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VAPOR PERMEABLE OR IMPERMEABLE BUILDING ENVELOPE MATERIALS, DOES IT MATTER?

MARIA SPINU, PHD, DUPONT BUILDING INNOVATIONS

W H I T E   P A P E R

The building envelope (or enclosure) is the part of the building that physically separates an interior conditioned space from the exterior environment. Its role has evolved from basic protection to providing a well-controlled and comfortable indoor space and consists of many components that must work together. The control functions include thermal, air, water, and vapor barriers for heat, air and moisture management. The thermal barriers are materials with high resistance to heat flow known as *thermal insulation*, the *air barriers* are materials with high resistance to airflow, the water barriers (Water-Resistive Barriers, *WRBs*) are materials with high resistance to bulk water infiltration, and the *vapor barriers* (retarders) are materials with high resistance to moisture vapor diffusion.

While each individual barrier is designed for a primary function, it is not uncommon for a material to perform multiple functions. Unfortunately there are often unintended consequences that are not always understood when a material performs functions beyond its primary intended uses. The most common unintended function is that of a vapor barrier: any vapor impermeable building envelope material provides an unintentional vapor barrier which could be located at the "wrong side" of the building enclosure or could introduce multiple vapor barrier(s) in the building assemblies. Such practices could have significant consequences on moisture management and long term durability. This article describes the potential consequences of unintentional vapor barriers and why vapor permeance of building envelope layers is relevant to moisture management and long term durability.

The Moisture Balance

Durability of the building enclosure is especially critical because the expected service life for the building enclosure is longer than for other building systems (e.g. mechanical equipment, lighting, water heating). A designer can significantly affect the service life of multi-component assemblies through materials selection, the placement of materials within the building assemblies, as well as design detailing.

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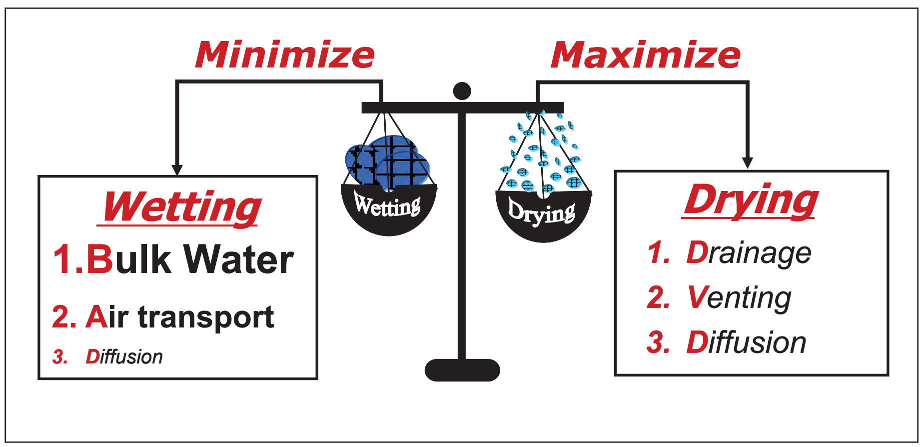
Moisture is one of the major factors affecting durability. In order to understand why vapor permeance of building envelope layers is relevant to moisture management and the long term durability one needs to understand the fundamental moisture management principles. There are many moisture sources in buildings which include exterior moisture (rain), interior moisture (from people using the building) and construction moisture (given off by new construction materials). Building assemblies may periodically get wet, or start out wet, yet can have an acceptable performance and can provide a long, useful service life, if allowed to dry. Problems only occur when buildings get wet and stay wet long enough under adverse conditions for materials to deteriorate. It is therefore important to understand that proper moisture management in the building enclosure must consider the balance of wetting versus drying [1]. Good enclosure design must minimize the risk of wetting, but moisture intrusion can never be completely avoided and drying pathways must always be considered. If a wall assembly is able to dry, it may experience some wetting without long-term durability risks. Figure 1 shows the Moisture Balance with wetting sources on the left side and drying pathways on the right side.

