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Exploring Air and Water-resistive Barriers

Part One

Using Building Wraps as Air Barriers

BY BIJAN MANSOURI

Using Building Wraps as Air Barriers

Photos courtesy Typar Construction Products

CONTROLLING THE MOVEMENT OF AIR BETWEEN THE CONDITIONED INTERIOR ENVIRONMENT OF A BUILDING AND THE EXTERIOR IS A CORE FUNCTION OF BUILDING SCIENCE. HOWEVER, IF YOU ASK SOMEONE THE BEST METHOD OF DOING THIS, YOU ARE LIKELY TO GET DOZENS OF DIFFERENT ANSWERS. THE BEST ROUTE DEPENDS ON SEVERAL FACTORS—FROM BUILDING SCHEDULES AND REGIONAL CLIMATE TO BUILDING CODES AND INDUSTRY BEST PRACTICES. THERE ARE ALSO MANY PRODUCT AND INSTALLATION FACTORS TO CONSIDER. ONE POTENTIAL OPTION FOR AIR BARRIER ASSEMBLIES INVOLVES USING BUILDING WRAPS AND OTHER WEATHER-RESISTANT COMPONENTS IN ORDER TO GUARD AGAINST AIRFLOW WITHOUT PREVENTING MOISTURE ESCAPE.

Quite simply, an air barrier is a material or system of materials designed to control airflow between conditioned and unconditioned spaces. It serves as the primary air enclosure boundary separating indoor and outdoor air. Within multifamily construction, the air barrier system also separates the conditioned air from any given unit and adjacent units. Air barriers also typically define the building enclosure's pressure boundary.

The requirement for continuous air barriers was added to the *International Energy Conservation Code* (*IECC*) for the 2012 version, and there are a number of ways to meet this requirement. As part of this mandate, the code requires all new construction and additions to be visually inspected, as well as pressure-tested, as standard operating procedure.

To know whether a given material can serve as an effective air barrier, it is first important to understand an air barrier can be defined as either

Equally important as selecting the right material, installing the products properly is critical in order for an air barrier system to work as intended.

a material or an assembly—each category is subject to a specific set of tests. For an individual building material to be classified as an air barrier, its air permeance (*i.e.* amount of air migrating through materials rather than holes or gaps) must be equal to or less than 0.02 L/(s•m^2) @ 75 Pa (0.0004 cfm/sf @ 1.57 psf) when tested in accordance with ASTM E2178, *Standard Test Method for Air Permeance of Building Materials*. Gypsum board, liquid-applied membranes, sprayed polyurethane foam (SPF) insulation, and this article's focus—polyethylene or polypropylene building wraps—are all examples of air barrier materials.

The requirements for an air-barrier assembly are somewhat less stringent, and are measured in terms of air leakage. When tested in accordance with ASTM E2357, *Standard Test Method for Determining Air Leakage of Air Barrier Assemblies*, the subject must be 0.20 L/(s•m^2) @ 75 Pa (0.04 cfm/sf @ 1.57 psf) in both directions (*i.e.* infiltration and exfiltration), which works out to 10 times greater than a material alone. This method is intended to simulate the performance of various air barrier materials and accessories when combined into an assembly. This "air barrier assembly" is defined as a group of materials assembled and joined together to provide a barrier to air leakage through the building envelope. For example, use of a weather-resistive barrier (WRB), combined with properly installed flashing and tapes, would be considered an air barrier assembly.

Air barriers can also be defined through whole-building testing in accordance with ASTM E779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization.* This test method is intended for the measurement of the airtightness of building envelopes of single-zone buildings. For the purpose of this test method, many multizone buildings can be treated as single-zone by opening interior doors or inducing equal pressures in adjacent zones.

Why use an air barrier?

It is important to establish a continuous air barrier for several reasons. As an air barrier isolates the indoor environment, it plays a major role in the overall energy efficiency, comfort, and indoor air quality (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 consumed due to uncontrolled air leakage.[1] Establishing a continuous air barrier reduces heating and cooling costs, thereby lowering greenhouse gas (GHG) production.

Air barriers create a much more comfortable environment for building occupants by reducing drafts, keeping conditioned air inside the building, and minimizing temperature differences between rooms. Air barriers play a central role in ensuring healthy indoor air, as well, because they reduce the infiltration of outdoor air pollutants and help control moisture issues that can lead to problems like mold growth.

