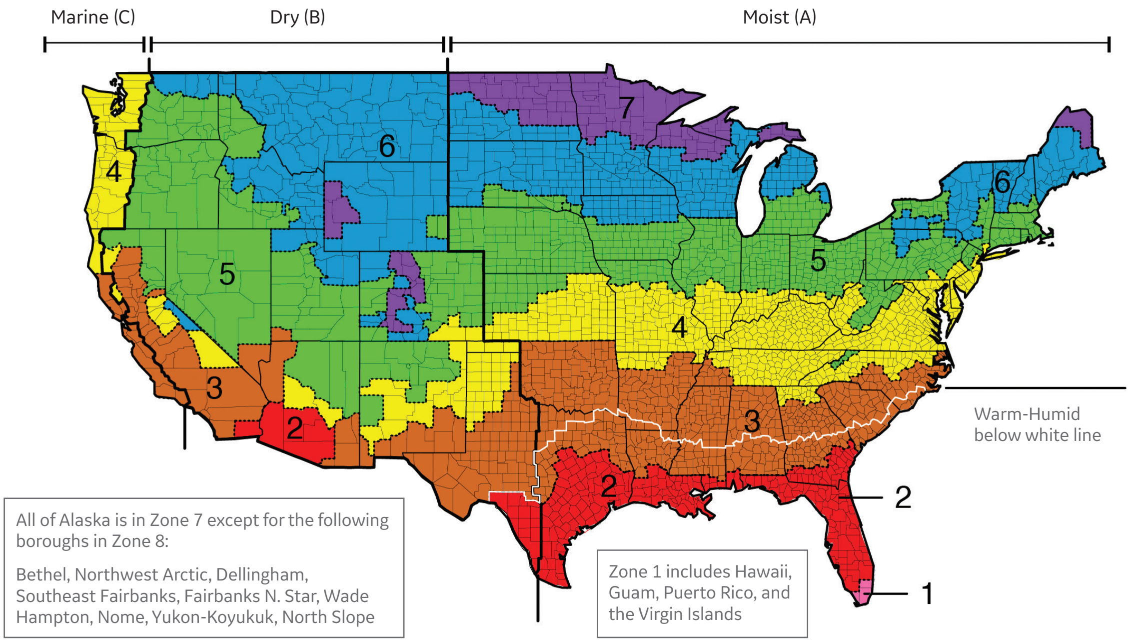
GE Silicones

VAPOR PERMEABLE VERSUS IMPERMEABLE AIR AND WATER-RESISTIVE BARRIER MEMBRANES IN NORTH AMERICAN WALL ASSEMBLIES

January 2018

Water vapor is the invisible source of many problems found in buildings today. Those working in commercial construction can anticipate and overcome the risks posed by moisture movement with careful attention paid to building material properties, their function within the building system, and the effects of the surrounding climate on the building.



DOE Climate Zones are areas defined by their heating degree-days. Climate Zones 1 to 3 are generally hot and sometimes humid climates, whereas climate zone 5 to 8 are predominantly drier and cold. Climate zones 3 to 5 are intermediate in both cooling and heating requirements (IECC, 2012).

Introduction

Combined air and water resistive barriers (AB/WRB or AWB) installed on the exterior of wall assemblies are critical for protecting buildings from moisture. These membranes form an integral part of the enclosure air and moisture barrier system and resist the inward movement of water that by-passes the cladding system. With proper detailing and flashing they both resist air leakage and safely drain water out of the wall system.

These membranes come with many different properties and are designed for specific building types and applications. Commercial construction, which generally features glass-faced gypsum sheathing over steel studs, concrete masonry units (CMU) or cast-in-place concrete, generally uses two categories of membranes: self-adhering membranes or liquid applied membranes.

Both self-adhering membranes (SAM) and liquid applied membranes (LAM) can either be vapor permeable, impermeable, or fall somewhere in between. While these membranes are primarily intended to prevent water ingress as a result of precipitation, they may also be specified to control vapor diffusion and air flow, and hence it is important to understand how these membranes impact the wetting and drying characteristics of the wall assembly. Secondary risks may be created from unintended vapor flow or other inadvertent moisture restriction based on the vapor permeance of the AWB. The ideal permeance of the AWB can vary significantly depending on the wall assembly and the micro-climate and should be carefully considered within this context.