Figure 1. The Moisture Balance: Minimize wetting / Maximize drying



Wetting Sources in Buildings – The Left Side of the Moisture Balance

Let's begin with the left side of the moisture balance, to understand where the moisture comes from. Moisture moves through the building envelope as liquid water and as water vapor. The wetting sources in buildings, ranked by the relative amount of moisture that could be transported by each mechanism, include: bulk water (the #1 source of moisture in buildings), water vapor transported by air currents (the #1 source of water vapor) and water vapor transported by diffusion. Moisture problems in buildings are generally the result of liquid water accumulation within the building enclosure, either from bulk water intrusion or from condensation of water vapors.

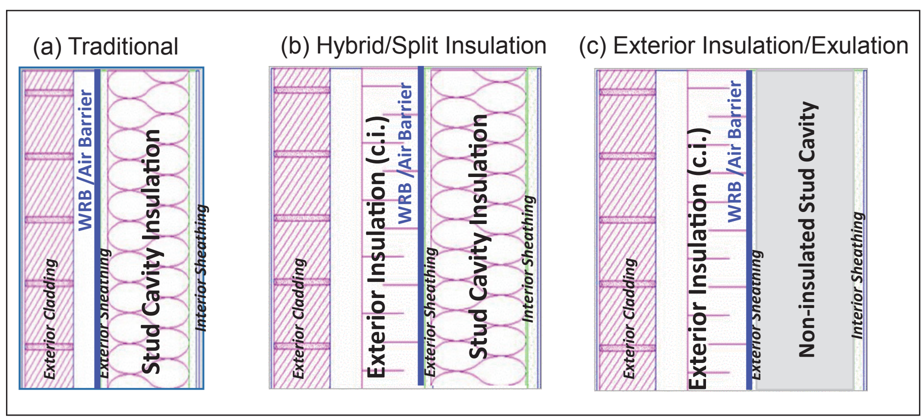
Bulk Water and Water Vapor Transport

Bulk (liquid) water is the number one cause of moisture in buildings. Rain, the main source of water for above grade walls, can penetrate behind cladding through openings, cracks, and gaps and can accumulate inside the wall assemblies. There are two basic approaches to rain penetration control: control the driving forces across the openings, or eliminate the openings. The first approach includes proper sloping to the outside (*i.e.* gravity drainage), capillary breaks (*i.e.* controlling capillary suction), shielding of openings (*i.e.* controlling rain penetration), and rain screen design (*i.e.* controlling pressure differences across the exterior cladding). The second approach can be achieved by using a secondary line of defense behind the cladding (*e.g. a water-resistive barrier*) or through a face-sealed design. However, face-sealed design can be less effective in practice due to the weathering of sealants and extensive maintenance requirements.

Water-resistive barriers (WRBs) are materials specifically designed to protect against bulk water infiltration. For effective protection WRBs must be continuous, and for durability it is often preferable for a WRB to be installed behind the exterior cladding to protect it from direct weather exposure. The *International Building Code (IBC)* requires that the exterior envelope must be designed with water-resistive barriers behind the exterior veneer [Section 1404.2, Water-resistive barrier] and must be installed in such a way as to prevent water from entering the wall or to redirect it through drainage pathways to the outside [Section 1405.4, Flashing].

The typical location for WRBs is shown in Figure 2 for basic types of framed wall construction. For (a) traditional framed walls, the WRB is typically installed over the face of the exterior sheathing. In the case of mass walls with over-cladding, the WRB is installed directly over the CMU backup wall or cast-in-place concrete. For (b) hybrid/split insulation framed walls the WRB can be installed either behind exterior insulation (sandwiched between exterior sheathing and exterior insulation, as shown in Figure 2), or on the outside of the exterior insulation. Similar installation options are available for (c) exterior insulation/exulation wall design. The choice between the two locations often depends on ease of detailing for continuity of the drainage plane.

