vapor pressure differences occur as the result of variations in air temperature and sources of humidity, such as occupants, showers, pools, plants, etc. The commonly used term "relative humidity" (RH), which is expressed as a percentage, refers to the amount of water vapor in the air (i.e., the vapor pressure) divided by the maximum amount of water vapor that the air could hold at the same temperature (i.e., the saturation vapor pressure). Dew point temperature is the temperature at which the RH of the air would be 100%. This is also the temperature at which condensation will begin to occur.

The direction of vapor diffusion flow through an assembly is always from the high vapor pressure side to the low vapor pressure side, which is often also from the warm side to the cold side, because warm air can hold more water than cold air (see *Figure 2*). Importantly, this means it is not always from the higher RH side to the lower RH side.

The direction of the vapor drive has important ramifications with respect to the placement of materials within an assembly, and what works in one climate may not work in another. Improper use and placement of vapor-impermeable materials within a wall can lead to condensation and, potentially, to damaged materials and fungal growth.

CONTROLLING VAPOR DIFFUSION

Vapor-retarding materials are used to control vapor diffusion through wall assemblies. All building materials provide some resistance to vapor diffusion, and the amount of resistance varies depending on the properties of the material. These properties can change with the RH and moisture content, age, temperature, and other factors. Vapor resistance is commonly expressed using the inverse term "vapor permeance," which is the relative ease of vapor diffusion through a material.

Vapor-retarding materials are often grouped into classes (Classes I, II, III) depending on their vapor permeance values. Class I (<0.1 US perm) and Class II (0.1 to 1.0 US perm) vapor retarder materials are considered impermeable to near-impermeable, respectively, and are known within the industry as "vapor barriers." Some materials that fall into this category include polyethylene sheet, sheet metal, aluminum foil, some foam plastic insulations (depending on thickness), and self-adhered (peel-and-stick) bituminous membranes. Class III (1.0 to 10 US perm) vapor retarder materials are considered semipermeable, and typical

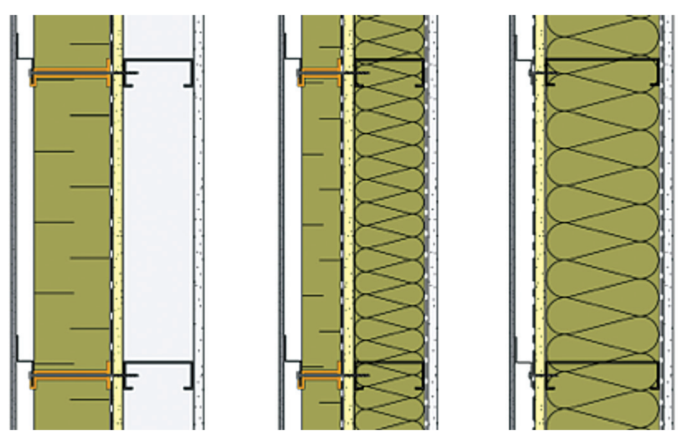

Figure 1 – Exterior-insulated (left), split-insulated (middle), and stud-cavity-insulated (right) steel-stud walls are three ways to insulate the building enclosure, but these walls can provide significantly different performance with respect to vapor diffusion and condensation.

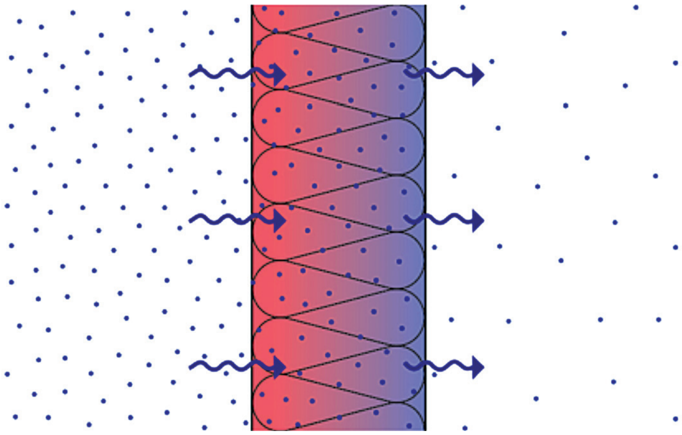

Figure 2 – Example of wall assembly showing outward vapor drive for a cold climate (interior on the left and exterior on the right).

