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Differences between air and vapor barriers

by Peter Barrett

Image courtesy Audain Art Museum

IT HAS BEEN SAID BEFORE, BUT BEARS REPEATING: AS MUCH AS 80 PERCENT OF PREMATURE BUILDING WEAR EXPENSES ARE RELATED TO MOISTURE IN ONE WAY OR ANOTHER.[1] WATER IS THE MOST SIGNIFICANT FACTOR IN THE PREMATURE DETERIORATION OF BUILDINGS, AS IT CAN CAUSE CORROSION OF METALS, ROTTING AND MOLD IN ORGANIC SUBSTANCES, DISSOLUTION OF MATERIALS, REDUCTION IN EFFECTIVENESS OF INSULATION, AND MORE.

Building industry professionals largely agree on the importance of moisture control methods, but there is frequent confusion about the use of vapor and air barriers.[2] To make the right decision on which methods and materials to include in a building envelope, it is critical to understand the simple, yet significant, differences between air and vapor barriers, and their role as part of an effective system.

Air barrier function

An air barrier's function is primarily to stop air leakage and resist differences in air pressure by keeping the indoor climate regulated. Simply put, air barriers keep the outdoor air out and the indoor air in. An air barrier should be:

- durable enough to withstand construction pressures and handling;
- impermeable to airflow; and
- continuous, enclosing, or enveloping the entire conditioned space.

While air barriers are key to limiting the airflow in and out of a living space, it is important to note air from either a conditioned or an unconditioned side may still find its way into walls. So, even though it is critical for a living space to have walls that are as airtight as possible, the assembly of the wall itself should always be moisture vapor permeable to allow for incidental moisture to escape, or diffuse, rather than be trapped and make the structural materials of the wall wet.

A vapor barrier's most important function, on the other hand, is to be impermeable to moisture in vapor form, thereby preventing the movement of water vapor through the wall cavity from going outside, and vice versa. While this notion sounds simple, it is not.

Effects of rainwater penetration through walls

One of the trickiest elements coming into the wall from the outside is rainwater (also known as bulk water), which almost always causes trouble. Most significant would be the issues caused by water moving inward and reaching the vapor barrier where it gets trapped, causing catastrophic failure of the wall in the form of rot and mold. One feasible solution is to eliminate the vapor barrier altogether, allowing the wall to dry from both sides, thereby creating a flow-through assembly. While it may be possible in many cases, the elimination of the vapor barrier is not always an option.

Leaving out the vapor control layer is only possible in structures with non-extreme environmental loads and continuous insulation (ci) on the outside. As noted by building industry educator Joe Lstiburek, a non-extreme environmental load essentially means a building enclosure on an office, house, or apartment as opposed to the façade of a natatorium, museum, hospital, or art gallery.[3] The enclosures subjected to an extreme environmental load are operated at high interior humidity (50 percent or higher year round) and are pressurized. Therefore, for natatoriums, museums, hospitals, or art galleries, a wall incorporating a vapor barrier layer to the interior is essential to maintain moisture vapor impermeability.

Some restrictions come into play for non-extreme environmental loads without ci on the outside. In colder climates, some kinds of interior

Prior to the design of Hotel Lismore in Eau Claire, Wisconsin, one important consideration was the type of air and moisture barrier the project team would use on the building envelope.

Photo courtesy Hotel Lismore

Figure 1

IECC Climate Zone	Minimum Continuous Insulation/Cavity Insulation Ratio
Marine 4	0.2
5	0.35
6	0.5
7	0.7
8	0.95

Ratio of continuous insulation (ci) to cavity insulation.

Images © Joe Lstiburek

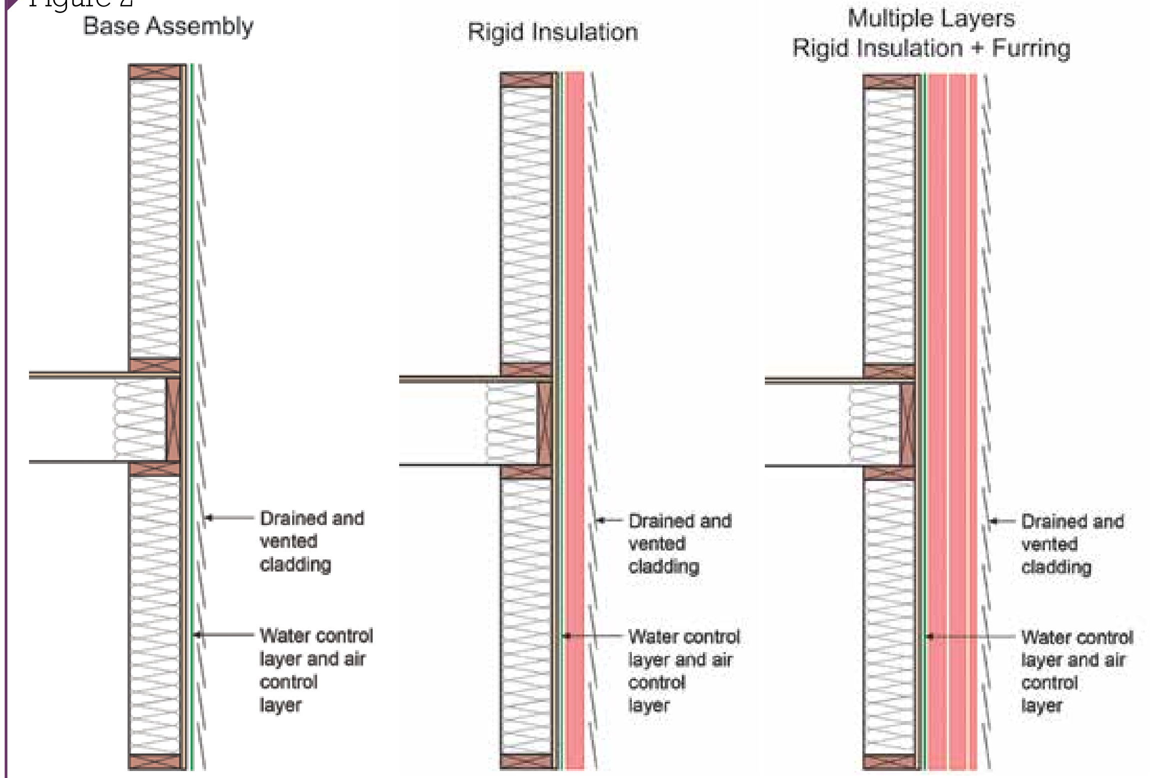
'vapor throttles' are required. A vapor throttle is essentially the component with the lowest moisture vapor permeability compared to the rest of the elements of the wall. This component tends to establish the overall moisture vapor permeability of the wall system. The *International Energy Conservation Code* (*IECC*) specifies climate zones 6 and higher as requiring a vapor control layer (Figure 1). In these cases, a 'smart' vapor barrier (a material whose moisture vapor permeability increases when relative humidity [RH] is high and decreases when RH is low), which works without the need for ci in such climate zones (6 or higher), can be used as well.

Attaining an effective flow-through assembly

To achieve an effective flow-through assembly, a system to reduce the vapor flow rate from the interior is required (when there is a lack of ci on the outside).

Additionally, for all flow-through assemblies, a ventilated cladding system is needed to cover the ci or exterior sheathing to let the passing moisture get around the wall assembly. Most claddings do not need a significant amount of space. Joe Lstiburek recommends a minimum of 9.5 mm (3/8 in.).[4]

Figure 2



Various configurations of flow-through assemblies.

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 larger space is needed. For brick, 25 mm (1 in.) is recommended. For stucco, the recommendation is to use paint coupled with an engineered ventilated rainscreen layer and the 9.5-mm space.

The larger gap and paint are needed for stucco because vapor can flow both in and outward.

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 cladding should be uncoupled with a ventilated air space, or the size of the reservoir has to be reduced by painting the cladding or by using additives with the ability to reduce water absorption.

Figure 2 (page 6) illustrates the various configurations of flow-through assemblies, whereby the 'base' assembly is limited to *IECC* climate zones 5 and lower (unless an interior vapor throttle such as a smart vapor barrier is used).

Not all membranes are moisture vapor permeable

Vapor retarders can assist with vapor management, as they are designed and installed in an assembly for the purpose of impeding the movement of water by vapor diffusion. These fall under Class I vapor retarders (Figure 3). Clearly, not all membranes are designed to be moisture vapor permeable. According to the *American Society of Heating, Refrigerating and Air-Conditioning Engineers* (ASHRAE) *Journal,* a membrane must have a permeance greater than 5 perms to be classified as permeable.[5]

The following are some key considerations to achieve vapor permeability when designing a well-performing wall assembly:

- use a water-resistive barrier (WRB) to keep bulk water out of the exterior wall;
- employ an air barrier to prevent air movement through the wall (which could otherwise cause condensation); and
- use a vapor retarder appropriate for the particular type of wall and climate zone.

High-performance air and moisture barriers

Vapor barriers can be placed on the warm side of the insulation without being sealed airtight, as long as there is an uninterrupted air barrier somewhere else in the wall and ceiling assemblies. The reason for this is simple: diffusion of moisture vapor is slow, while moving air carries

Figure 3

Class 1:	0.1 perm or less
Class 2 Vapor Retarder:	1.0 perm or less and greater than 0.1 perm
Class 3 Vapor Retarder:	10 perm or less and greater than 1.0 perm
Test Procedure for vapor retarders:	ASTM E-96 Test Method A (the desiccant method or dry cup method)

The unit of measurement typically employed in characterizing the water vapor permeance of materials is the 'perm.'

During the construction of the Boulder Wildland Fire Station in Boulder, Colorado, an air- and water-resistive barrier (A/WRB) system was selected for its high standard of durability.

Photo courtesy Boulder Wildland Fire Station moisture vapor faster. Multiple materials to achieve this are not always necessary, especially as some products provide a combination of these qualities already. The key here would be to find a high-performance air and moisture barrier resistant to air movement, and in turn, resistant to the moisture vapor carried by the moving air as a result of increased airtightness. As discussed, though some projects will call for the use of individual barriers and membranes, for an airtight and moisture-controlled building one need not always have a combination of materials. According to John Straube, vapor barriers primarily control the diffusion, used only when needed, and are only placed near the warm side of a wall. Air barriers, on the other hand, control air flow and can be placed anywhere.[6] Fortunately, there are products incorporating all these qualities. For example, fully adhered polymeric spun-bonded membranes are multifunctional and provide high moisture permeability along with the all-important water- and air-tightness.