Figure 2. Typical WRB location in framed wall design



Water vapor can be transported across the building envelope by air currents or by vapor diffusion. The two mechanisms and control strategies for water vapor transport are often confused. This section will describe the difference between the two mechanisms and the two control strategies for water vapor transport: *air barriers* which protect against water vapor transported by air currents, and *vapor barriers* (also called vapor retarders) which protect against moisture transported by vapor diffusion.

Air Leakage and Air Transported Moisture

Air leakage is the unplanned and unpredictable airflow across the building assemblies and can occur when two conditions exist: a total pressure difference across the building envelope (resulting from wind pressure, stack effect and HVAC design) and unintended openings in the buildings assemblies. Air leakage could occur in both directions (infiltration and exfiltration) and could transport significant amounts of water vapor into the building enclosure. The amount of water vapor contained in the air depends on the temperature and relative humidity. In general, warm air is able to hold more moisture than cold air. As air travels through the building enclosure and cools down, it can deposit excess moisture on cool interstitial surfaces with temperatures below the dew point temperature of the air.

For example, **ex**filtration of warm, moisture loaded interior air could be the main source of wintertime condensation for cold climates or seasons. The excess moisture in the exfiltration air could be deposited on cooler exterior surfaces (e.g. exterior sheathing) if air exfiltration reaches the condensation plane and if the temperature of the condensation layer is below the dew point of the interior air. The lower the dew point temperature of the sheathing and the longer the time the sheathing temperature is below the interior air dew point, the higher the condensation potential. For warm/hot humid climates or seasons the **in**filtration of warm, moisture loaded exterior air could be the main source of summertime condensation. The excess moisture in the infiltration air could be deposited on cooler interior surfaces (e.g. backside of the interior sheathing) if air infiltration reaches the condensation plane and if the temperature of the condensation layer is below the dew point of the exterior air. The lower the dew point temperature of the condensation plane and the longer the time its temperature is below the exterior air dew point, the higher the condensation potential.

Air barriers

Air leakage and air transported moisture can be controlled using materials with high resistance to airflow known as air barriers. Many building materials are air infiltration resistant and therefore could function as air barrier components. However, for an effective envelope seal, these materials must be joined into airtight assemblies, and further joined into a *continuous air barrier system*.

Air barrier location in the building envelope

When it comes to air leakage control, the air barrier location within the building envelope is not important **as long as the air barrier material is vapor permeable.** This will become more clear after addressing the drying side of the moisture balance. However, in terms of durability and constructability, location is critical. Placing the air barrier to the exterior side of the structure allows for a greater degree of simplicity with fewer transition detailing, fewer materials, and fewer trades involved. The exterior air barrier approach is the most common method used in the US. Most often, the WRB and air barrier functions are performed by the same membrane installed under the exterior cladding, as shown schematically in Figure 2. However, additional installation details are required when the WRB is also the air barrier, in order to ensure air barrier continuity at all interfaces, transitions and penetrations. By comparison, air barrier complexity increases when an interior air barrier approach is utilized with frame construction. Transition detailing for air barrier continuity can become complex, often involving multiple materials and components. The interior air barrier approach (often named "the drywall approach") is sometimes practiced in parts of Canada.

Air barrier codes

Air leakage can affect many aspects of building performance, but air leakage control is regulated through energy codes because its impact on energy use could be estimated through whole building energy simulations while other effects are very hard to quantify. Compliance with air barrier requirements can be achieved via materials, assemblies or whole building testing as summarized in Table 1 which lists the main air barrier standards and compliance options for North America. National Building Code of Canada (NBC), the first air barrier code in NA introduced in the 90s, has an air barrier material compliance option. The US states that have adopted air barrier codes in the early 2000s have similar compliance option as NBC, i.e. air barrier materials. ASHRAE 90.1- 2010 was the first National Standard requiring an air barrier and allows for two compliance options: air barrier materials or assemblies. More recently, energy and sustainability standards as well as government agencies introduced whole building testing requirement (these are shown in green shaded rows in Table 1). USACE (US Army Corps of Engineers) was the first agency to mandate whole building testing. GSA (General Services Administration), NAVFAC (Naval Facilities Engineering Command), and USAF (United States Air Force) adopted similar air barrier standards as USACE, even though the actual airtightness requirements vary among different agencies. IECC-2012, ASHRAE 189.1 -2009 and IgCC 2012 (International Green Construction Code) either require whole building testing or allow as an option.