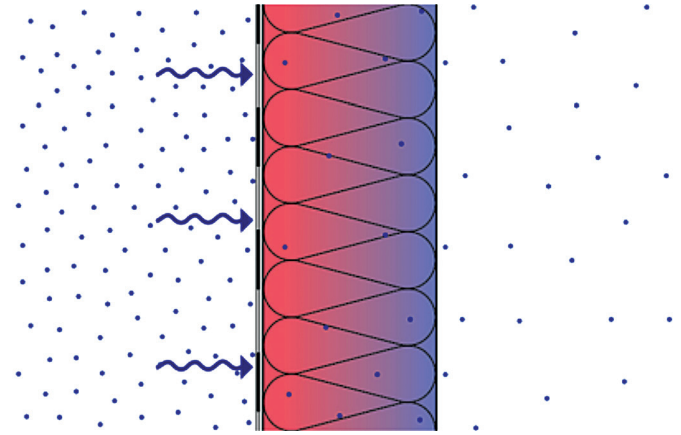

Figure 3 – Schematic vertical cross section showing how a vapor barrier on the interior (left) side of a wall assembly can control vapor diffusion through the assembly (interior on the left and exterior on the right).

materials that fall into this category include latex paints, plywood, OSB, and some foam plastic insulations (depending on thickness). Materials greater than 10 US perms are considered vapor-permeable.

Figure 3 illustrates how a vapor retarder can be used in a cold climate to control the diffusion of vapor through the wall assembly.

WHEN DOES CONDENSATION OCCUR?

Condensation occurs within a wall assembly when the temperature of a material in the assembly is lower than the dew point temperature of the air at that location. This will typically occur when the temperature of the cold side of the assembly is lower than the dew point temperature of the warm side, and the materials on the cold (low vapor pressure) side provide greater resistance to vapor diffusion than the materials on the warm (high vapor pressure) side of an assembly. An extreme example of this condition arises if a vapor retarder material is placed on the low vapor pressure side of a wall assembly where it can restrict vapor diffusion through the wall and potentially create a condensing plane within the wall assembly (see *Figure 4*).

WETTING VS. DRYING

Vapor diffusion is typically thought of as a negative phenomenon—one that needs to be completely stopped. In reality, vapor diffusion is a positive mechanism that can be used to a designer's benefit, and is a very important drying mechanism for an enclosure assembly. In fact, vapor diffusion is the only process through which the interiors of most in-service wall assemblies can dry. The control of vapor diffusion within a wall assembly is therefore a balance of minimizing or managing wetting sources and maximizing drying potential, should the wall be constructed wet or somehow be wetted in-service. This is particularly important with highly insulated wall assemblies, as more insulation means less heat energy is available to dry moisture from within assemblies.

A potentially damaging example of restricted drying of an assembly can be caused by a condition referred to as a "double vapor barrier," in which a vapor retarder is installed at two different locations in an assembly such that any moisture that manages to get between the vapor retarder materials is unable to dry effectively. When the materials between the vapor retarders are moisture-sensitive, this trapped moisture can lead to damage. Moisture between the vapor retarders may be the result of air leakage, rainwater ingress, or built-in construction moisture. *Figure 5* illustrates a schematic double vapor barrier situation restricting the drying of a wall assembly.