Conclusion

Making a building as airtight as possible is an important first step when determining what barriers to use. The more airtight the building, the fewer vapor issues will arise and the less critical a vapor barrier will be. Having said that, airflow is not the sole cause of vapor issues, so while an air barrier is a must, a vapor barrier can still significantly benefit a building. **CS**

Notes

[1] For more information, see the chapter on Moisture Control and Ventilation in *WHO Guidelines for Indoor Air Quality – Dampness and Mould* at www.ncbi.nlm.nih.gov/books/NBK143947.

[2] Read more on vapor barriers in "Understanding Vapor Barriers – industry insights," by Joe Lstiburek at buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers.

[3] Joe Lstiburek's article speaks about how vapor barriers are critical in the system and provides an argument for flow-through assemblies in many circumstances. Read it at buildingscience.com/documents/building-science-insights-newsletters/bsi-091-flow-through-assemblies.

[4] Read more on the recommended space needed for most claddings, as discussed by Joe Lstiburek in "Vitruvius Does Veneers: Drilling Into Cavities" at buildingscience.com/documents/insights/bsi086-vitruvius-does-veeners.

[5] The article "Moisture Control for Buildings – membrane classifications" provides more information on membranes. Visit buildingscience.com/documents/published-articles/pa-moisture-control-for-buildings/view to access it.

[6] John Straube's paper from the University of Waterloo on air and vapor barriers can be accessed at www.civil.uwaterloo.ca/beg/Downloads/Affordable-2005-Myths-%20Vapor.pdf.

ADDITIONAL **INFORMATION**

Author

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Abstract

When it comes to making the right decision about the methods and materials to include in the building envelope, understanding whether or not vapor barriers are critical in the system is an important first step. This article identified the critical difference between air and vapor barriers, and examined the role of vapor barriers and vapor permeability in creating a flow-through system. It also demonstrated how flow-through assemblies workin a practical application.

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07 27 00—Air Barriers

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Wall assembly

Managing Moisture without Sacrificing Breathability

by Bijan Mansouri

Images courtesy Typar Construction Products

IN THE BUILDING INDUSTRY'S EVER INCREASING PURSUIT OF TIGHTER AND MORE WATERPROOF STRUCTURES, IS THERE A POINT AT WHICH A WALL IS BUILT TOO TIGHT? WHILE A WATERTIGHT ASSEMBLY IS VITALLY IMPORTANT FOR WALL CONTROLLING ISSUES SUCH AS MOLD GROWTH AND PROTECTING INDOOR AIR QUALITY (IAQ), SOME BUILDING PRACTICES MAY BE INADVERTENTLY MAKING IT EASIER FOR MOISTURE-RELATED ISSUES TO FESTER. AFTER ALL, NO MATTER HOW TIGHTLY A WALL IS CONSTRUCTED, WATER IS INEVITABLY GOING TO FIND ITS WAY IN. THERE IS NO SUCH THING AS A 'WATERPROOF' WALL, JUST ONE BUILT SO TIGHTLY IT IS ALMOST GUARANTEED TO GET AND STAY WET.

The highest performing wall assemblies are the ones designed to realistically manage moisture and dry out, and not those designed with the unachievable goal of completely locking out all moisture. The good news is there are a growing number of methods for managing moisture, driven by advances in material technology, evolving building codes, and a growing awareness among end-users for mold prevention, IAQ, and energy efficiency.

Finding the 'sweet spot' for material permeability

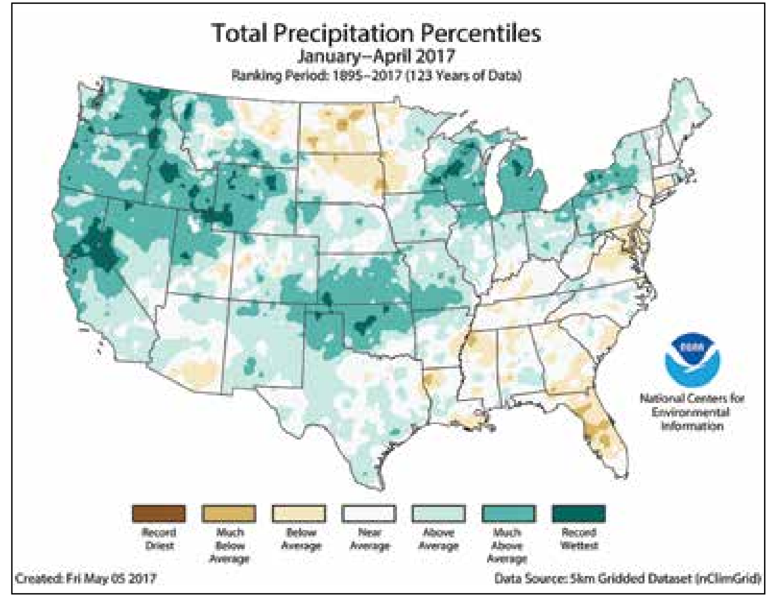
Water can find its way into a wall in numerous ways. High humidity and extreme temperatures can cause vapor diffusion when warm, indoor air causes condensation on colder, outside surfaces. Wind-driven rain can be forced into small openings in the exterior cladding at joints, laps, and utility cutouts, and wind blowing around the building can create a negative pressure within the wall assembly, which siphons water into the wall.

One of the most challenging situations to manage moisture is when a reservoir cladding like fiber cement, brick, or stone is specified in a region where air-conditioning is often used and with an annual rainfall of 508 mm (20 in.) or more. Most of the country falls within these conditions, and a growing preference for reservoir claddings require more careful attention to managing moisture.

When reservoir claddings become wet from rainwater or condensation and are then warmed by the sun, the vapor pressure of the stored water increases, driving it both inward and outward from the cladding material. Where the moisture goes from there—and how quickly it gets there—is largely a function of the permeability of the adjacent building materials within the assembly.

Permeability measures the amount of vapor transmission a building material will allow over a period of time. ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*, addresses two testing procedures for measuring permeability—the desiccant method and the water method.

In the desiccant method, the material to be tested is sealed to a test dish containing a desiccant, or drying agent, and the assembly is placed in a controlled atmosphere. Periodic weighing determines the rate at which water vapor has moved through the specimen into the desiccant. In the water method, the dish contains distilled water, and periodic weighing determines the rate of vapor movement through the specimen from the water.



The majority of the United States receives more than 508 mm (20 in.) of rainfall a year.

In most wall assemblies, outwardly driven moisture will not cause many problems (unless one is dealing with a material like stucco painted with a low-perm paint, in which case bubbling and cracking would be visible). However, the inwardly driven moisture presents a problem, especially in situations where conditioned indoor air is much cooler than the warm, moist exterior.

Typically, this inwardly driven moisture vapor is managed by separating the cladding from the rest of the assembly with a capillary break, which can be a gap or a sheathing material able to shed water or not absorb or pass water. Impermeable sheathing, such as extruded polystyrene (XPS), is one option for halting inward vapor drive. In these types of assemblies, the inwardly driven moisture condenses on the surface of the XPS sheathing and drains downward.

However, in situations where a reservoir cladding is paired with a highly permeable sheathing like gypsum board (which can be as high as 50 perms) or a moisture-retentive material like oriented strand board (OSB), an air gap may not be enough to slow down inward moisture intrusion. In these applications, an added weather-resistant barrier (WRB)—commonly referred to as a building or house wrap—is needed to reduce unwanted moisture intrusion.

In the paper, "Inward Drive – Outward Drying," building scientist Joseph Lstiburek identifies the 'sweet spot' for the permeance of this WRB layer as between 10 and 20 perms.[1] Too high, he writes, and the moisture driven out of the back side of the reservoir cladding into the air space will blow through the layer and the permeable sheathing and into the wall cavity. Too low, and the outward drying potential of the cavity is compromised. Thankfully, advances in building wrap technology are adapting to meet this need.

Evaluating WRBs

Plastic building wraps made of polyethylene or polypropylene fabric have been a popular method of protecting against moisture intrusion since the 1970s because of their durability and ease of installation. Since building assemblies have gotten tighter, building wraps have taken on a new function—helping to remove trapped water from the building enclosure. Their unique functionality enables them to both block moisture from the outside while also allowing walls to 'breathe' to prevent vapor buildup. The latest innovations in building wrap technology are taking this moisture removal function one step further to incorporate drainage capabilities as well.

The 2018 *International Building Code* (*IBC*), Section 1402.2, "Weather Protection," requires exterior walls "provide the building with a weather-resistant exterior wall envelope…designed and constructed in such a manner as to prevent the accumulation of water within the wall assembly by providing a water-resistive barrier behind the exterior veneer…and a means for draining water that enters the assembly to the exterior."

Since building assemblies have gotten tighter, building wraps have taken on a new function—helping to remove trapped water from the building enclosure.

This water-resistive barrier, as defined by Section 1403.2, "Weather Protection," comprises at least "one layer of No. 15 asphalt felt, complying with ASTM D226, *Standard Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing*, for Type 1 felt or other approved materials…attached to the studs or sheathing."

It is important to note the difference between a weather-resistant barrier and a water-resistant barrier, as they have distinct purposes but are often confused with one another. The American Architectural Manufacturers Association (AAMA) defines WRBs as a surface or a wall responsible for preventing air and water infiltration to the building interior. The differentiating factor is a WRB must also prevent air infiltration, while water-resistant barriers are only responsible for stopping water intrusion.

WRBs are commonly specified for commercial buildings or projects where a higher level of performance is desired of the vertical building enclosure and when it is critical to have greater control of interior environmental conditions. Water-resistant barriers, on the other hand, are usually limited to residential and low-rise structures.

The International Code Council-Evaluation Service (ICC-ES) evaluates the following key performance characteristics for building wrap. These characteristics provide a valuable starting point for deciding which product best suits a specific project.

Water resistance

As its most basic function, a building wrap must hold out liquid water. A building wrap should be able to pass both 'water ponding' tests, which measure a house wrap's resistance to a pond of 25 mm (1 in.) water over two hours, and a more stringent hydrostatic pressure test where the wrap is subjected to a pressurized column of water for five hours.