Table 1. North America air barrier standards and compliance options

Air Infiltration Requirements [cfm/ft^2 @ 0.3 in w.g., 75Pa]	**Materials** (ASTM E2178)	**Assemblies** (ASTM E2357 or E1677)	**Whole Building** (ASTM E779)
NBC (National Building Code of Canada, 1990)	**0.004**	**--**	**--**
Massachusetts, Minnesota, New Hampshire, Georgia, Oregon, Washington, New York, *etc…*	**0.004**	**--**	**--**
ASHRAE 90.1 (2010)	**0.004** *or*	**0.04**	--
USACE(2008); **NAVFAC** (2011)	**0.004**	**--** ***AND***	**0.25**
Washington State (2010)	**0.004**	**--**	**0.25**
GSA (2010) **USAF** (2011)	**0.004** *or*	**0.04** ***AND***	**0.40**
ASHRAE 189.1 (2009) **IECC** (2012)	**0.004** *or*	**0.04** *or*	**0.40**
IgCC (2012)	--	**--**	**0.25**

ASHRAE – American Society of Heating, Refrigeration and air Conditioning Engineers; USACE - US Army Corps of Engineers; GSA - General Services Administration; NAVFAC - Naval Facilities Engineering Command; USAF- United States Air Force; IgCC – International Green Construction Code

Air barrier types

Based on the installation methods there are many types of air barriers. The main classes of air barrier membranes include mechanically attached flexible membranes (building wraps), self adhered membranes (peel and stick), and fluid applied membranes. In addition to air barrier membranes, there are other building materials which can resist air flow such as sprayed polyurethane foams (SPFs) and rigid foam boards (boardstock). Their primary function is thermal insulation, but these materials could also perform as air barriers provided they could be installed as continuous air barrier systems and provided that the continuity can be maintained over the life time of the building envelope. The choice of air barrier based on installation method often depends on the wall construction type and the knowledge and preference of the building envelope designer.

Based on vapor permeability, air barrier materials can be classified into vapor permeable and vapor impermeable. Vapor permeable materials are diffusion open – allow vapor diffusion, while vapor impermeable materials are diffusion closed – do not allow vapor diffusion (water vapor diffusion will be discussed in the next section). The amount of water vapor that passes through a material by vapor diffusion is measured in perms [grains/ft^2.hr.inHg]: the higher the perms, the more permeable the material and the more diffusion will take place under given conditions. The vapor permeability of an air barrier is critical to wall performance, because it could impact the drying rates, therefore the long term durability of a wall assembly. The importance of vapor permeability for air and water barriers will be addressed in the next section.

Air Barrier Association of America (ABAA) is a trade organization representing the center of excellence in the air barrier industry. In order to promote the use of air barriers and to develop a professional specialty trade dedicated to the installation of effective air barrier systems ABAA requires 3rd party evaluation not only for air barrier materials but also for air barrier assemblies, in order to demonstrate installed performance. Air barrier manufacturers must provide 3rd party test reports for air barrier materials and assemblies in order to be listed at the ABAA web site (http://www.airbarrier.org). Water vapor permeance of air barrier materials is among the properties required to be tested, recognizing that vapor permeance is a critical design criteria for a durable building envelope.