WALL ASSEMBLY DESIGN

For the design of durable wall assemblies, the placement of insulation and vapor-retarding materials needs to be carefully

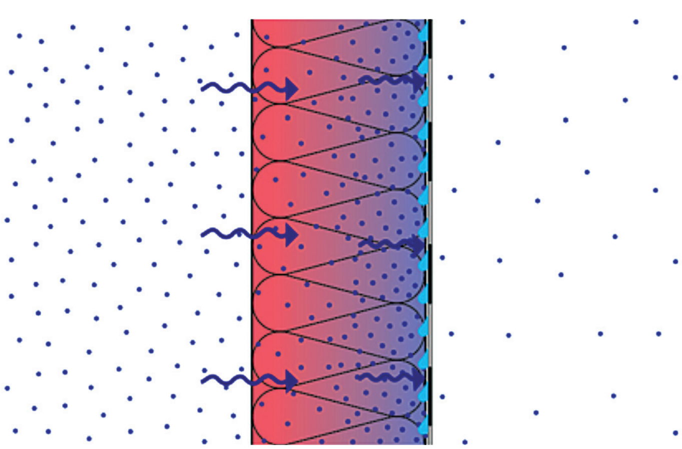

Figure 4 – Schematic vertical cross section showing condensation of moisture on a vapor-retarding material placed on the wrong (cold side) of a wall assembly (interior on the left and exterior on the right).

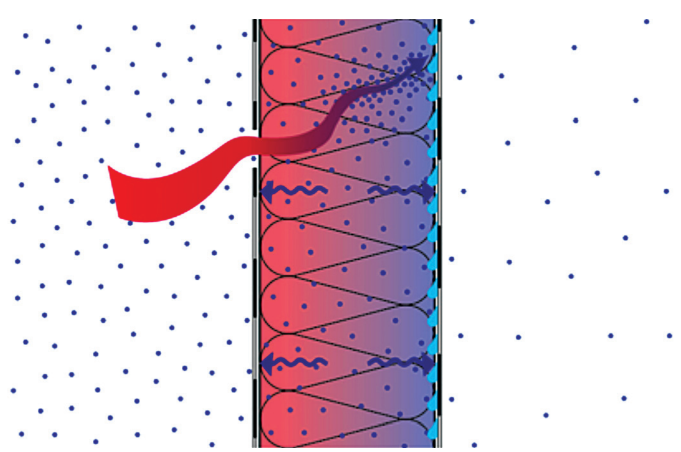

Figure 5 – Schematic vertical cross section showing air leakage (red arrow) from the interior to the exterior, causing moisture to become trapped within a wall assembly due to the presence of a two vapor barriers (interior on the left and exterior on the right).

considered. Many building codes and building enclosure design publications provide guidance for the selection of appropriate vapor control layers within wall assemblies in North American climate zones, based on the class of vapor retarder (I, II, or III). This guidance is also based on the anticipated indoor conditions for certain building types, which is related to exterior climate, indoor moisture generation rates, and ventilation rates.

Walls with insulation between the studs are pervasively used in North American construction (see *Figure 6*). In cold climates, interior vapor control is often provided by a polyethylene sheet vapor barrier, although other options—such as vapor barrier paint, Kraft paper, and smart vapor retarder products—can also be used. This interior vapor retarder limits the diffusion of moisture through the wall assembly toward the exterior. Outward vapor diffusion drying can still occur from within the wall cavity to the exterior through the sheathing, membrane, and cladding.

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 (or less commonly as the sheathing itself). Usually, split-insulated wall assemblies are used because they can provide the necessary R-value in a relatively compact (i.e., thinner) assembly (see *Figure 7*).

Split-insulated walls can also include an interior vapor retarder to control outward vapor diffusion, but there is the potential that the addition of exterior insulation will impact the diffusion of moisture. Specifically, insulation on the exterior of the sheathing keeps the sheathing closer to the interior temperature (i.e., warmer in a cold climate), generally reducing the risk of condensation at the sheathing plane. In a split-insulated assembly, the more insulation placed outboard of the sheathing compared to the insulation within the stud cavity, the closer to interior conditions the sheathing will be and the lower the risk of condensation. This can also apply to the steel studs, as when insulation is only provided in the stud cavity, these studs create significant thermal bridges that can also potentially create condensation locations.