Air resistance
According to the Air Barrier Association of America (ABAA), an air barrier is a system of assemblies within the building enclosure—designed, installed, and integrated in such a manner as to stop the uncontrolled flow of air into and out of the enclosure. Since an air barrier isolates the indoor environment, it plays a major role in the overall energy efficiency, comfort, and IAQ of a building. According to the U.S. Department of Energy (DOE), up to 40 percent of the energy used to heat and cool a building is due to uncontrolled air leakage. As such, the American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers/Illuminating Engineering Society (ANSI/ASHRAE/IES) 90.1-2016, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* and the *International Energy Conservation Code* (*IECC*) include air barrier requirements.

For an individual building material to be classified as an air barrier, its air permeance must be equal to or less than 0.02 L/(s-m^2) @ 75 Pa when tested in accordance with ASTM E2178, *Standard Test Method for Air Permeance of Building Materials*. However, this air permeance test only measures the amount of air migrating through the material itself and not through holes or gaps in the larger assembly. Therefore, it is important to keep in mind a material's effectiveness as an air barrier is largely dependent on proper installation and the use of compatible tapes, fasteners, and sealants.

Durability
The ICC-ES looks at the tear resistance and tensile strength as the best measure of a building wrap's durability, since it must be able to withstand the handling and application process without compromising its water resistance. Ultraviolet- (UV) and low-temperature resistance are also important measures of durability because prolonged exposure to the elements can compromise the integrity of the product or cause it to crack.

Housewrap works in conjunction with other weatherproofing products, such as window flashing, to keep out excess water. When installed as a complete system, some manufacturers offer extended warranties.

Vapor permeability
For a product to be considered as a building wrap and not a vapor retarder, ICC-ES mandates the permeance rating must be higher than 5 perms. However, permeability is achieved in a variety of ways, and as noted by Lstiburek, a higher perm rating does not always equal a better building wrap.

When selecting a building wrap, look for one that hits the 'sweet spot' of 10 to 20 perms to achieve the desired balance of moisture protection and drying capacity. For example, some wraps have mechanical micro-perforations, which may allow the passage of more water vapor, but could also be more vulnerable to bulk water leakage. Generally, it is better to go with a higher quality, non-perforated or micro-porous product allowing for sufficient vapor mitigation while providing excellent resistance to bulk water.

Drainage
Drainage is widely accepted as one of the most effective measures for reducing moisture damage due to rain penetration. Drainage is a critical component in allowing a building wrap to do its job,

particularly in keeping walls dry. Usually, this can involve the use of furring strips separating the wrap from the structural sheathing and framing, but emerging technologies are helping to simplify this process.

Building wrap manufacturers have developed new products integrating drainage gaps into the material itself through creping, embossing, weaving, or filament spacers. These new technologies eliminate the need for furring strips as a capillary break, helping to reduce material costs and streamline installation.

These drainable building wraps meet all current standards for drainage efficiency (ASTM E2273) and are also vapor permeable, helping to address many of the moisture management issues described earlier.

Flammability

When designing wall assemblies, considerations should also be taken to ensure the wall system meets all applicable fire codes. The National Fire Protection (NFPA) 285, *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components*, is the standardized procedure for fire testing of overall exterior wall assemblies when combustible materials, such as foam plastic continuous insulation (ci), panels, and water-resistive barriers, are components within the wall assembly. NFPA 285 is an assembly test, meaning all components of the wall system must be tested together. *IBC*, generally, requires NFPA 285 testing for exterior wall assemblies with combustible materials on buildings more than 12 m (40 ft) tall.

In addition to the NFPA 285 wall assembly test, relevant combustible components must also pass a series of material tests, per *IBC*. ASTM E84, *Surface Burning Characteristics,* comparatively measures product surface flame spread and smoke density. Products are then classified as A, B, or C based on their flame spread index, with Class A offering the lowest flame spread levels. It is important to note this test does not measure heat transmission, determine an assembly's flame spread behavior, or classify a material as noncombustible. Specifiers should also request ICC-ES reporting data as part of their evaluation to ensure products meet the necessary standards.

Other variables

Outside of the aforementioned evaluation criteria, specifiers must consider a number of other variables when selecting a WRB.

Building wrap manufacturers have developed new products integrating drainage gaps into the material itself through creping, embossing, weaving, or filament spacers.

Cladding

In addition to the challenges associated with reservoir claddings, other types of cladding require careful consideration when it comes to managing moisture. For example, tightly fastened cladding such as cedar siding or fiber cement board might allow water trapped between the siding and a smooth building wrap to pool and could make its way through the wrap and into the framing. These are cases where a drainable building wrap would provide the needed capillary break to allow water to drain out of the assembly.

Surfactant resistance

The water resistance of a building wrap can be degraded by chemicals known as surfactants (or surface active agents), often found in cladding materials such as cedar and stucco and also in solutions used to power wash siding. These chemicals reduce the surface tension of water, easing its ability to pass through microscopic openings in the membrane. Some building wraps offer added protection against the harmful effects of these chemicals, which might be an important consideration for assemblies constructed using these materials.

Geography and climate

As stated, *IBC* now mandates an exterior wall assembly incorporate "a means for draining water that enters the assembly to the exterior." However, a growing number of states have added even more prescriptive measures to their codes. Oregon, for example, now requires "…the [building] envelope shall consist of an exterior veneer, a water-resistive barrier (housewrap, building paper, etc.) and a minimum ⅛-in. [3-mm] space between the WRB and the exterior veneer."

As a rule of thumb, the Building Enclosure Moisture Management Institute (BEMMI) recommends any area receiving more than 508 mm (20 in.) of annual rainfall should incorporate enhanced drainage techniques in the wall system, especially if using an absorptive cladding material. Areas receiving 1016 mm (40 in.) or more should utilize rainscreen design regardless of cladding material. The orientation of the wall, amount of overhang, altitude, and even nearby trees can have an impact on how much water intrusion can be expected and how likely it is to dry.

Taking a system approach

A WRB material alone—no matter how advanced it is—cannot be counted on to protect a structure from unwanted air and moisture movement without taking the whole assembly into consideration. It is important to specify compatible materials to ensure all components work together.

For example, sealants with high solvent or plasticizer content can damage bitumen flashing products causing functional and aesthetic issues. When seams and tears are not properly taped, they will allow windblown rain to infiltrate the assembly. Failure to use galvanized roofing nails or plastic cap nails to attach the WRB to the sheathing and framing can also compromise performance.

To counter this problem, some manufacturers have developed a system approach including compatible tapes for seaming and adhesive flashings for openings. When installed together, these systems are often assured through extended warranties from the manufacturer. When in doubt, always check the manufacturer's website for additional guidance.

Changing building codes and greater adoption of certain cladding materials have caused specifiers to take a closer look at how moisture is managed in the wall assembly. Advances in building wrap products have added a powerful tool to help achieve these goals. The smart way forward is to avoid waterproofing the wall to the detriment of breathability, but to rather take a holistic approach to designing a wall system providing adequate protection against water but also able to dry out when it inevitably gets wet. **CS**

Note

[1] Visit buildingscience.com/documents/building-science-insights/bsi-061-inward-drive-outward-drying.

ADDITIONAL **INFORMATION**

Author

Bijan Mansouri is the technical manager at Typar Construction Products. He has been with Berry Plastics for 25 years, working in different technical capacities. Mansouri is responsible for building code requirements, design and development of new construction products, and education on proper practice and installation of building envelope. He received his bachelor's and master's degrees in mechanical/aerospace engineering, and is a member of the Air Barrier Association of America (ABAA) and ASTM. He can be reached via e-mail at bijanmansouri@berryglobal.com.

Abstract

The race to achieve waterproof wall assemblies may be inadvertently making it easier for moisture-related issues to fester. There is no such thing as a waterproof wall, just one built so tightly it is almost guaranteed to get and stay wet. One of the most challenging situations in which to manage moisture is when a reservoir cladding like fiber cement, brick, or stone is specified in a region where air-conditioning is often used and which has an annual rainfall of 508 mm (20 in.) or more, applicable to most of the country. The best wall assemblies are the ones designed to realistically manage moisture and dry out. Choices for managing moisture are expanding, driven by advances in technology, evolving building codes, and a growing customer concern with mold prevention, indoor air quality (IAQ), and energy efficiency.

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07 25 00–Weather Barriers

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Key Words

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Reservoir cladding
Vapor permeability
Weather-resistant barrier

Permeability and Performance in Water-Resistive Barriers (WRBs)

Identifying the Proper Choice for Applications

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Contrary to popular belief, building codes do allow for use of permeable WRBs in cold climates. In fact, high-perm water-resistive barriers may actually be preferable in many cold-climate applications.

Abstract

The topic of *water-resistive barrier* (WRB) *permeability* in a building assembly is wrought with confusion. The design principles make the topic sound simple - prevent moisture issues by ensuring the building envelope manages moisture and the movement of air throughout the building, and allow for moisture in the assembly to drain away or evaporate - but the science behind it can quickly get technical and confusing.

Generalizations and misconceptions about accomplishing these principles are perpetuated based on practices that have lagged behind advancements in understanding the movement of water vapor through a wall assembly, inaccurate application of dew point analysis, and a misunderstanding of the differences in application of *vapor retarders, vapor barriers,* water-resistive barriers and air barriers. The complexity caused by air carrying moisture is a factor in the correct application of envelope components fighting moisture intrusion.

This has led to the common misunderstanding that code* only allows for the use of *impermeable WRBs* in cold climate zones, which is not the case. In this white paper, we'll address why code* allows both high- and low-perm WRBs, with proper selection depending on the other materials used within the wall assembly. We'll present how understanding code* requirements and *vapor drive* dynamics is key to designing an optimal wall assembly.

For the purposes of this white paper, WRBs above 10 perms, when tested per ASTM E96 Procedure B (wet cup), are classified as *high permeability*. WRBs less than 10 perms (wet cup) are classified as *low permeability*.

Water's Three Invasive Forms

Determining the appropriate degree of permeability in the assembly begins with an understanding of the forms of water that the assembly confronts.

Liquid – Gravity and wind can pull rainwater, groundwater, and melting snow into the envelope, but so can surface tension, capillary action and differences in air pressure.

Vapor – Water in a gaseous form that exists in the air both inside the building and outside of the building can diffuse through the building envelope through differential vapor pressure.