Water Vapor transported by vapor diffusion

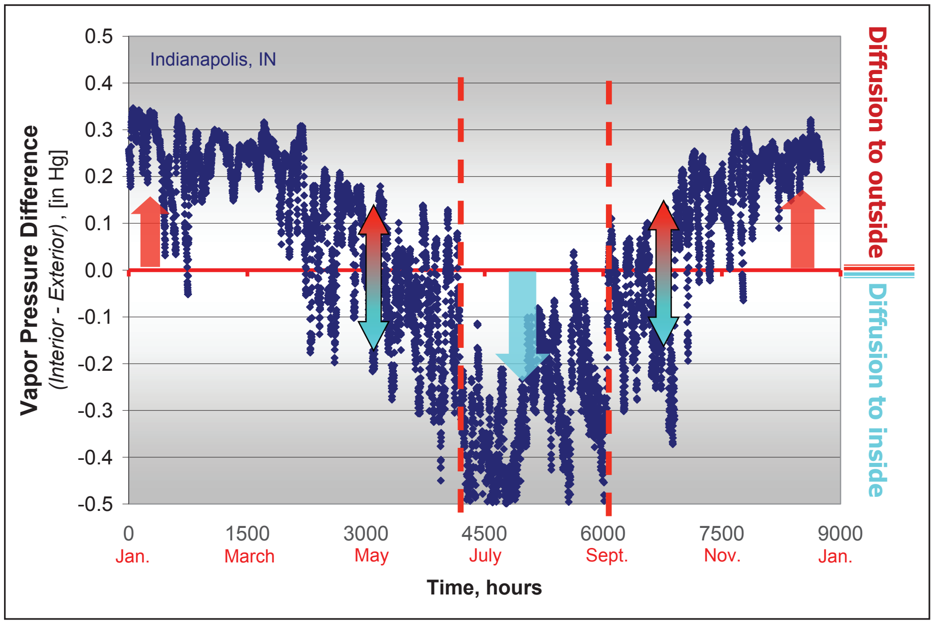
The second mechanism for water vapor transport is vapor diffusion which is a slow movement of individual water vapor molecules from regions of higher to lower water vapor concentration (higher to lower vapor pressure). The rate of vapor diffusion depends on concentration difference across the material (vapor pressure difference), as well as the material's vapor permeance (expressed in perms): the lower the perms, the more resistant to vapor diffusion the material will be under given conditions. Materials with high resistance to vapor diffusion (diffusion closed) are called *vapor barriers or retarders*. International Building Code classifies materials with vapor permeance below 10 Perms as vapor retarders (Class I, II or III, see vapor barrier codes section), which makes materials with vapor permeance above 10 Perms vapor permeable.

Vapor barrier location in the building envelope

Vapor barriers/retarders are used to control diffusion wetting of the building envelope. In order to control moisture vapor diffusion into the building envelope, the vapor barrier must be located on the side with higher water vapor concentration (higher vapor pressure). This is usually the warm side of the building envelope (because warmer air holds more moisture), and explains the general guideline for the vapor barrier to be located "on the warm in winter side of the insulation". The challenge with many US climates is that the side with higher water vapor concentration (higher vapor pressure) changes with seasons, and a vapor barrier at any location will be on "the wrong side" of the enclosure part of the year. The graph in Figure 3 showing the hourly vapor pressure difference between the interior conditioned space and the exterior environment for climate zone 5A (Indianapolis, IN) exemplifies this challenge. This example shows that during the winter months the primary diffusion direction is from the inside to the outside (interior vapor pressure is higher than exterior vapor pressure).

During the summer months, the primary diffusion direction is reversed (exterior vapor pressure is higher than interior vapor pressure). There are a few months during the year when the diffusion occurs in both directions, as weather conditions change from day to night or day to day. For this reason, the vapor barrier location must be carefully considered and the vapor barrier requirements are climate specific.

Figure 3. Hourly Vapor Pressure Difference (VPInterior – VPExterior) [in. Hg]. Exterior climate: Indianapolis, IN; interior conditions: 70° F & 40% to 76°F & 50%



Vapor barrier codes

Vapor barriers were first introduced in Canada for the predominantly cold climates, and installed to the interior side of the building enclosure *(i.e.* the side with higher water vapor concentration). Without a proper understanding of design criteria for vapor barriers, these practices were originally adopted by US codes, for all except extreme hot and humid US climates. As the role of vapor diffusion became better understood, the codes have changed to address climate specific needs. The IBC code classifies vapor barriers (retarders) into 3 classes, based on their vapor permeance (Section 1405.3 – Vapor Retarders):