Designed for Climate

North America is categorized into different climate zones based on outdoor temperatures and humidity. The Department of Energy (DOE) climate zone map shows the boundaries between the defined regions based on heating and cooling requirements for each zone (decreasing in temperature from 1 to 8). These zones are further subdivided into their relative humidity load (increasing in humidity from A, B, and C). Naturally, enclosures designed for one climate zone will not necessarily work in other climate zones.

Over the course of decades, rules of thumb have been developed based on research and the collective experience of the construction industry in each climate zone. However, many existing standards of practice are based on historical building materials, systems, and operational norms, and are unable to provide guidance on new products and systems with different material properties used to enclose buildings with different interior conditions.

This bulletin discusses the fundamental physics of moisture movement, how they apply to different climate zones, and how the material properties of AWB membranes are important to ensure moisture resilient design.

The Water Problem

Corroded steel studs and tracks within the exterior wall of a multi-family building undergoing a full enclosure rehabilitation in Climate Zone 4 as a result of water ingress into a wall assembly with low drying potential.

All buildings materials have a certain safe moisture storage limit. If this limit is surpassed for long enough, moisture related problems start to occur. Moisture sensitive materials are either susceptible to moisture damage or have a lower safe storage limit. These are materials that may lose their functionality or pose health risks to the building occupants if exposed to an excessive moisture load.

Some causes of moisture damage include mold growth and decay, corrosion of metallic elements, freeze-thaw damage to masonry, and pest infestation (ants, termites, etc.). Such damage leads to a multitude of problems including aesthetic concerns, property damage, sick building syndrome, or even structural failure.

How Do Walls Get Wet?

The main sources of moisture, in approximate order of magnitude, are listed below:

Bulk Water Leaks

Bulk water leaks are the most significant source of water leading to moisture damage. While rain is the most common source, snowmelt can also leak and cause damage. Floods and plumbing leaks can also be significant sources of moisture.

Air Leakage Condensation

Air leakage condensation occurs when warm and humid air contacts a cold surface in the wall assembly. In cold weather, this would typically be warm interior air leaking out of a wall and reaching a cold surface. In hot and humid weather, this would be outdoor air leaking into the walls and coming into contact with cool, usually air-conditioned, interior surfaces.

Construction Moisture

Construction moisture is water that is built in to the building during its construction. This can be stored in moisture absorbing materials that are wetted during construction or as a part of their installation (e.g., cast-in-place concrete, drywall mud). Construction moisture typically dries out over time, but can become a problem if a vapor impermeable material inhibits drying, especially over wood or paper components.

Vapor Diffusion

Vapor diffusion is typically the least significant moisture transport mechanism. While it is generally a small source of wetting, ***vapor diffusion is the most important mechanism for drying.***

Water Vapor Fundamentals

Water vapor diffusion is caused by the random movement of water molecules. A larger number of water vapor molecules (higher concentration) will spontaneously flow to areas with a lower concentration (fewer molecules). Put more simply, water vapor diffuses from wetter to dryer. It also diffuses in all three dimensions, but in wall assemblies, it is often simplified to flow in only two directions: inward and outward.

Measuring Water Vapor

Water vapor can be quantified in many ways, but is typically measured as grains of water per pound of dry air or as vapor pressure (e.g., inches of mercury or Pascals). The transmission of water vapor is generally measured in perms, which is one grain of water vapor per square foot of wall area over a period of an hour, with a vapor pressure difference of 1 inch of mercury.