Solid – Moisture can condense and freeze within the envelope, compromising its integrity through the contraction and expansion that occurs when ice thaws, returns to liquid water, and refreezes again.

Follow the Three D's: Deflect, Drain, Dry

Good water management can be achieved by following three basic principles: deflect, drain, and dry. No matter how hard you try to avoid water infiltrating your structure, it's just a matter of when it will get in and to what degree. But the rule still stands: Deflect water wherever possible. When water can't be deflected, drain as much of it away from the building envelope assembly as possible. For any water that does get into the building envelope assembly, create as much ability for fast drying as possible.

Strategy One: Deflect

Inevitably, all buildings will eventually leak due to the natural movement and degradation of materials over time. Cladding serves as the first defensive protocol against the most significant cause of building envelope deterioration – driving rain. It acts as the primary plane of deflection. A variety of cladding systems exist.

DensElement® Barrier System integrated into wall assembly, Fannie Emanuel, Chicago, Illinois.

Sandwich panels are impervious to rain. Through the tongue and groove connecting of the impermeable metal panels, water, vapor and air barriers are achieved.[1]

Curtain Walls are comprised of aluminum frames with infill panels, glazed or opaque, which are fixed to the frames. While aesthetically pleasing, water infiltration, condens-ation and air leakage can occur and in cold climates, condensation can occur and ice can form.[2]

But where primary deflection fails, secondary water-resistive barriers help to manage liquid water concerns by stopping water from moving deeper into the wall assembly. Rainscreens are a component of double-wall construction.[3] While some water will find its way into the cavity, direct rain is deflected and the wall is protected from significant amounts of water. The inner part of the wall assembly provides the airtightness, structural stability and the thermal insulation.[4]

Good design practice further protects buildings when proper flashing and channels for drainage are included and permeability of the WRB is optimized for drying. This is where water-resistive and air-resistive barriers come crucially into play to avoid mold, mildew, corrosion, decay, and other issues that can cause critical damage to building structures and human health. A variety of tools are available to help prevent damage from water that passes the primary weather barrier in its different forms.

Strategy Two: Drain

Liquid water in the assembly needs to be able to drain to the exterior of the building. A number of cladding types, such as stucco, wood, fiber cement, concrete and masonry absorb water and become, as Building Science Corp. refers to them, reservoir claddings.[5] Absorbed water is transported by capillary action. Keeping water from the wall assembly begins with controlling that capillary action in the cladding, which is the function of a drainage plane, along with ample space between the reservoir cladding and the wall assembly.

An air barrier inwardly placed from the cladding can function as the drainage plane if it is continuously sealed. When absorbed water is exposed to the sun's heat, the water turns to vapor, and serious inward vapor drive occurs – even in warm climates.[5] Drainage cavities formed by drainage mats and channels can help facilitate this action. Vapor drive occurs in an assembly when pressure differentials between the inside and the outside of the building cause moisture-laden vapor to move from an area of high pressure to an area of low pressure where cooler, drier air is present. Pressure differentials are only a consideration for the assembly if the materials have the permeability to allow for vapor diffusion, where vapor molecules pass through porous materials. The rates of vapor diffusion are dependent upon the degree of permeability. Although it has often been considered a negative occurrence for the envelope, vapor diffusion can actually perform an important drying function and should be considered a necessary component for proper assembly design.

Strategy Three: Dry

As water heats, the vapor particles are able to travel through much smaller openings in the wall assembly. Creating the ability for that vapor to escape the assembly becomes crucial to long-term building endurance, regardless of the locale and climate outside.

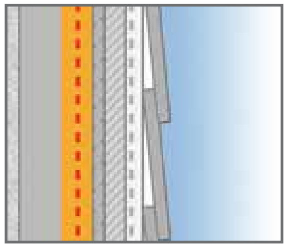
Cooling air becomes less able to hold moisture, raising relative humidity as water vapor density falls. At 100% relative humidity, the air is saturated in moisture, condensing into dew droplets that can form on the surface of the assembly. Whether condensation occurs within the wall assembly is a function of the temperature of the wall components. In a cold winter climate, for example, the indoor temperature is likely around 70° F degrees, while the outside temperature may be 10° F degrees. Based on the wall assembly components, the temperature of the sheathing may be at the dew point, where moisture-laden air condenses as water droplets. When components such as continuous insulation are added, outbound of the exterior sheathing, the location within the assembly where dew point temperature is reached may also be moved outbound of the sheathing. In this scenario, a vapor permeable WRB may allow water vapor to be carried beyond the secondary water barrier and, assuming a drainage cavity is in place, allow for liquid water to form where it can be safely drained out of the assembly.

Complexity in building envelope design occurs because the dew point is variable depending on atmospheric pressure and temperature, as well as the variance in the assembly components and their temperature throughout the building. This results in variances in the temperature of the wall assembly components. Condensation can occur on any of the assembly components, driving consideration of material usage with vapor diffusion capabilities as a means of moisture management. Understanding this dew point analysis plays a vital role in successfully designing and constructing new buildings and assessing the state of existing ones.

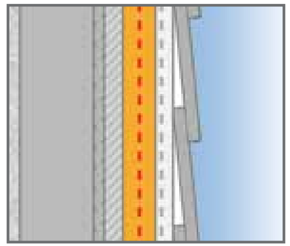
When water condenses on a building's exposed internal surfaces (like cold windows), this is called surface condensation. When it occurs within the fabric of the building (such as on the surfaces of assembly materials), it is called interstitial condensation, which can cause mold and other moisture-related issues. Historically in cold climates, a vapor retarder was installed on top of the sheathing to prevent vapor diffusion from the exterior to the interior. This, however, results in potential condensation from the warm, moist interior air in high pressure toward the cold, dry exterior air in low pressure. The warm, moist air cannot escape, causing condensation to occur on the inward-facing side of the sheathing.

Conversely, when the weather is warm outside, placing a vapor retarder on interior side of the sheathing restricts the movement of warm, moist outside air in high pressure toward the cool, dry low-pressure air inside the building, causing condensation to form on the outwardly facing side of the sheathing.

Vapor Retarder on Interior of Sheathing



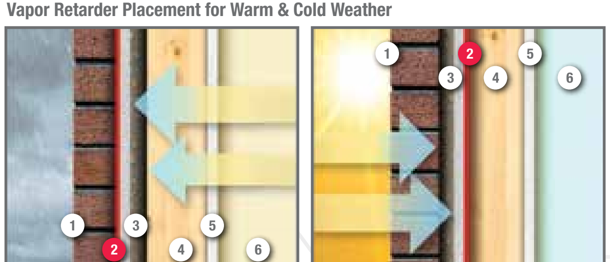
Vapor Retarder on Exterior of Sheathing



The natural response to this is to assume placing a vapor retarder on both sides of the sheathing will solve the dilemma; however, this only restricts moisture-laden vapor from escaping the building in both directions. Water vapor needs to escape for the assembly to remain dry. It can move inside or outside to dry, or the location where dew point is reached must be strategically located so when liquid water forms it can drain out and away from the building.

In freezing conditions when ice forms on the wall, the concern is that melting water can leak into the building materials as the water droplets heat up and expand. Warmer temperatures inside create opportunities for condensation to evaporate.

Vapor Retarder Placement for Warm & Cold Weather



1 Cladding
2 Vapor Barrier
3 Exterior Sheathing
4 Wall Studs
5 Interior Drywall
6 Building Interior

Building Code Requirements

Industry nomenclature has contributed to confusion about materials application. The lowest permeability occurs in a vapor retarder that has a permeance rating of 0.1 perm or less referred to as a vapor barrier. Vapor retarder permeance ratings can range from 0.1 perm through up to 10 perms. Such vapor retardant materials come in a range of products, including gypsum mats, asphalt saturated building papers, oil- or latex-based paints, elastometric coating, vinyl wall coverings, or sometimes a combination of these materials. Water-resistive barriers resist liquid water from entering the building envelope, while air barriers prevent the uncontrolled flow of air. Some products may act as both water-resistive barriers and air barriers, and in some cases a single product may act as a water-resistive barrier, air barrier, and vapor retarder. Unfortunately, because multiple functions may be performed by single components, confusion has arisen about how to label these products leading to improper naming and even improper understanding of the functions of these components. As an example, it is not uncommon for an "air and vapor barrier" to be referenced when the design professional is actually describing an "air and water-resistive barrier."

Depending on the various materials used within the wall assembly, code* allows for both high and low-perm WRBs, with proper selection depending on the climate zone, type of building, and other materials used within the wall assembly. Understanding code* and vapor drive dynamics reveals that, often, a vapor-permeable WRB is a preferable choice, provided that the rest of the wall assembly addresses issues of air-tightness and liquid water penetration.

The IBC states:

- *Exterior walls shall provide the building with a water-resistant exterior wall envelope.[6] This envelope shall include flashing.*
- *The exterior wall envelope shall be designed and constructed in such a manner as to prevent the accumulation of water within the wall assembly by providing a water-resistive barrier behind the exterior veneer, and a means of draining water that enters the assembly to the exterior.*
- *Not fewer than 1 layer of No. 15 asphalt felt, complying with ASTM D226 for type 1 felt or other approved materials, shall be attached to the studs or sheathing, in such a manner as to provide a continuous water-resistive barrier behind the exterior veneer.*

It's worth noting that the code* says asphalt felt, or another approved substitute must be used with flashing to keep water outside the sheathing. The International Code Council Evaluation Service (ICC-ES) has evaluated a number of WRB materials for use as a substitute for No. 15 asphalt felt, including but not limited to building wraps, liquid-applied WRBs, Grade D building paper, and certain wall components incorporating rigid foam insulation. Building papers and asphalt felt have a permeability of approximately 30 perms (wet cup). With this level of permeability, the asphalt felt will shed water and allow for drying to the exterior but will not likely be able to serve as the vapor retarder.

The Role of Climate

Climate doesn't entirely dictate WRB choice, but it does play a major role. Analyzing the temperature profile of the varying wall components for specific indoor and outdoor conditions for the building determines the use of specific materials. For example, determining the dew point of a wall configuration informs where you can expect condensation to occur.