- *Class I:* 0.1 perm or less (e.g. PE film)
- *Class II:* 0.1 < perm ≤ 1.0 perm (e.g. oil-based paints)
- *Class III:* 1.0 < perm ≤10 perm (e.g. water-based paints, other materials)

IBC 2009 & 2012 code requirements for vapor barriers are based on climate and wall design. Class I and II vapor retarders (less than 1 Perm) are required in cold climates (climate zones 5 through 8 and Marine 4C), and must be installed on the interior side of the building assembly. Class III vapor retarders (1-10Perms) installed on the interior side of the wall assembly are allowed in these climates if certain design conditions are met, such as vented cladding or use of continuous insulation. It is important to notice that vapor barriers are always required to be installed to the inside of the wall and are only required in cold climates. Vapor barriers are NOT required in warm or hot climates, e.g. climate zones 1 through 4 (4A and 4B).

Before addressing the second half of the moisture balance, DRYING MECHANISMS, it is important to emphasize the difference between the two water vapor transport mechanisms, air leakage vs. vapor diffusion. The driving force for air leakage and air transported moisture is the total pressure difference across the building envelope, and occurs through cracks and openings in the building assemblies. The moisture contained in the air rides along, so moisture gets a free ride on air currents. By comparison, water vapor diffusion is a slow molecular process in which individual water vapor molecules travel from areas of higher water vapor concentration to areas of lower water vapor concentration, through vapor permeable materials (through micropores). Because diffusion is a slow molecular process the amount of moisture transported by diffusion is significantly lower than that transported by air currents [2].

It is obvious that there is a big difference between air transported moisture and vapor diffusion, and between air barriers and vapor barriers. However, this difference is not always clear and the two are often confused. What should be clear is that the amount of moisture transported by *air currents* is **far more significant** than the amount transported by *vapor diffusion*. What should be clear is that you do NOT need a vapor barrier in all climates, but you DO need an air barrier in every climate. What should be clear is that while an air barrier could be installed anywhere in the building enclosure (**as long as the air barrier material is vapor permeable**), the vapor barrier should be installed on the side of the building enclosure with higher water vapor concentration. Locating a vapor barrier on the "wrong side" of the building envelope could impact the drying rates, as described in the next section.

DRYING MECHANISMS – THE RIGHT SIDE OF THE MOISTURE BALANCE

Figure 1 shows that water vapor diffusion plays a role on both sides of the moisture balance: as a wetting source but also as a drying pathway. The previous section explained the role of vapor diffusion as a wetting source for the building enclosure and the use of vapor barriers to control diffusion wetting. Vapor barriers are diffusion closed or vapor impermeable materials. This section will explain the role of vapor diffusion as a drying mechanism. Vapor diffusion occurs through diffusion open or vapor permeable materials. The amount of water vapor that passes through a material by vapor diffusion is measured in perms. The higher the perms, the more permeable the material and the more diffusion will take place under given conditions.

Now that we understand the double role of diffusion, let's go back to the original question: why is vapor permeability of building envelope materials relevant to moisture management and long term durability? Vapor permeance is relevant because vapor permeable materials allow diffusion drying when incidental moisture intrusion occurs. Good enclosure design must minimize the risk of wetting, but moisture intrusion can never be completely avoided and drying pathways must *always* be considered. Drying is very important for long term durability: if a wall is able to dry, it may experience some wetting without long-term durability risks.

The drying mechanisms for the building enclosure include drainage of water to the outside, controlled ventilation (not to be confused with uncontrolled air leakage), and vapor diffusion. A continuous drainage plane can remove incidental bulk water, and a ventilated air space behind cladding will increase the drying rates [3]. However, diffusion is critical for moisture to escape from the interior envelope layers into the ventilated spaces or the drainage plane, and often time diffusion is the only drying mechanism available [4, 5]. Given the importance of vapor diffusion as a drying mechanism, it is critical that a diffusion drying pathway is considered in the design and specification phase of every project.