The International Building Code identifies three classes of vapor retarders:

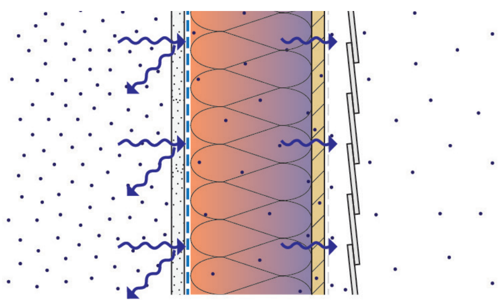
- **Class 1:** Less than 0.1 perm (e.g., vapor barrier)
- **Class 2:** Greater than 0.1 but less than 1 perm (e.g., vapor retarder)
- **Class 3:** Greater than 1 but less than 10 perms

A perm is a measure of flow, and so its reciprocal is vapor resistance. This means that resistance to vapor flow is subject to diminishing returns. The maximum permeance in a wall assembly is the interior air film, which is about 260 perms. Consequently, the relative difference in vapor resistance to the maximum between a 10 perm to 20 perm membrane is only about 5%.

Relative humidity is a measure of the degree of saturation of a volume of air. Air at 100% relative humidity is completely saturated; any additional water added will condense as liquid. But the maximum amount of water that can be stored in this volume of air changes significantly with air temperature; hot air can store much more moisture than cold air. Thus, increasing the temperature of a surface will decrease the relative humidity of air at that surface.

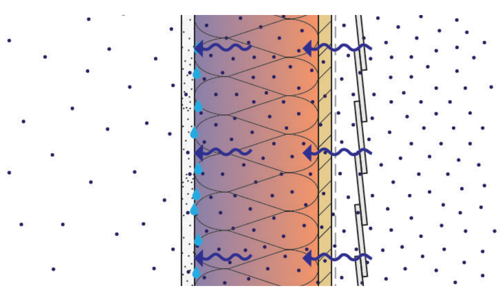
Vapor Flow in Walls

To avoid high humidity or condensation conditions, water vapor diffusion needs to be controlled. This can be achieved in one of three ways; 1) by blocking water vapor flow, 2) by designing a flow-through system that is sufficiently permeable to avoid any moisture accumulation, or 3) by raising the surface temperatures to decrease the relative humidity. The first approach is quite common in cold climates; a vapor retarding layer is used.



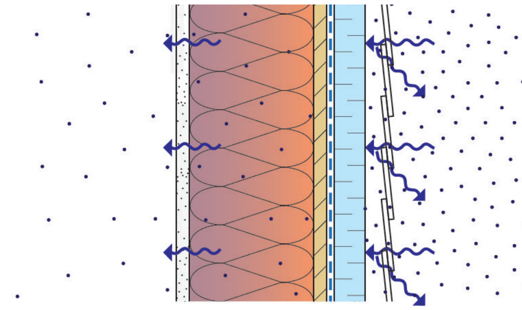
1) Vapor diffusion is blocked from flowing into the wall assembly and condensing within it using a vapor barrier at the interior side in cold climates.

In warmer climates, an impermeable exterior membrane or coating is a viable option.



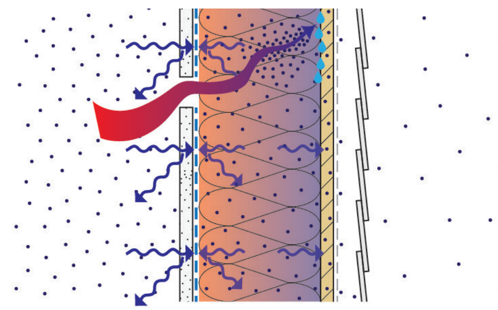
Humid outdoor air diffuses through the wall assembly until it reaches the cooler drywall. The cooler air is unable to store as much water as the warmer exterior air and so the relative humidity increases, but the water vapor concentration remains the same. If the RH exceeds certain thresholds, condensation and/or potential mold growth could happen.

A variation is using a vapor retarding exterior insulation, like extruded polystyrene foam, to throttle the vapor flow.



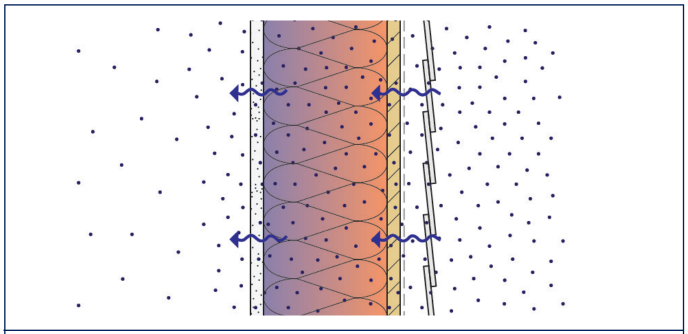
1.A) Vapor diffusion flow through a wall is restricted with the use of a vapor retarding insulation layer (shown as exterior insulation in this image).