The IBC's requirements for exterior walls address different needs for different climate zones, dividing vapor retarders into 3 classes (Section 1404.3 –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)*

Class I or 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 framed wall. Class III vapor retarders (1-10 perms) installed on the interior side of the wall assembly are allowed in these climates if certain design conditions are met, such as vented cladding over specified sheathings or continuous insulation used with specified R-values. The exterior portion of the wall assembly must compensate with materials that account for or move the location of the dew point to prevent moisture penetration and trapping.

In cold climates, vapor retarders must always be installed to the inside of the wall to defend against condensation pooling from the warmer temperatures inside the building to the colder outdoors, transforming from vapor to liquid that can accumulate and mold in unconditioned areas like inside batt insulation. Class II vapor retarders should not be used on the interior in climate zones 1 and 2. Class I vapor retarders should not be used in climate zones 1 through 4, other than Marine 4 because of the marine layer's condensation in the air. These climate considerations are where dew point analysis is most important to the hygrothermal modeling of the building fabric to determine the ideal water- and air-restrictive barrier system assembly.

Choosing Climate-Appropriate Permeability

Liquid water isn't the only potential threat that climate can pose. Vapor diffusion is the movement of water vapor molecules through materials when driven by differences in vapor pressure. These differences in vapor pressure are caused by variations in air temperature, among other things. The direction that vapor diffuses through materials is always from high pressure to low pressure, usually this means from the warm side to the colder side. In cold climates, vapor drive typically moves from inside (where it is warm) to outside (where it is cold).

Concerns arise when the higher-density moisture in the warm air becomes trapped inside, pushing in all directions toward the wall, ceiling, and flooring assemblies. High-perm WRBs will allow for drying if there is continuous insulation outbound of the sheathing. This configuration can also shift the location of the dew point outbound of the sheathing. High-perm WRBs aid in vapor diffusion and drying potential moisture intrusion.

In walls with sufficient exterior insulation, the dewpoint temperature of the interior air will be below the temperature of the back of sheathing: therefore condensation due to air leakage cannot occur within the stud space. If an assembly is shown by calculation to be safe against air leakage condensation (using the method described below), then diffusion condensation cannot occur, even if absolutely no vapor resistance is provided inside of the sheathing (i.e., no vapor barrier or other control layer), and even if the sheathing is a vapor barrier (such as foil-faced insulations).[14]

Defining Selection Factors

With climate no longer the primary influence in choice of permeability level, other factors must be considered. The choice may come down to what the WRB's function will be within the wall assembly.

1) Is the WRB meant simply to keep rain water off the sheathing?

2) Is it meant to keep rain water off the sheathing and allow for drying when water intrudes the wall cavity?

3) Is it also intended to serve as a vapor retarder or barrier?

4) Is it also the wall assembly's air barrier?

Comparing Vapor Retardation Performance

Low-Perm WRBs

Building science tells us if a low-perm WRB is used outside the sheathing, it will shed water and retard some level of vapor drive. If properly sealed, some WRBs may also serve as the wall assembly's air barrier. In cold climates, a low-perm WRB will shed water but could also slow the vapor diffusion (or moisture-drying potential), which is driven from the inside to the outside of the building. Without proper diffusion, moisture in the warmer air can settle within the assembly. The impacted components are based on the location of the dew point. This is when mold can develop and degradation can occur.

Primary Concern: Given that a vapor barrier is installed on the outside wall, will water be trapped in the wall assembly?

High-Perm WRBs

High-perm WRBs allow for water shedding, but they do not retard the vapor drive like a low-perm WRB. When properly sealed, they can also serve as the air barrier. In hot or cold climates, a high-perm WRB will shed rainwater; however, it will allow a higher rate of vapor diffusion compared to a low-perm WRB.

Primary Concern: Given that the high-perm WRB has a higher rate of vapor diffusion compared to a low-perm WRB, is moisture being allowed into the wall assembly?

Considering Water Intrusion Via Openings and the Importance of Airtightness vs. Vapor Permeability

Small holes and other openings that exist throughout the structure of exterior walls are perhaps one of the most difficult sources to manage. In fact, testing demonstrates that, when a hole is in extreme water and wind, leaks may occur regardless of the water-resistive barrier used.[7] These leaks allow for a greater volume of water to gain entry.

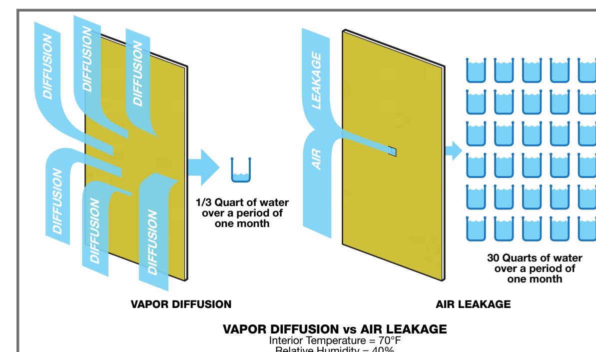


Figure 1: Vapor Diffusion vs. Air Leakage *(Source: Building Science Corporation)*

A common misunderstanding of moisture intrusion is the volume of water attributed to different phenomena such as diffusion through materials or water vapor carried by uncontrolled air movement. Vapor diffusion and vapor drive are often cited as concerns in moisture management. Depending on certain factors – including the climate and location of the building, the wall assembly design, the performance of building control systems and the presence of small air leaks — moisture intrusion via diffusion might only pose a fraction of the risk compared to moisture intrusion via uncontrolled air movement.

The DensElement® Barrier System installed on Eagle's Landing Apartments, Burlington, Vermont.

Vapor retarders slow or stop vapor movement that might occur as a result of diffusion of water vapor through porous materials. Building science research, testing and modeling suggest that the volume and rate at which water diffuses through materials is often minimal. The wall assembly's drying capability is an additional offset to incidental moisture intrusion as a result of vapor diffusion. Good design principles tell us that we should account for the possibility of wetting via diffusion and minor leaks in our assembly and offset that wetting with greater drying capability. However, moisture movement as a result of uncontrolled air leakage can be substantial and more frequently contributes to deleterious effects caused by moisture intrusion. Air leakage normally occurs through holes, cracks, and other openings present in the wall assembly.

This is demonstrated by consultants Building Science Corp. through testing two 4'x8' sheets of drywall, comparing vapor diffusion through one solid piece of gypsum wallboard to the amount of water penetrating the wall cavity when the other piece of gypsum wallboard has a 1" square hole cut in it.[8]

The conditions were:[9]

Position:	**Exterior:**	**Within Cavity:**	**Interior:**
Temp:	80°F	100°F	75°F
Relative Humidity:	75%	100%	60%
Vapor Pressure:	2.49 kPa	6.45 kPa	1.82 kPa

When the two drywall panels were subjected to the same conditions in the experiment, 1 ½ pints of water was collected by diffusion through the painted gypsum wallboard (approximately 5 perms), whereas 14 pints of water was collected through the 1" square hole in the panel. In more simple terms, in the experiment described above, air leakage carried almost 10 times more water vapor through the drywall than vapor diffusion does. This experiment demonstrates why preventing air leakage may be a higher priority in planning for moisture management than vapor diffusion.

It is critical to remember that no matter how masterful the installation, the WRB and sheathing will never be flawlessly sealed. There will always be openings present where water can penetrate over time. Furthermore, each component of the wall assembly, such as insulation, will make its own contribution to the wall assembly's total level of permeability. Use of continuous insulation can provide moisture vapor control and can function as a water-resistive barrier and air barrier.

IBC and IRC Building Codes allow for more permeable vapor retarders to be used in climate zones 5, 6, 7 and 8 when the proper amount of plastic foam continuous insulation is used on the outside of the studs.[10] Specific R-values are provided in the codes based on climate zone. The amount of continuous insulation used impacts the heat transfer rate of the assembly.

Since temperature of wall assembly components determines where condensation may occur in the assembly, maintaining an assembly temperature above the dew point temperature can restrict condensation.[11] Every part of the wall structure must be considered when judging the necessary perm level of the installation's WRB.

Understanding the various factors that affect the transfer of water and air through a building's envelope assembly helps to determine the best low or high-perm vapor retarders to use in your design to best defend against the elements, depending on the conditions that exist.

Modern Innovations in Water-Resistive Barriers

Though it is the only type of WRB called for by the code*, the traditional asphalt felt papers of yesteryear no longer have widespread usage as WRBs. They have since been replaced by mechanically attached sheet products, fluid-applied membranes, self-adhered membranes, and integrated sheathing materials that have gained code* approval through product/system evaluations.

Each of these material types has a wide range of function and permeability. In general, if a WRB material holds a product evaluation report, it has been tested to a specific WRB criteria verifying that the material will keep water outside the sheathing and drain the rain regardless of the permeability and its function as an air barrier or vapor retarder.

Many WRBs also have to meet compliance requirements as air barriers. These solutions have evolved over the past decades in response to demand for greater performance, durability, energy efficiency and ease of installation.[12] Integrated systems have become particularly popular in recent years for their ability to save time, lower costs and produce more reliable results.

DensElement® Barrier System

Georgia-Pacific's DensElement® Barrier System is one of the latest contributions to the industry's collection of integrated products. The gypsum panels integrate the water-resistive barrier and air barrier already within the structure. Specifiers can use the system to address water, and air-resistance needs with a single product.

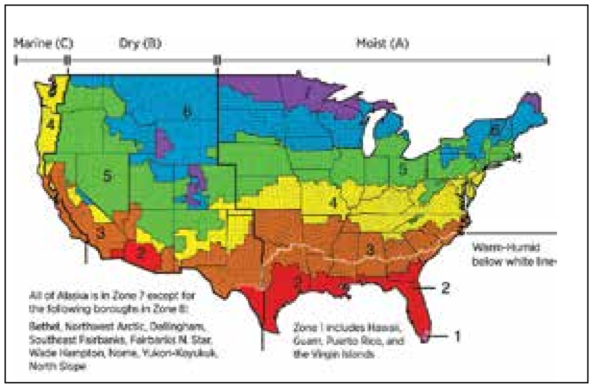
AquaKor™ Technology transforms the entire gypsum sheathing into a WRB-AB by integrating the fiberglass mat and gypsum core to form a monolithic, hydrophobic surface that blocks bulk water but allows vapor to pass through. This innovative 3-in-1 solution eliminates the need to finish the sheathing with a wrap, peel-and-stick, or fluid-applied barrier. Misapplication risks are thus greatly reduced.