In addition to the 2012 *IECC* requirement, a growing list of states now includes air-barrier requirements in their commercial energy conservation codes. Among these are California, Oregon, Illinois, the District of Columbia, and Massachusetts. The U.S. government mandates air barriers be installed on federally funded building projects, as well.

Air barrier systems comprising building wraps

Numerous materials can achieve the ASTM air leakage requirement, but this does not necessarily mean they will perform in the field once installed as part of a system. The question becomes whether the material will be able to hold up to the rigors of the jobsite and installation. After all, an air barrier's performance is defined by its weakest link, and it only takes one tear or unsealed connection to compromise the entire system's integrity.

Standing up to the elements is a tall task. As the primary boundary between indoor and outdoor air, the assembly will be subjected to constant air movement, water, ultraviolet (UV) light, and surfactant chemicals present in certain cladding materials and cleaning agents. Any one of these elements could potentially cause materials to break down over time, jeopardizing their effectiveness as air barriers. Likewise, if a material is not sufficiently durable to stand up to installation conditions, it cannot perform its function.

Commercial construction amplifies the importance of these concerns. Exceptional durability is needed to handle the stronger wind loads faced by taller buildings. Tear strength, as measured by the grab trapezoidal tear test as part of ASTM D5034, *Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test)*, is a good measure for predicting an air barrier's ability to stay on the wall after installation. In this test, a 1.2 x 1.8-m (4 x 6-ft) sample is tested for tensile strength by moving a pair of clamps apart at the specified rate until the specimen breaks or ruptures.

Further, the longer construction timelines typical of many commercial building projects put added emphasis on an air barrier's ability to withstand extended exposure to UV light, as weeks or even months may pass before exterior cladding is installed over the building wrap. It is critical to double-check how much exposure time the manufacturer's warranty covers.

It is also important to consider the type of exterior cladding to be installed over the building wrap. Some materials, such as brick or stucco, absorb moisture that can be driven into the wall assembly by solar energy. Stucco, cedar, and other wood sidings may also contain surfactant chemicals (*e.g.* soaps, oils, and paints) that can degrade the performance of a building wrap over time, so it is important to choose a material resistant to these chemicals to ensure sustained performance.

While several materials can impede air movement through a wall assembly, certain technologies perform better than others in demanding conditions. Historically, wood-pulp-based building paper was the most commonly used material for weather-resistant barriers, but it tends to tear easily and is not very durable. In the 1970s, plastic building wraps made of polyethylene or polypropylene fabric began gaining popularity for their durability and ease of installation, and these remain reliable options.

Plastic building wraps are typically either woven or non-woven—an important difference when it comes to specifying an air barrier. Woven polypropylene with slit-film perforated coating typically offers two months of UV resistance, but most types do not meet ASTM requirements for air-barrier materials and are not surfactant-resistant. That said, spun-bonded polypropylene with micro-porous coating, on the other hand, often meets ASTM requirements set for air barriers, is resistant to surfactant chemicals, and offers six months UV exposure resistance. Depending on the type of cladding to be installed over the wrap, and how long the wrap will be exposed to the elements before the cladding's installation, these additional durability benefits may be important.

The longer construction timelines typical of many commercial and light commercial building projects put added emphasis on an air barrier's ability to withstand jobsite rigors.

In addition to the 2012 *International Energy Conservation Code* (*IECC*) requirement, a growing list of states (including Oregon—the Portland skyline is pictured above) now include air-barrier requirements in each of their commercial energy conservation codes.

Photo © BigStockPhoto

Proper installation

Equally important as correct material selection, proper installation is critical in order for an air barrier system to work as intended. Even when the primary air-barrier material meets ASTM requirements, system continuity can still be compromised by incompatible tapes and flashing or improper installation. (This is

The simplest way to ensure the entire system works together effectively and meets all code requirements is to specify wrap, tapes, and flashing from a single manufacturer. Doing so provides added assurance each component comes together seamlessly.

Photo courtesy Typar Construction Products

just one of several reasons why construction details and pre-installation meetings are so important.)