There are two concerns with blocking water vapor diffusion; the drying capacity of the wall is restricted, and the vapor barrier does not necessarily address air leakage unless it is also specified as an air barrier.



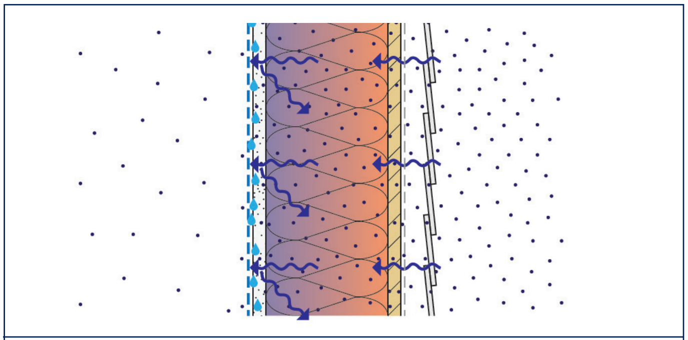
1.B) Air leakage by-passing the vapor barrier will still condense on the backside of the sheathing in cold climates.

The second approach is to design a wall system that doesn't excessively restrict vapor diffusion. These systems are sensitive to the interior and exterior humidity conditions and are therefore riskier. However, guidance is provided in the IBC with the provisions for Class III vapor retarders in different wall assemblies. The key is to carefully throttle the flow of water vapor at the high vapor pressure side to avoid causing a problem while still permitting sufficient drying. These types of wall assemblies may not function adequately in colder climates or in buildings with very high humidity loads because the drying direction is almost always one way and the high pressure side is always inside.



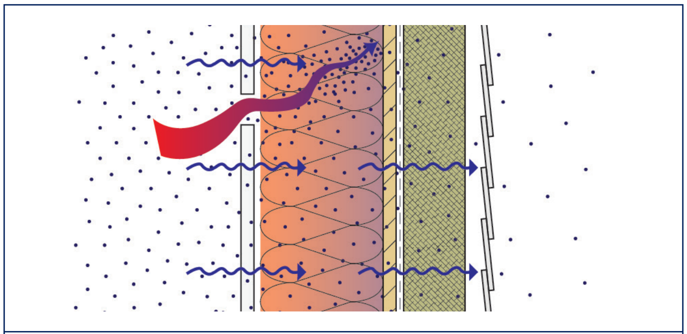
A Class III vapor retarder in combination with a drained and vented cladding systems designed to the IBC sufficiently restricts outward flowing vapor.

An issue with flow-through assemblies is the risk of inadvertently trapping moisture. In humid climates, if an impermeable material is placed on the interior of the wall, such as vinyl wallpaper or cabinetry, inward flowing vapor can become trapped and create significant damage.



Vinyl wallpaper traps inward flowing vapor, resulting in condensation and later potentially mold and decay.

A more robust approach is to use insulation to keep the critical layers warm enough that the water vapor does not reach its saturation point. A warm enough substrate is also resistant to air leakage condensation. This solution is more commonly found in cold climates, but can be equally applied in warm climates with careful positioning of the vapor retarding and insulation layers.

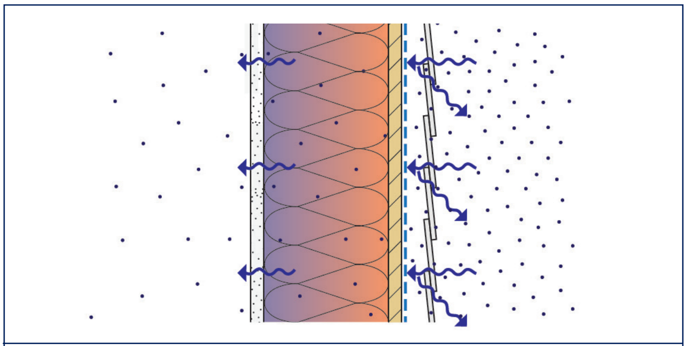


The exterior insulation keeps the sheathing sufficiently warm to avoid condensation due to cold weather water vapor diffusion or air leakage.