Superior Drying Performance

DensElement Barrier System is vapor-permeable, measuring at greater than 20 perms. Thanks to its high vapor-permeability, the DensElement Barrier System offers excellent drying capability. Using a high-perm, fast-drying WRB may significantly reduce the moisture damage potential in wall assemblies that have taken on moisture.

Code Provisions

Climate Zone Map (2012 IECC)[15]



ICC-ES Acceptance Criteria AC212 is the basis of recognition for the DensElement Barrier System to be used as a water-resistive barrier. Meeting acceptance criteria AC212 means that the DensElement® Barrier System, without an additional WRB product applied on top of it, performs as well as liquid WRBs applied over sheathing. The DensElement Barrier System also qualifies as a continuous air barrier according to the Air Barrier Association of America and as prescribed in the IECC Section C 402 on building envelope requirements, as related to air leakage, for both materials and assemblies (provided that the joints, fasteners, openings, penetrations, and material transitions are sealed with a GP-approved fluid-applied flashing).[13]

Vapor diffusion is far less of a concern than water penetration via air leaks through openings.

In Conclusion

Conventional practices reflect the belief that code* only permits the use of impermeable WRBs in cold climate zones. As has been demonstrated in this white paper, that belief is untrue. Both high- and low-perm WRBs may fulfill code* requirements when considered in the context of other materials within the wall assembly. Understanding code* requirements and the dynamics of vapor drive are essential to designing an optimal wall assembly.

DensElement® Barrier System installed at University of Florida's O'Connell Center, Gainesville, Florida.

Glossary of Terms

A knowledgeable builder is a successful builder. With such a scientific and technical topic and terms that seem extremely similar, there's bound to be confusion. Know the differences to avoid common misinformation pitfalls.

Dew Point:	the temperature that air must cool to be fully saturated with moisture, condensing to become liquid water "dew drops"
Hygrothermal Modeling:	a computer-based modeling that predicts movement of heat and moisture through buildings
Impermeable WRB:	a liquid water barrier that will not let water vapor pass through
Interstitial Condensation:	the process of water condensing from a vapor to a liquid when moist air permeates hidden spaces inside an enclosed wall, ceiling, or floor structure
Vapor Permeability:	amount of water vapor able to pass through a material
High Vapor Permeability:	water vapor flow is less restricted
Low Vapor Permeability:	water vapor flow is more restricted
Relative Humidity:	the amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature Surface Condensation: the process of water condensing from a vapor to a liquid on a construction's surface, rather than hidden between its layers
Vapor Barrier:	an impenetrable material that resists water vapor diffusion
Diffusion:	the movement of water gasses through vapor-permeable materials
Drive:	moisture gasses moving from an area of high density to low density (typically moving from warmer temperatures to cooler temperatures)
Retarder:	allows some movement of water vapor between materials
Water-Resistive Barrier:	building materials designed to resist bulk liquid water that has penetrated past the exterior wall cladding
WRB-AB:	water-resistive barrier and air barrier, a membrane that resists liquid water and uncontrolled air flow

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Evolving Buildings Yield Evolving Design Principles

by Ted Winslow

All images courtesy CertainTeed Insulation

CONSTRUCTION PROFESSIONALS SEEM TO FIND WAYS TO ADD MORE LAYERS AND NEW MATERIALS TO BUILDING ENVELOPES. WHILE THESE ADDITIONAL LAYERS HAVE HELPED REDUCE ENERGY LOSSES, THEY HAVE NOT MANAGED TO KEEP WATER OUT OF THE WALLS. FOR EXAMPLE, THE USE OF CONTINUOUS INSULATION (CI) ON EXTERIOR WALLS AND THE AIRTIGHTENING OF BUILDING ENVELOPES HAVE ONLY INCREASED THE NEED FOR MATERIALS WITH ELEVATED DRYING POTENTIAL (*E.G.* FIBERGLASS INSULATION) BECAUSE WHEN (NOT IF) MOISTURE INFILTRATES THE ASSEMBLIES, IT NEEDS TO ESCAPE. THIS IS WHERE RESILIENT DESIGN COMES INTO PLAY.

Buildings must be durable and treated individually based on their climate zone (CZ), region, and the location—they must be robust. However, to do so, architects and specifiers must first understand how systems behave in different markets and how designs can be optimized to make the wall assemblies truly robust. Managing moisture would be the key to successfully constructing the sustainable buildings of the future.

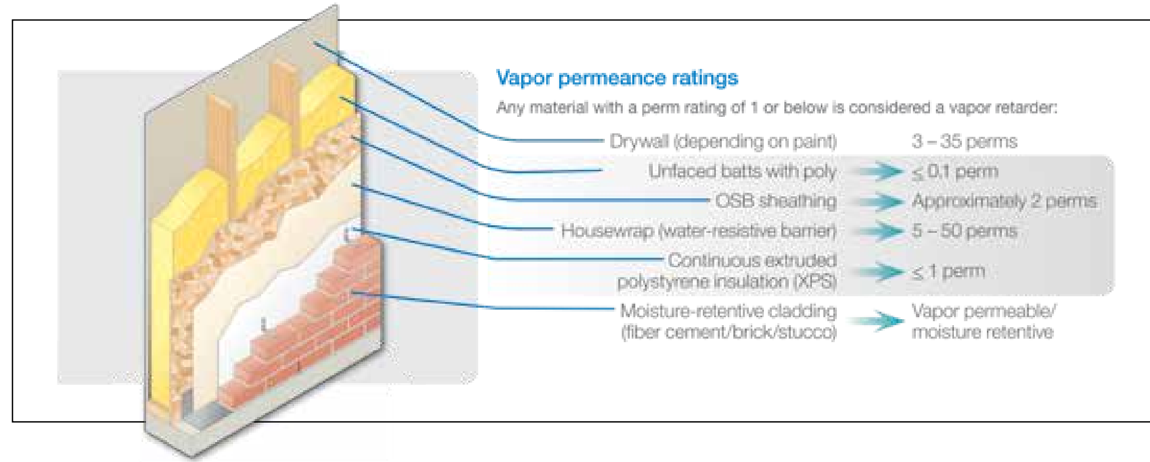
In several building science circles, the concept of a 'perfect wall' is often discussed. It has a lot of sound principles, such as 'keeping the outside out and the inside in' and designing the wall assembly to not just manage, but also control rain, air, vapor, and heat. However, even walls deemed 'ultimate' or 'perfect' fail due to the multitude of unforeseen events, such as faulty installations and poorly communicated design details. Due to this uncertainty, the ultimate perfect wall is only flawless until it fails. What will happen then? Can the wall withstand failure?

A robust wall is able to anticipate the areas where a wall system or component may not succeed. It includes layers that are designed to reduce the impact of failure. Alternatively, a robust wall could be considered the perfect failure, as it is designed to fail. It embraces the fact that building professionals cannot always predict complete success. However, the building team can anticipate at-risk areas and potential failures. By minimizing the risks and anticipating the perfect failure, construction professionals can create truly robust building assemblies.

Background

Let us take a step back and first understand the evolution of building construction. How has the industry shifted in the robustness of today's building assemblies? How have building methods changed, and how are they impacting things like insulation?

The evolution of framing techniques has largely been driven by the need to build more efficiently. Platform framing became the norm as it was much more efficient to construct than balloon framing. Traditional roof rafters have been shifted to roof trusses as they can be built on the roof, ground, or even prefabricated offsite—making room for more options and versatility as well as expediting the construction.

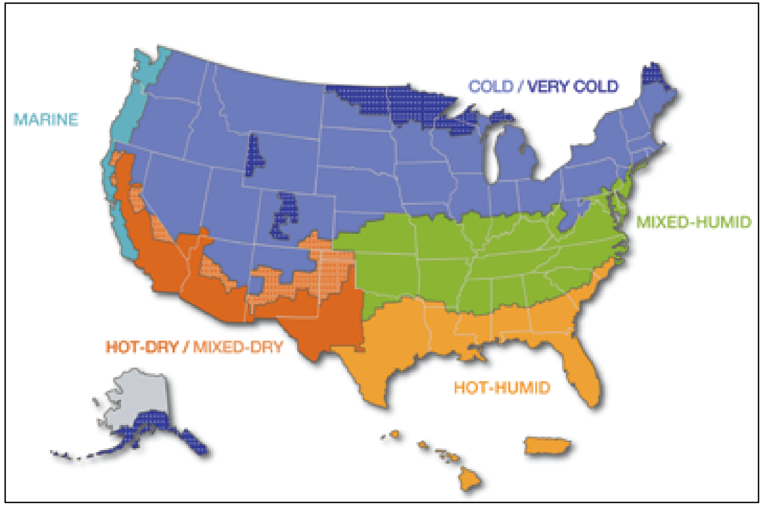


Expanded view of vapor permeance of an assembly and the components therein.

Even framing is changing with high-performing, lightweight joists and open-web trusses. Industry professionals are also seeing more and more elements being borrowed from prefabricated construction, which, on its own, is rapidly growing and changing how buildings are put together.

All of these changes come at a cost, especially as the industry is heading toward higher R-values and airtightness levels. There are even more challenging details to address and increasing opportunities for air to leak through the walls. Having said that, the primary goal still resonates within these structures—building professionals do want to develop healthy, durable, and energy-efficient structures. To do this, the project team must understand how the building works and where to look for key problems.

It is important to keep in mind that contractors are no longer just responsible for one role or function—even trades are evolving. For example, the insulation contractor is now required to be an energy expert for the entire building envelope, the most important piece of the entire building. The contractor must be equipped with the tools and knowledge to decrease air infiltration and increase building comfort. He/she must understand where to air seal, how to inspect work for quality, and potential problem areas and how to prevent them from happening.



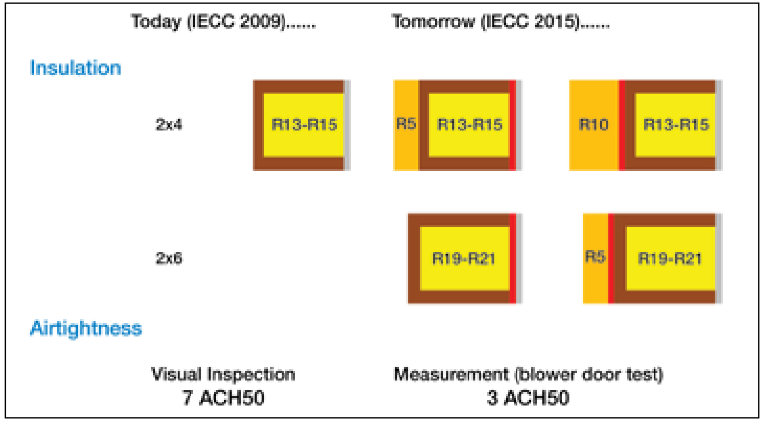
The different climate zones of the United States.