Sealing all laps and penetrations with the proper tape can improve the building wrap's performance by 20 percent. Horizontal laps are just as important as vertical laps because windblown rain can travel sideways or even up and over an improperly installed lap. Any tears and holes should be sealed with manufacturer-recommended tapes, and all windows and doors should be properly flashed. The goal should be to create a continuous building envelope free from any penetrations through which air could potentially pass.

During installation, it is also important the proper nailing pattern be followed to ensure the material is kept against the wall and not blown off. Galvanized roofing nails or plastic cap nails should be used to attach the air-barrier material to the structural sheathing and framing. Uncapped nails, staples, or screws can contribute to tearing and moisture intrusion—they must not be overlooked.

The simplest way to ensure the entire system works together effectively and meets all code requirements is to specify wrap, tapes, and flashing from a single manufacturer. Doing so provides added assurance each component comes together seamlessly; further, the system will be covered by the manufacturer's warranty.

Conclusion

The use of air barriers in commercial construction is growing, driven by advances in building codes and increased awareness of their ability to support sustainable, comfortable buildings. However, not all air barriers are equal in performance or design, and there is not one solution suitable for all climates, regions, and project conditions.

Understanding how air-barrier materials and systems are evaluated, and knowing their performance characteristics, helps design professionals find the right solution for their project needs. Approaching air barriers from a holistic view and evaluating the entire system—rather than just an individual material—results in a tighter and far more durable enclosure that can stand the test of time. **CS**

Notes

[1] For more information, visit www.airbarrier.org/views/design_e.php.

ADDITIONAL **INFORMATION**

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Abstract

This article highlight the details of air barriers assemblies, specifically those systems comprising weather-resistant barrier (WRB) components and building wraps. It looks at how they are defined when it comes to building codes, and the key function they serve in creating comfortable and sustainable buildings. It seeks to outline several considerations to keep in mind when evaluating materials and strategies for proper installation.

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Key Words

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Building wrap
Weather-resistive barrier

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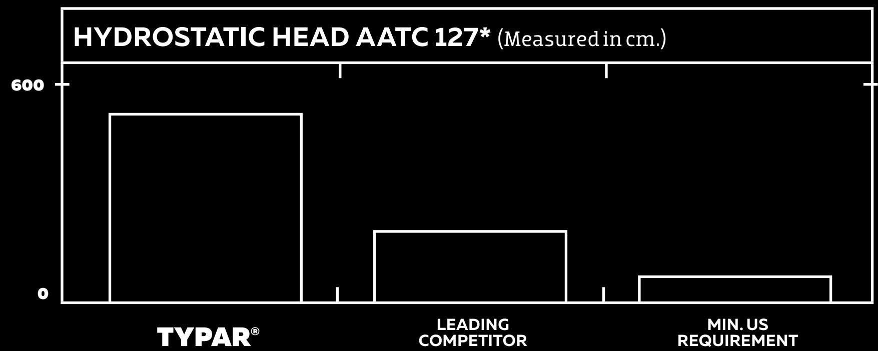


*Based on published results for hydrostatic head test according to AATC 127 testing.

Exploring Air and Water-resistive Barriers

Part Two

Using Vapor Retarders to Manage Airflow and Reduce Moisture

BY TED WINSLOW

Using Vapor Retarders to Manage **Airflow and Reduce Moisture**

All images courtesy CertainTeed

INDUSTRY CODES ARE TIGHTENING THE BUILDING ENVELOPE AND INCREASING THE REQUIRED R-VALUE OF WALLS. THIS IS A GOOD THING FOR ENERGY SAVINGS AND THERMAL COMFORT. YET, ONE CHANGE TO A BUILDING'S SYSTEM SETS FORTH A SERIES OF OTHER CHANGES.

The tight-envelope construction techniques to which architects and builders must now adhere have led to a steep reduction in air movement through walls. This means moisture gets trapped inside wall cavities without sufficient means for it to escape, leading to reduced drying potential for a wall's interior. Therefore, the airtight standards for energy efficiency have created new challenges for moisture management that cannot be neglected. This "moisture sandwich" is occurring with increasing frequency as architects design walls and incorporate newer insulation practices to enhance energy efficiency.

How moisture enters a building envelope

The first step is to understand how moisture penetrates wall assemblies. Generally, there are four forces driving moisture through the building envelope:

- gravity;
- capillary suction;
- water vapor diffusion; and
- airborne movement of water vapor.