Permeable and Impermeable AWB Membrane Guidance

There are three broad categories of climate zones for vapor flows; primarily to the exterior (cold climates), primarily to the interior (hot and humid climates), and mixed (equal inward and outward flows). The guidance for the optimal AWB permeability depends significantly on climate zone and typical humidity conditions.

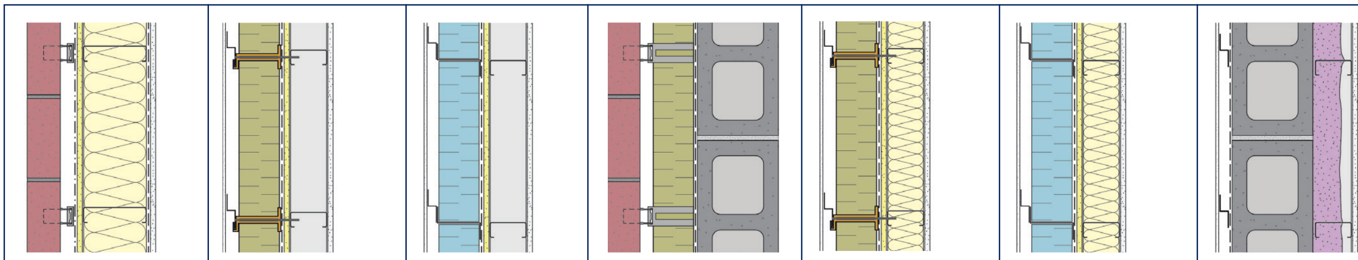
Hot and humid climates (Climate Zone 1 and 2) with significant inward drives are generally best served with an impermeable exterior AWB. However, with 'flow-thru' systems, permeable AWB are acceptable if no interior vapor retarding layers are used or if the substrate is itself is relatively impermeable moisture tolerant (e.g. concrete or CMU).



Impermeable exterior AWB restricts inward flowing vapor, but only permits drying to the interior.

Mixed climates pose a challenge with both inward and outward vapor flows. These generally fall in Climate Zones 3 and 4, some areas in CZ5, and some coastal regions of colder climate zones. The use of impermeable membranes may inadvertently trap outward flowing moisture. Consequently, a flow-thru system, which uses adequately designed vapor control systems (i.e., Class 3 vapor retarders), needs to sufficiently throttle moisture in both directions to minimize moisture risks.

In predominantly cold climates or in high moisture load buildings (e.g., swimming pools in CZ4+), the main concerns are generally outward flowing moisture. Generally, a level of interior vapor control is needed, and so an impermeable AWB could cause significant problems by creating a two-sided vapor barrier system. Cold climate assemblies with permeable AWB can have significant outward drying, which adds resiliency to the wall assembly, particularly with respect to construction moisture.



Conceptual candidate wall assemblies for hygrothermal simulations in DOE Climate Zones 1 through 8. Variations in the insulation thickness and types of vapor retarders were required to comply with IBC-2012. In all instances, efforts were made to only use a Class III interior vapor retarder. (1) Cavity insulated on framed wall, (2) Permeable exterior insulation, (3) Impermeable exterior insulated, (4) Permeable exterior insulated on masonry, (5) Permeable split-insulated on framed wall, (6) Impermeable split-insulated on framed wall, and (7) Impermeable interior insulated on masonry.*To comply with minimum prescriptive insulation requirements of ASHRAE 90.1 in colder climates, this wall assembly requires the addition of exterior insulation for steel framed assemblies.*

Hygrothermal Simulations

A series of hygrothermal models were prepared to evaluate the effectiveness of different wall assembly types in all U.S. climate zones (1 through 8) by only varying the permeability of the exterior WRB. The wall assemblies all meet the prescriptive requirements of IBC-2012. Some additional scenarios were modeled of Assembly #1 but with modifications to assess the impact of following alternative ASHRAE 90.1-2010 energy code compliance pathways. The walls were compared based on the maximum likely extent of mold growth, using the latest empirical models.