Builders are balancing and juggling multiple management strategies to address the needs—especially the management of heat, air, and moisture—of their projects. No single product or system can be used to address all of these. At a practical level, building project teams strive to achieve a balance between costs and performance, and sometimes one is compromised for the other. Trade-offs are made to reduce project costs. This can, in turn, negatively impact the building's ability to control the flow of heat, air, and moisture through the building envelope.

Enter the HAM principle—heat, air, and moisture flows must be balanced to ensure optimum performance for any building.

Heat flow

When design professionals manage heat, they are trying to keep what is in inside and what is out outside, at least to the best of their abilities. Heat will always try to move from a warm area to a cold zone. The rate of transfer can be slowed by adding insulation between those areas.



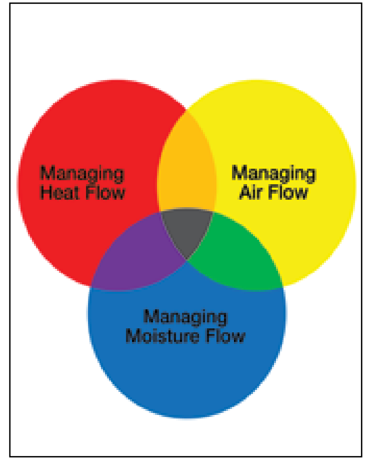
The shift to tomorrow's building code requirements.

When it comes to developing strategies for managing heat flow, the author's preference is to divide the wall into two sectors: the cavity and the exterior. There are many reasons for this, but the two primary ones for the author are:

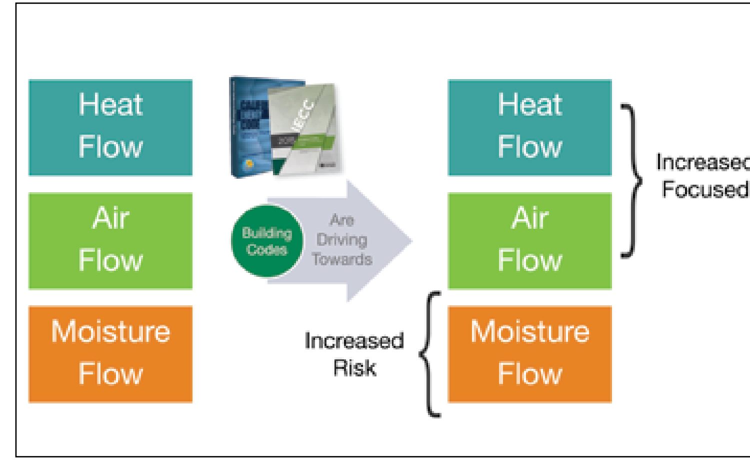
- each sector is designed to manage different elements of heat, air, and moisture flow; and
- multiple trades are installing various products on different parts of the wall.

The entire project team, including the architects and contractors, plays a huge role in building the ultimate perfect wall in all phases of a project. From the tradesperson installing the materials onsite to the specifiers designing the assembly, each of these roles need to be considered when designing crucial components and details for wall and roof assemblies.

Air permeable materials (*e.g.* fiberglass, mineral wool, and cellulose) and products like spray foam, radiant barriers, and even hybrid systems combining multiple types of insulation and sealing techniques are employed within the cavity. Vapor impermeable insulations (*e.g.* expanded or extruded polystyrene [EPS or XPS], polyisocyanurate [ISO], etc.) or vapor permeable materials such as fiberglass or stone wool are utilized on the exterior wall.



A balance is needed when managing heat, air, and moisture flow.



Building codes are focusing on heat and air flows. This leads to an increased risk for moisture flow because the drying potential is reduced.

The challenge becomes when to choose certain insulations over others and the factors that come into play when making those decisions. For instance:

- external rigid foam board greater than 50 mm (2 in.) thick could address many building code requirements, but there will still be challenges in attaching cladding and detailing around windows and it could be cost prohibitive for certain types of construction; and
- external closed-cell sprayed polyurethane foam (ccSPF) can be utilized in both residential and commercial applications, but the foam surface may limit cladding types due to surface irregularity.

When managing heat flow, the goal is to limit heat transfer to improve comfort and protect the building from moisture damage to improve the wall's durability.

Airflow

Building codes, particularly standards such as the *International Energy Conservation Code* (*IECC*) are focusing on reducing things like air changes per hour (ach) by evaluating them at certain pressure levels (typically 50 Pa [1 psf]) to simulate how air will leak in and out of a building. Tools like infrared (IR) and blower doors can be employed to pinpoint the location of leaks.

Just like heat, there are both interior and exterior strategies to address airflow. Exterior air barrier strategies employ products like fluid-applied membranes, water-resistive barriers (WRBs), and insulation boards. Combining these systems with tapes and joint sealants is a great way to address the leakage paths on the exterior side of the wall.

Interior air barrier strategies include a variety of solutions. SPF can be used to address challenging details (*e.g.* rim joists) or with hybrid applications in more cost-conscience jobs. It can also be utilized as a full-cavity solution or in conditioned attic assemblies with mechanical equipment. Airtight drywalls, window foam sealants, and caulk and seal packages can also be suitable to address a variety of details from the inside. Newer, more-advanced approaches include the installation of a smart vapor retarder as a continuous air barrier with tapes and sealants. Alternatively, the building team could utilize a similar system integrated with batt insulation that can be simply taped to tackle air, moisture, and heat in a single application.

What makes it 'smart'?

A smart vapor retarder has the ability to react to changes in relative humidity (RH) by altering its physical structure. During winter, when RH is low, smart vapor retarders have the ability to provide resistance to vapor penetration from the interior. However, when RH rises to 60 percent or above, its permeance also increases, thus allowing the water vapor to pass through, facilitating the drying of wet building systems.

When it comes to air infiltration and exfiltration, "air out always equals air in," so if air can be either stopped from coming in and/or going out, the building team can be fairly confident in the success of the system as a whole. One key advantage of also including an interior air barrier system is they are far better protected from hazards (*e.g.* rips, tears, getting blown-off, ultraviolet [UV] degradations, etc.) that could diminish performance. Another detail to consider is climate, as it also dictates the amount of airtightness a building would need. For example, a home in the northern half of the United States will generally need an ach 50 of three or less; whereas, the same home in the South would require an ach 50 of five or less. This is because buildings in the northern climates are susceptible to losing more energy due to the larger temperature differentials between the inside and the outside, especially in the winter months, so losing less air from the building allows it to more easily maintain internal air temperatures, thereby saving energy.

Another interesting nuance is exterior systems involve exterior trades (framers, siders, etc.) and interior strategies that generally involve insulators, drywallers, and other interior tradespersons. This raises the question of who is responsible for the occupants' comfort, indoor air quality (IAQ), and energy efficiency? Regardless of whether or not the responsibility lies on the inside, outside, or both, the project team must make sure that the above-mentioned strategies are utilized. Otherwise, hot air would be let out instead of keeping it under control.

Moisture flow

How are building professionals trying to manage moisture? Similar to heat and airflow, the goal is to always keep what is in inside and what is out outside. Of course, all of this changes once moisture gets inside the wall. The focus then is to provide the moisture with a pathway to escape the assembly and 'breathe,' so it can dry out.

Every component of the building assembly has a different vapor permeance and falls into one of the following four categories:

- vapor barrier – includes polyethylene (PE) sheet, unperforated aluminum foil, etc., and is between 0.01 and 0.1 perms (per the *International Building Code* [*IBC*], this is a Class I vapor retarder);
- vapor retarder – includes kraft-faced fiberglass batts and is greater than 0.1 but less than or equal to 1 perm (according to *IBC*, this is a Class II vapor retarder);
- semipermeable – includes latex or enamel paint and is greater than 1 perm but less than or equal to 10 (Class III vapor retarder, per *IBC*); and
- permeable – includes housewraps, building papers, etc. and is greater than 10 perms.

Quite often, construction practitioners focus on the permeance of just a few materials, but it is critical to take a much more holistic approach and understand how the entire assembly behaves from a moisture management standpoint. It should inspire building professionals to consider solutions that are robust in managing moisture. For example, smart vapor retarders are able to adapt their permeability based on the moisture trapped within a wall cavity—providing it has the means to dry out and minimize risks.

Good design and practice involve controlling the wetting of building assemblies from both the exterior and interior, and each climate zone requires a different approach.

Back to robustness

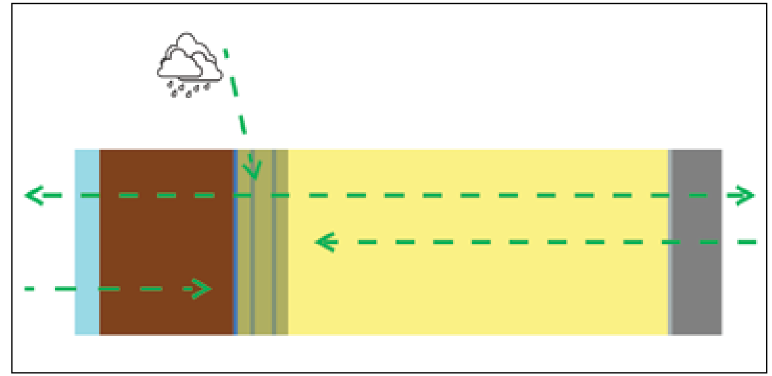
Heat and air flows are relatively static in how they are managed. For example, a hole can be sealed (hopefully during the construction phase itself) and additional insulation can be installed either in the wall's interior or exterior. However, moisture is a bit different. No wall or roof is completely impermeable to moisture. A robust wall is one with the ability to actively and passively manage moisture while accounting for the fact moisture management changes with the time of day, season, and life of a building.