When humidity levels in the wall are low, a smart vapor retarder will prevent moisture from entering.

When humidity levels in the wall increase, a smart vapor retarder becomes porous to let excess moisture escape.

Gravity moves rainwater down a building's exterior surface. When there are openings in exterior wall assemblies, such as downward-sloped openings, water will pass through them. This force is typically countered by roof systems designed with shingles and flashings. Also, overlapping, sealing, or covering exterior wall joints in a manner that diverts rain from the building helps keep gravity-drawn water out of the wall.

Another mechanism of water penetration is capillary suction, which is a result of the surface tension of water. Water is drawn inside through tiny pores in building materials, often so small they are invisible to the eye. To hinder this moisture flow mechanism, it is best to break the continuity of materials from the exterior through to the interior to obstruct moisture's path. Breaks in components can be accomplished by incorporating small cavities that prevent moisture from migrating through all the layers of materials. Specifying moisture-tolerant exterior wall materials like concrete and masonry is also helpful.

A third way moisture enters a building envelope is through water vapor diffusion. Water vapor will pass or diffuse through building materials whenever areas of high and low vapor pressure exist on opposite sides of that material. This movement is from the material's high vapor pressure side to the low-pressure side.

Water vapor permeance of a building material can be determined through ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*, which measures diffusion using two possible means: the dry cup method (also known as Method A or the desiccant method) and the wet cup method (also referred to as Method B or the water method).[1]

Air movement is yet another way moisture gets inside a building. In fact, air can bring a large amount of moisture into a building if it is not impeded by good construction practices. Compared to moisture entering a building by water vapor diffusion, moisture carried into a building by air can be up to 100 times greater. For example,a 1.2 x 2.4-m (4 x 8-ft) sheet of gypsum board will permit up to 285 ml (9.6 oz) of water to pass through it over a heating season in a cold climate. If, however, a 25-mm (1-in.) hole were to open in that board to permit airflow, airborne moisture flow could add up to 28 L (7.5 gal) of water over the same period. This phenomenon creates an excellent case for making wall assemblies airtight and preventing moisture from condensing on cold surfaces.

Naturally, moisture can enter the cavity from either the inside or outside of the wall—an average family of four can create two to three gallons of water vapor per day from cooking, bathing, and washing dishes and laundry. Over a heating season in colder climates, these moisture loads are driven toward a building's exterior and penetrate into the wall cavity. Air can transport moisture quantities up to 28 L through holes in the building envelope's interior side that are as small as 25.4 mm^2 (1 in^2). This has led to an increased focus on developing more airtight wall systems.

Smart vapor retarders with polyamide film allow excess moisture to escape from the wall cavities.

While an airtight wall is important, there is need for a means of escape for moisture that gets trapped in the assembly. If there is no established escape plan, then the building has a high likelihood of creating a moisture sandwich inside its walls.

Making a moisture sandwich

A moisture sandwich occurs when a well-insulated wall system traps moisture from both the interior and exterior components. It is a scenario playing out with frequency as architects design walls and incorporate insulating products that create energy-efficient buildings. For example, many areas of the country are beginning to install exterior insulation to help increase a wall's R-value, decrease its thermal bridging, and reduce the permeance level.

Extruded polystyrene (XPS) has a permeance level of .03, which is similar to 152.4-μm (6-mil) poly. A common assembly may comprise:

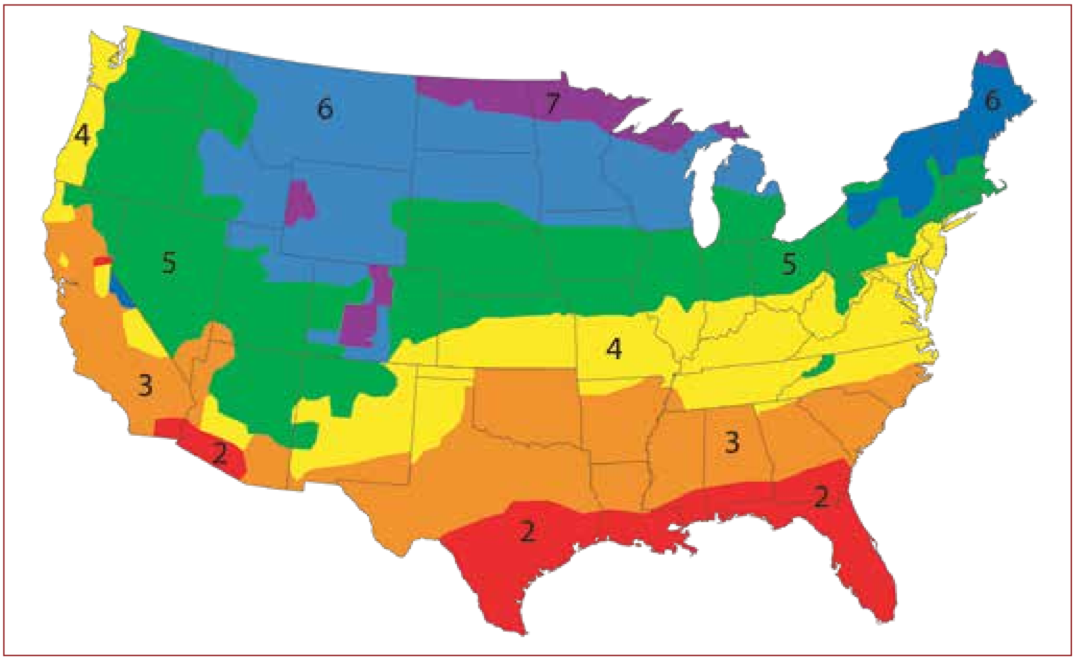
- moisture-retentive cladding like fiber cement, brick, or stucco;
- exterior insulation that acts as a vapor retarder similar to 152.4-μm polyethylene;
- oriented strandboard (OSB), which is semi-permeable at 2.0;
- kraft-faced fiberglass batts at a range of 0.3 to three or unfaced batts and 152.4-μm polyethylene with a permeance rating of .05; and
- dryall with a permeance rating of three to 35, depending on the paint.

Unfortunately, this creates a moisture sandwich: moisture gets into the wall and is trapped between polyisocyanurate (polyiso) foam board on the exterior, and a 152.4-μm polyethylene on the interior with no ability to dry. It is a probable situation that is likely under construction throughout the country at this moment.

Consequences of a moist wall

Having moved beyond the era of leaky buildings, the industry is now facing a new set of challenges stemming from this era of airtight construction. Moisture, when trapped inside a wall cavity for an extended period, can cause building materials like wood, traditional paper-faced gypsum, and steel to eventually deteriorate or corrode. Even R-value goes down when insulation gets moist, and thermal performance is the reason the wall system was constructed to be airtight in the first place.

It is common knowledge moisture buildup can lead to health issues through mold growth that releases potentially harmful spores into the air. These airborne spores can cause occupants to experience acute health and comfort issues that correlate with the time they spend inside the building.



Large portions of North America are considered mixed-climate regions, where the moisture drive direction is balanced between winter and summer. In these regions, buildings using traditional polyethylene vapor retarders may successfully keep moisture out of the cavity in the cold season, while essentially trapping it there during summer when the moisture drive reverses.

Architects want to design wall systems that are able to dry; otherwise, these types of product deterioration scenarios and mold growth are likely. Since the moisture is within the wall, the issues are unlikely to be found until it is too late. This is when the large and expensive problems like mold remediation and litigation arise.

It is possible to design a continuous airtight wall system that also exerts moisture control. A great first step is to focus on the management of air and moisture flow through the building envelope. Continuous air barriers and smart vapor retarders are able to address airflow and manage the moisture profile of the exterior wall cavity. This helps minimize and limit the risk of moisture-based building issues while adding minimal additional labor to projects.