The emphasis that many place on diffusion wetting often considered responsible for condensation problems is simply a lack of understanding. It is very unlikely that vapor diffusion alone could lead to significant condensation problems, as the amount of moisture transported by vapor diffusion is insignificant when compared to the other moisture sources. It is much more likely that condensation problems are the result of air exfiltration (wintertime condensation) or air infiltration (summertime condensation), as discussed in the previous section. Air currents could carry significantly more moisture than vapor diffusion, and poor air barrier continuity could contribute to air leakage condensation. The importance of a *continuous air barrier* in every climate could not be emphasized enough.

While diffusion wetting is over emphasized, diffusion drying is often neglected and diffusion drying pathways are not always provided. For example, every time that a vapor impermeable material is used for the building envelope, it means that in addition to its intended function it will also introduce an unintended vapor barrier at that particular location, and may potentially eliminate diffusion drying pathway. In many climates these practices could also lead to double/multiple vapor barriers. In the case of air & water barriers which are generally installed on the exterior side of the enclosure, a vapor impermeable material will introduce a vapor barrier at the cold in winter side (the wrong side) of the building enclosure for many climates. Furthermore, since interior vapor barriers are required by code (on the side with higher water vapor concentration) this practice also leads to double vapor barriers. A vapor-permeable air & water barrier will not interfere with diffusion drying and can be used without restrictions. These considerations do not apply to air and water barriers, but to any building enclosure materials such as thermal insulation or others. The choice of vapor permeable or vapor impermeable building envelope materials plays an important role in moisture management because it determines the building's ability to dry following incidental moisture intrusion.

CONCLUSIONS

Durability of the building enclosure is part of a sustainable building design. The expected service life for the building enclosure is longer than for other building systems, which makes the building envelope durability even more critical. A designer can significantly affect the service life of multi-component assemblies through materials selection, placement of materials within the building assemblies, or design detailing.

Moisture is one of the major factors affecting durability. Building assemblies may periodically get wet, but if allowed to dry they can have an acceptable performance. Moisture problems only occur when buildings get wet and stay wet long enough under adverse conditions for materials to deteriorate. Good enclosure design must consider both sides of the moisture balance: minimize the risk of wetting and maximize drying potential. If a wall assembly is able to dry, it may experience some wetting without long-term durability risks. Vapor diffusion as a wetting source is highly overestimated while vapor diffusion as a drying mechanism is poorly understood and often neglected.

One of the most often asked questions is about how to address *diffusion wetting*: do I need a vapor barrier, what type/class of vapor retarder is best (I, II or III), and where should it be located in the wall assembly? Unfortunately it is less recognized that every time a vapor impermeable material is used, an unintentional vapor barrier is introduced in the assembly, which eliminates a very critical *diffusion drying pathway*. While vapor diffusion cannot handle large amounts of moisture and cannot compensate for repeated and extended wetting events, it can provide a very effective drying pathway for incidental moisture intrusion.

Still have questions about why vapor permeability of building envelope materials is relevant to moisture management and durability? Still have questions if you should use a vapor permeable or vapor impermeable air and water barrier? The simple things to remember are: if a material is vapor permeable it can be located anywhere in the building envelope without interfering with diffusion drying pathway; if a material is vapor impermeable, it should only be located on the side with higher water vapor concentration (where the diffusion wetting comes from) and not on the side with lower water vapor concentration (where the diffusion drying wants to transport the moisture to). Another thing to keep in mind -- watch for unintended vapor barriers located in the path of diffusion drying, these will close the drying pathway!

References

1. Vapor Barriers and Wall Design, Research Report – 0410, November-2004, Joseph Lstiburek
2. Air Barriers vs. Vapor Barriers, Research Report – 0004, 2000, Joseph Lstiburek
3. Ventilated Wall Claddings: Review, Field Performance, and Hygrothermal Modeling, Research Report 0906, John Straube and Graham Finch, 2009
4. Air Flow Control in Buildings, Building Science Digest 014, John Straube, October 2007
5. The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance, Research Report – 1101, 25 March 2011, John Straube