Additionally, building solutions need to evolve with codes that are driving the increased levels of insulation and airtightness. In the past, R-15 or even R-13 were considered acceptable thermal insulation targets for exterior walls, but today's walls mostly require either increasing the wall thickness toward the inside (*e.g.* 2x6) to achieve R-20 and more, which is a code-driven requirement, or adding exterior insulation to the outside of the wall (up to R-10). Airtightness requirements are also more stringent than before. This is great from an energy efficiency perspective, but it increases the risk of moisture condensation in a wall with less drying potential. Surprisingly, there has been limited change in the building and energy codes (*e.g.* the International Codes [I-codes]) to account for these moisture-management challenges. It should be clarified this does not mean there are no areas where moisture management strategies are suggested (or implied) in some building codes. The issue is there are not enough deliberate references to construction practices to prevent moisture issues from occurring altogether. For example, Section 1404.3, "Vapor retarders," in the 2018 *International Building Code* (*IBC*) suggests "approved designs for accepted engineering practices for Hygrothermal analysis" could be utilized. However, this "code speak" is vague and does not clearly identify acceptable assemblies that would enhance a building's performance directly. The author anticipates focus will tilt toward areas like durability and resiliency during the next few code cycles as moisture-related problems arise and ideally there will be a shift in a direction that will provide content in an easy-to-understand format for all parties involved.

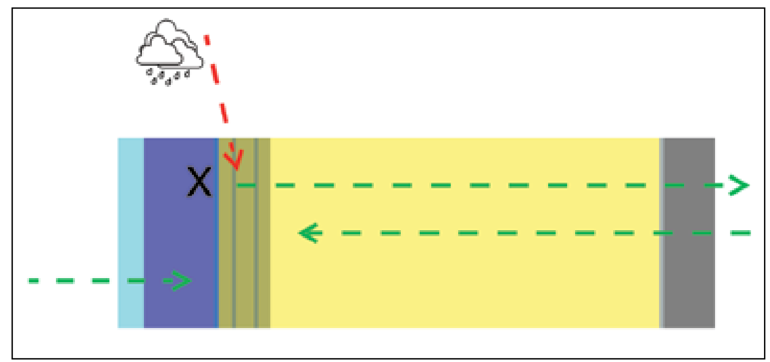
The challenge with moisture management led insulation product manufacturers to develop criteria to evaluate the durability and resiliency of a wall and to assess the robustness of an assembly. To be robust to moisture, the wall assembly needed to perform without moisture issues all year long. Based on research and analysis from dedicated building scientists throughout North America, the team was able to conduct a moisture analysis across various regions built on the following three fundamental performance benchmarks:

- Criterion 1: Assembly should avoid winter moisture condensation risk in the interior gypsum;
- Criterion 2: Assembly should avoid summer moisture condensation risk in the oriented strand board (OSB); and
- Criterion 3: Assembly should avoid water accumulation in case of rain penetration.[1]

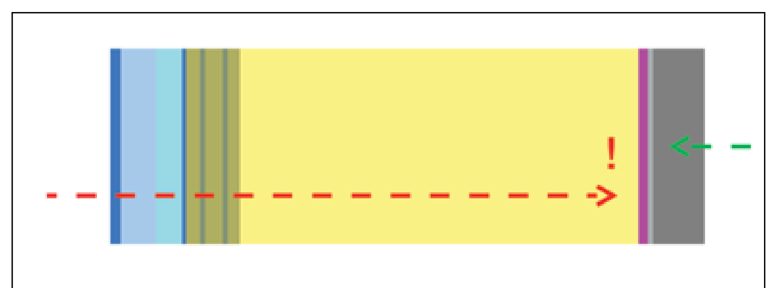
Here is what the team discovered when looking at various regions throughout the United States.



Continuous insulations (ci) with a higher permeance are more favorable as they dry toward the exterior and interior.



Ci with R-13 in cavity can still be at risk if rain infiltrates the wall assembly.



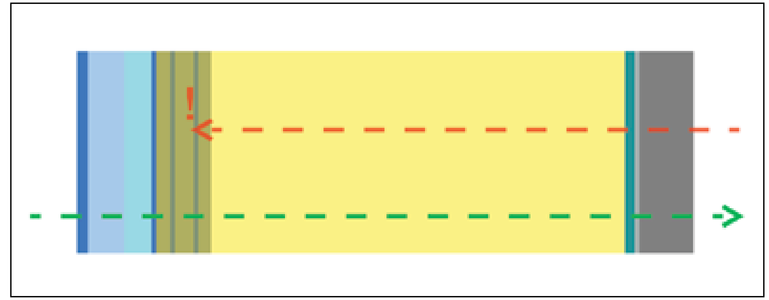
Polyethylene (PE) has high risk of summer condensation as assembly dries toward the interior of the building envelope.

Marine (CZ 3C and 4C) – San Francisco and Seattle, and cold humid (CZ 5A and 6A) – Boston and Minneapolis

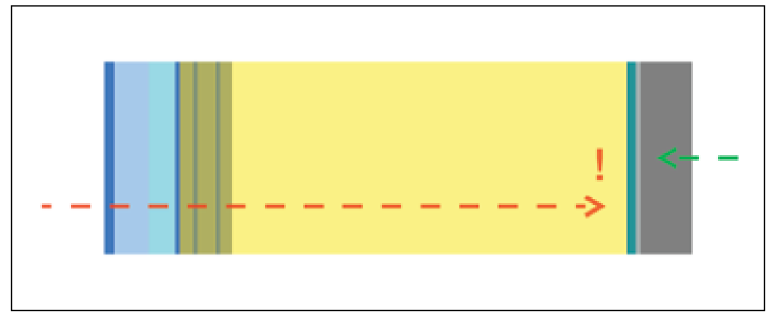
- Kraft batts
  - Pass Criterion 1.
  - Criterion 2: Moderate risk of summer condensation.
- Polyethylene (PE)
  - Pass Criterion 1.
  - Did not pass Criterion 2: High risk of summer condensation.
- Smart vapor retarders
  - Pass both Criteria 1 and 2.
- Closed-cell SPF
  - Pass both Criteria 1 and 2.
- 25-mm (1-in.) XPS (R-5) exterior insulation with R-13 fiberglass
  - Pass both Criteria 1 and 2.
  - Criterion 3: If rain infiltrates the assembly it can dry only toward the interior.
  - Note: Risk increased in markets like Seattle and Boston where rain is frequent.
- 38-mm (1.5-in.) mineral fiber (R-5) exterior insulation with R-13 fiberglass
  - Passes Criteria 1, 2, and 3.
  - Criterion 3: If rain infiltrates the assembly it can dry toward the interior and the exterior.

Hot humid (CZ 2A and 3A) – Houston, Tampa, Atlanta, Oklahoma City, and warm humid (CZ 4A) – Nashville and Philadelphia

- Unfaced batts
  - Pass Criterion 1 except in cities with cold winters (*e.g.* Houston and Philadelphia).
  - Pass Criterion 2.
- Kraft batts
  - Pass Criterion 1.
  - Did not pass Criterion 2: High risk of summer condensation in fiberglass behind the kraft (vapor-closed); moderate in Philadelphia.



Cities with cold winters could still be at risk even though they pass Criteria 1 and 2.



Kraft batts have moderate risk of summer condensation because the wall assembly dries toward interior.

- Smart vapor retarders
  - Pass both Criteria 1 and 2.
- Closed-cell SPF and open-celled SPF (ocSPF)
  - Pass both Criteria 1 and 2.
- 25-mm (1-in.) XPS (R-5) exterior insulation with R-13 fiberglass
  - Pass both Criteria 1 and 2.
  - Criterion 3: If rain infiltrates the assembly it can dry only toward the interior.
- 38-mm (1.5-in.) mineral fiber (R-5) exterior insulation with R-13 fiberglass
  - Passes Criteria 1, 2, and 3.
  - Criterion 3: If rain infiltrates the assembly it can dry toward the interior and the exterior.

Making these learnings universal – available tools and resources

The great news is the industry is at a point where access to reliable knowledge and information focused on the science and performance of buildings is readily available. Manufacturer websites have a plethora of information. BuildingScience.com is another great resource.

Trade associations like the North American Insulation Manufacturers Association (NAIMA) are also developing excellent resources to utilize and leverage like the Canadian Wood Council's (CWC's) simulator tool that allows design professionals to evaluate various assemblies across Canada against several performance criteria.

Recently, the US Department of Energy (DOE) and Building America have been developing a building science advisor tool to evaluate the performance of various wall assemblies across the country. The intent of these tools is to provide the industry with a better gauge to measure how buildings will perform.

Embrace failure to learn the path forward

Everyone fails. Many thought leaders have been quoted about being fearless in their pursuit of accepting failure, but one quote from Woody Allen has always stood out to the author: "If you are not failing every now and again it is a sign that you are not doing anything very innovative."

As codes move forward, building professionals cannot remain complacent and static in their approach to construction. They need to adapt, change, evolve, and be dynamic. If the same thing is done constantly despite environmental changes, construction teams cannot anticipate different results, or it may yield different results, just not the expected ones.

The industry needs to keep moving forward and try to understand the local considerations of product, material, and system selections as well as the behaviors they exhibit to make durable and resilient buildings. The structures must be robust by maintaining a greater potential to dry than wet.

It is advisable to consider more resilient and adaptive product choices such as smart vapor retarders and hybrid systems in certain climate zones to optimize their performance. Building professionals need to not just anticipate failures, but also understand how structures fail. Systems designed to recover when exposed to failure must be employed to make the building envelopes truly robust. **CS**

Note

[1] This initial analysis was done on a single type of exterior wall construction with plans to expand the study to other construction types. Key findings from that preliminary analysis have been presented in this article. It is recommended to consult a professional building science consultant for questions related to any construction type.

ADDITIONAL **INFORMATION**

Author

Ted Winslow is the brand product manager of building science, systems, and technical marketing for CertainTeed Insulation. He serves the company as a technical resource on topics ranging from code reviews to sustainability programs, and oversees development of CertainTeed insulation systems. Winslow holds a bachelor of science degree in mechanical engineering from Temple University. He can be reached via e-mail at ted.winslow@saint-gobain.com.

Abstract

Buildings must be durable and treated individually based on their climate zone, region, and location. To do so, architects and specifiers must first understand how different systems behave in various markets, and how they can optimize the design to make exterior wall systems truly robust. Building professionals need to not just anticipate failures, but also understand how structures fail. Systems designed to recover when exposed to failure must be employed to make the building envelopes truly robust.

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