A special condition exists when a relatively vapor-impermeable insulation product, such as many foam plastic insulation products (i.e., extruded polystyrene [XPS], polyisocyanurate, medium-density spray polyurethane foam) is used on the exterior. These insulation materials can be considered Class I or Class II vapor retarders, depending on type, density, thickness, and facings. This relatively vapor-impermeable layer on the exterior of the wall assembly can potentially lead to a double vapor retarder situation when another vapor retarder, such as polyethylene sheet, is installed on the interior of the wall assembly. To avoid this, a more permeable interior vapor retarder, such as a smart vapor retarder, would typically be recommended so that some drying to the interior is possible in the event of moisture entering the stud cavity (see *Figure 8*). In terms of balancing the wetting and drying potential, split-insulated walls with vapor-impermeable exterior insulation are generally more sensitive than walls with permeable exterior insulation.

Recently, a number of projects have occurred on which a vapor-closed insulation (XPS) has been placed over a high-performance, vapor-permeable, self-adhesive

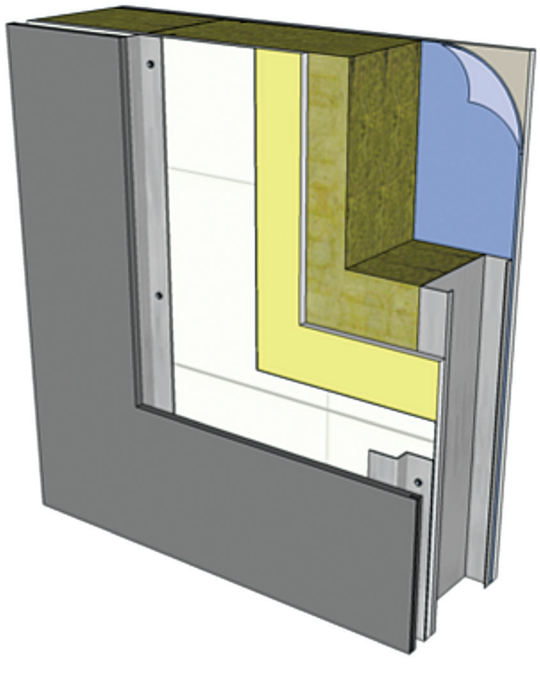

Figure 6 – Stud-insulated wall assembly using mineral wool batt insulation is relatively standard and straightforward.

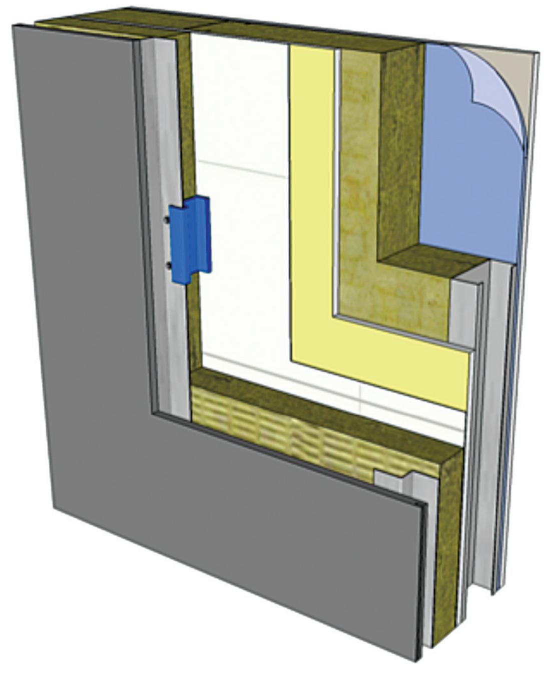

Figure 7 – Split-insulated wall assembly using semi-rigid mineral wool insulation to provide a combination of the performance of stud-insulated and exterior-insulated walls. These walls can provide good performance with respect to vapor diffusion and air leakage, but is important to use the correct type of insulation on both the exterior and within the stud cavity, and also the correct type of sheathing membrane.