Seven types of commercial wall assemblies were identified and modeled. Assemblies 1, 2, 3, 5, and 6 are variations of steel-stud walls with exterior glass-fiber faced gypsum sheathing and either cavity insulated, or with combinations of permeable or impermeable exterior insulation or split insulated assemblies. Wall assemblies 4 and 7 are based on concrete masonry units and similar construction. In these two cases, they are either insulated on the interior or exterior. The main variable of comparison is the permeability of the AWB; either as a Class 1 or Class 3 vapor retarder.

Recommendations

The findings are all in support of the IBC recommendations regarding vapor control. All the exterior insulated wall assemblies posed virtually no risk of any mold growth, but the permeable insulations with a permeable AWB do create a concern for inward moisture flow caught with an impermeable interior layer (e.g., vinyl wallpaper). The only wall assemblies that demonstrated some concerns were the cavity insulated wall (Wall Assembly #1).

Wall Assembly 1—Cavity Insulation

The risks demonstrated by the typical cavity insulated walls is due to a combination of factors. With a **permeable** WRB, the risk is generated by inward flowing vapor that could be trapped by an interior impermeable layer, such as vinyl wallpaper or cabinetry. This is exacerbated in warm and humid weather, which can also include hot and humid summers in typically “cold climates”, like Chicago, Il, with absorbent claddings where the interior is air conditioned. The hygrothermal modelling indicates that if no interior vapor restricting layer (i.e., vinyl wall paper) is provided, then this type of wall can perform well. This is supported by broad industry experience with this wall assembly design.

With an **impermeable** WRB, the risk becomes entrapment of outward flowing water vapor if the insulation ratio is insufficient. The modeled Class III vapor retarder does not sufficiently restrict water vapor diffusion, which condense and collect on the AWB membrane. With the **permeable** WRB, this outward flowing moisture was permitted to flow to the exterior without any concern.

Wall Assembly 2, 4, and 5—Permeable Exterior and Split Insulated Assemblies

Similar to Wall Assembly 1, these wall assemblies with permeable exterior insulations and permeable AWB are at risk if interior impermeable membranes are used in mixed and humid weather. In such instances, an impermeable membrane may be preferred in humid climates, but in mixed climates, sufficient exterior insulation should also be provided to minimize the effects of outward flowing moisture.

Wall Assembly 3 and 6—Impermeable Exterior Insulation

These wall assemblies were the most resistant to moisture issues and the most insensitive to the permeability of the AWB as the exterior insulation provides the majority of the vapor control function. This ensures the vapor impermeable surface remains near the same temperature as the source of water vapor, minimizing condensation risks.

Wall Assembly 7—Interior Insulated

Closed-cell spray polyurethane foam provides a durable wall assembly that is only marginally susceptible to inward flowing moisture, which is a minor risk with a permeable exterior WRB. The impermeable WRB effectively eliminates this concern but eliminates drying of the masonry. The moisture tolerance of both the spray foam and the concrete masonry unit makes this wall assembly resistant to moisture concerns, though in cold climates, freeze-thaw issues could occur.

CLIMATE ZONE

	1	2	3	4	5	6	7	8
	INWARD FLOW						OUTWARD FLOW	
1 | Stud Wall Cavity Insulation	● / ■	● / ■	● / ■	● / ■	● / ■	● / ▼	▼	▼
1 | Stud Wall Cavity Insulation, Non-prescriptive	● / ■	● / ■	■	■	■	▼	▼	▼
2 | Stud Wall Permeable Exterior Insulation	● / ■	● / ■	● / ■	● / ■	● / ■	● / ▼	● / ▼	● / ▼
3 | Stud Wall Impermeable Exterior Insulation	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼
4 | Mass Wall Permeable Exterior Insulation	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼
5 | Stud Wall Split Permeable Exterior Insulation	● / ■	● / ■	● / ■	● / ■	● / ■	● / ▼	● / ▼	● / ▼
6 | Stud Wall Split Impermeable Exterior Insulation	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼
7 | Mass Wall Interior Impermeable Insulation	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼	● / ▼

● LOW PERMEANCE (<1 perm) ▼ HIGH PERMEANCE (>10 perms) ■ HIGH PERMEANCE, NO INTERIOR VAPOR BARRIER RESTRICTION

This table provides recommendations on the optimal permeance of the AWB. High-permeance AWB may be used in climates with inward flowing moisture, but it is critical to ensure that all innermost materials from the sheathing do not restrict vapor flow. Most wall assemblies with exterior-insulation built in accordance with ASHRAE 90.1-2010 and IRC-2012 are designed to accommodate either low- or high-permeance AWB.