Changing the drying potential of a wall

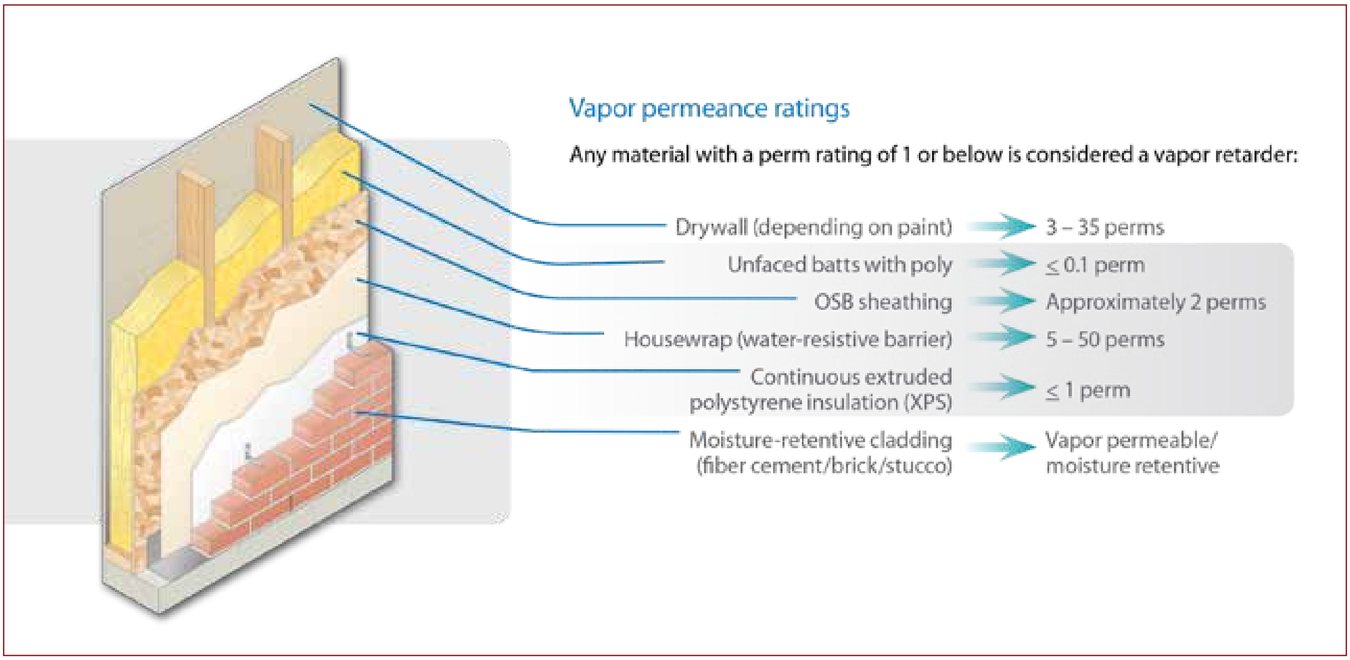
Poly vapor retarders are part of the traditional approach to keeping moisture out of a wall, but as mentioned, moisture seems to find its way in, one way or another. Historically, building codes have classified vapor retarders as having a water vapor permeance of 1 perm or less when tested in accordance with the ASTM E96 desiccant/dry cup method. As such, most products are only evaluated under dry conditions. Products like polyethylene film or aluminum foil have low permeance values that remain constant between dry and wet conditions.

Rather than contributing to a healthy wall cavity, vapor retarders can often become part of the problem. These low-perm materials slow the rate of water vapor diffusion, but do not totally prevent its movement. As water vapor moves from a warm interior through construction materials to a cooler surface, the water vapor may condense on these vapor retarders as liquid water that could damage the building. It is for this reason smart vapor retarders are needed. Not only do they retard moisture penetration, but they also increase the potential for materials to dry. The wall's drying potential must always be greater than the wetting potential so the amount of moisture getting into the system is less than the amount of moisture that can leave it.

Smart vapor retarders, though not required by code, are the better approach to a healthy wall assembly in many regions. Fortunately, building codes are continuing to evolve and adapt; it is important to use progressive solutions that also actively manage conditions within the wall assembly. Design professionals should strive to build beyond current practice—selecting adaptive solutions like smart vapor retarders can be the better practice in various situations.

How smart vapor retarders work

A smart vapor retarder reacts to changes in relative humidity (RH) by altering its physical



structure. During the winter, when relative humidity is low, it provides high resistance to vapor penetration from the interior. However, when the RH increases to 60 percent or above, its permeance dramatically increases, thus allowing water vapor to pass through, which facilitates the drying of building systems. The moisture building within the wall system is now able to move from the high-moisture concentration area and dry toward the assembly's interior.