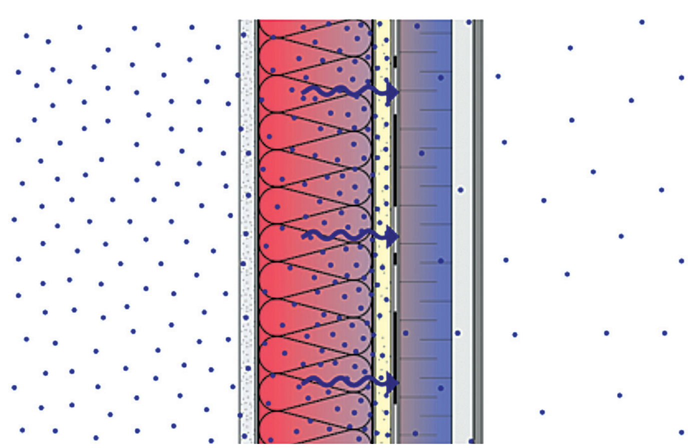

Figure 8 – Schematic vertical cross section of a split-insulated wall located in a cold climate with impermeable exterior insulation (interior on the left and exterior on the right).

sheathing membrane. Unfortunately, in this arrangement, the vapor resistance of the insulation negates the potential benefits of the vapor-permeable sheathing membrane.

Vapor-impermeable and vapor-permeable exterior insulation can both be used successfully to provide robust performance with respect to vapor diffusion when used in fully exterior-insulated assemblies. These types of wall assemblies place all the insulation on the exterior of the wall and move the vapor retarder from the interior of the studs out to the exterior of the sheathing. Bitumen-based, peel-and-stick-type membranes are commonly used for this application. By moving the insulation to the exterior of the sheathing, all materials inside of the vapor retarder are kept warm, and all materials outside of the vapor retarder are durable to wetting. Thus, the risk of damage from condensation is substantially reduced.

SUMMARY

The control of vapor diffusion within walls is a balance between minimizing wetting and maximizing drying potential. Correctly placed vapor control layers prevent excessive moisture from diffusing into wall assemblies and potentially condensing, while vapor-permeable materials allow moisture to diffuse outward and are beneficial to drying performance of an assembly. In the design and construction of walls in cold climates, it has been common practice to install a polyethylene sheet vapor barrier at the interior of the insulation to control vapor flow (and often air flow) and, therefore, limit vapor diffusion wetting, while using vapor-permeable materials to the exterior to encourage drying.

When insulation is added to the exterior of the walls (as in the case of split-insulated or exterior-insulated walls), this insulation maintains the temperature of the stud cavity and exterior sheathing closer to interior conditions, reducing the potential for vapor diffusion (and air leakage) condensation to occur within the cavity. However, in cold climates, the type of insulation installed outboard of the sheathing (or as the sheathing) has an important impact on the vapor diffusion-drying capability of the wall. Vapor-permeable insulation allows for greater outward drying than can be achieved with vapor-impermeable insulation such as foam plastics. Consequently, when a vapor-impermeable exterior insulation is used in cold climates, an interior vapor barrier should be avoided to prevent trapping moisture within the wall assembly. A more permeable (i.e., Type II or III) vapor retarder or an adaptive, permeance-smart vapor retarder material may be appropriate.

Overall, the correct selection and placement of vapor-impermeable materials within wall assemblies is fundamental to their durability. Failure to correctly account for the impacts of vapor diffusion can lead to damage and premature failure of wall assemblies.

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