When designing wall assemblies with non-vented cladding systems such as direct applied stucco, additional considerations should be made with respect to the selection of vapor permeable or impermeable AWB membranes. Non-vented cladding systems are more susceptible to moisture concerns, as the outward drying potential is significantly reduced, and the risk for inward vapor drive is increased when the exterior vapor pressure is higher than the interior. In this situation, a permeable AWB coupled with a permeable exterior insulation means that moisture driven inward from the cladding may end up within the backup wall and could condense on colder inner surfaces. In these unvented assemblies, the use of a less permeable AWB or less permeable insulation may be desirable to reduce inward vapor drive, especially in a hot humid climate. Where non-vented cladding systems are used in humid and wetter regions, they need to be more carefully designed and detailed to address potential moisture risks.

		CLIMATE ZONE							
		1	2	3	4	5	6	7	8
Max U-Value	Steel Frame	0.124	0.084	0.084	0.064	0.055	0.049	0.049	0.037
	Mass	0.58	0.151	0.123	0.104	0.09	0.08	0.071	0.048
Assembly Number	1	3.5"	5.5"+1"	5.5"+1"	5.5"+1.5"	5.5"+2.5"	5.5"+3"	5.5"+3"	5.5"+4.5"
	1*	3.5"	3.5"	3.5"	5.5"	5.5"	5.5"	5.5"	5.5"
	2	3.5"	4"	4.5"	5"	5.5"	6"	6"	7.5"
	3	3"	3.5"	4"	4.5"	5"	5.5"	5.5"	6.5"
	4	NR	1.5"	2"	2.5"	3"	3.5"	4"	4.5"
	5	3.5"	3.5"+1"	3.5"+1.5"	3.5"+2"	3.5"+2.5"	3.5"+3"	3.5"+3"	3.5"+4.5"
	6	3.5"	3.5"	3.5"+1"	3.5"+1.5"	3.5"+2"	3.5"+2.5"	3.5"+2.5"	3.5"+4"
	7	NR	1"	1.5"	1.5"	2"	2.5"	2.5"	3"
		No Class 1 or 2 VB Required			Vented Cladding Over Gypsum			Class 1 VB Required	
					Sufficient Exterior R-value				

The permeance guidelines are all based on the above wall design assumptions. The details of the analyzed wall assemblies show the required U factors for either steel frame or mass walls, the vapor control strategy as required by the IBC shaded in orange, red, blue, or green, and the nominal thickness of the cavity insulation with exterior insulation identified by the '+' sign. All wall assemblies have vented cladding systems on the exterior of gypsum sheathing, except for mass walls. All walls also have Class III vapor control layers, unless otherwise noted. Wall Assembly 1 represents an alternative pathway to ASHRAE 90.1-2010 compliance and consists of a steel stud wall with only cavity insulation.*

Conclusions

With new technological developments in building materials, old rules of thumb need to be periodically re-evaluated. Selection of an appropriate AWB must be made with careful consideration of its material properties, especially its vapor permeance, and how it interacts with the rest of the building system. In this context, both high- and low-permeance AWBs have a place within the commercial building industry and can form part of long-lasting, durable building systems.

NOTE: The content of this bulletin and the underlying study, along with the honest opinions and conclusions expressed herein, are the product of RHD Building Science Inc. www.rdh.com, and for which they were retained by Momentive Performance Materials Inc., the manufacturer and/or seller of GE-branded sealants, adhesives, and coating products.

GE Silicones

Vapor permeable versus impermeable air and water-resistive barrier membranes in North American wall assemblies

Customer Service: 866.275.4372

siliconeforbuilding.com