During conditions of low RH, a smart vapor retarder maintains its impermeable state to prevent moisture from migrating and then condensing within the wall system. However, as soon as the material comes into contact with moisture (*i.e.* 60 percent RH), it opens up and softens its structure to allow the polar water molecules to penetrate through. As a result, the smart vapor retarder acquires pores through which further water molecules can penetrate, and the permeance increases to greater than 10 perms as tested in accordance with ASTM E96's wet cup method. When the air is humid in the summer, the moisture penetrates through the pores into the building interior, allowing building materials to dry out. If the relative humidity decreases, the pores close up again, and the smart vapor retarder then acts as a barrier to moisture. In the winter, the smart vapor retarder protects the building materials behind it from condensation.

Climate's role in specifying air barriers

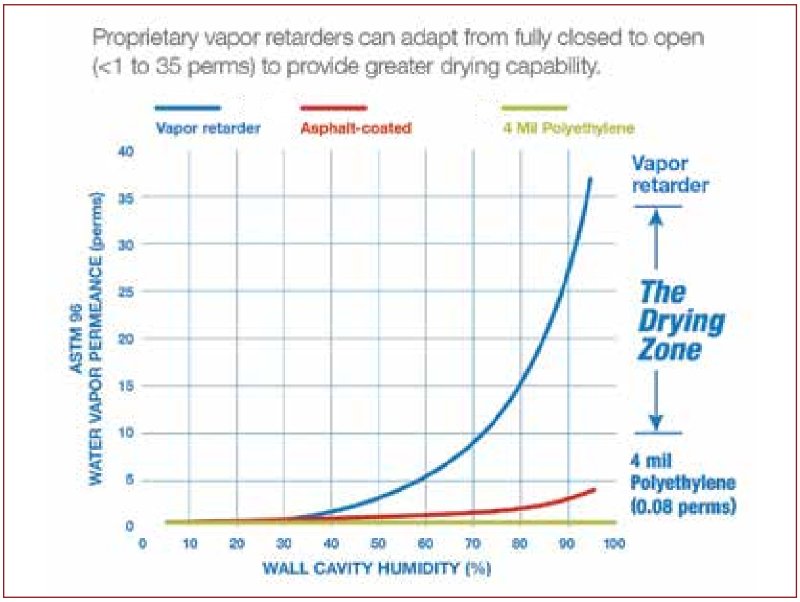
Large portions of North America are considered "mixed-climate" regions, where the moisture drive direction is balanced between winter and summer. In these regions, buildings using traditional polyethylene vapor retarders may successfully keep moisture out of the cavity in the cold season, while essentially trapping it there during summer when the moisture drive reverses. This problem is further exacerbated by the use of moisture-retaining cladding, such as masonry, fiber cement, and stucco, which release moisture into the building cavity.

As such, for cold climates, vapor retarders are required for wall assemblies and should be placed at the wall's interior side. In heat-dominated climates, the vapor retarder should be placed at the building envelope's exterior. In most applications, vapor or air barriers should be installed over un-faced insulation before the drywall is installed. Again, smart vapor retarders are a good choice in these mixed-humidity climates because of their ability to adapt to the varying moisture conditions that occur throughout the year.

While smart vapor retarders can reduce the risk of moisture damage in the building envelope by increasing the construction's tolerance to moisture load, they are not suitable for every climate. Hot climates with high outdoor humidity are always under high RH conditions,

Many areas of the country are beginning to install exterior insulation. While this helps increase a wall's R-value, decrease thermal bridging, and reduce the wall's permeance level, it can also trap moisture within the walls. Popular cladding products like brick, stucco, and fiber cement hold moisture, which can also increase moisture buildup in walls.

Moisture in the wall is unavoidable, so it is important assemblies are designed with the potential to dry. By incorporating adaptable solutions like smart vapor retarders, occupant comfort can be managed.



A smart vapor retarder can adapt from <1 to 35 perm to keep moisture out of the cavity in the winter while letting it escape when cavity humidity increases in the summer.

which in turn, would cause a smart vapor retarder to always be permeable and never provide the wall cavity with vapor retarding benefits. These materials also do not work well in buildings with exceptionally high, constant indoor humidity levels, such as indoor pools and spas. However, in rooms with short peaks of high humidity like restrooms and kitchens, the performance of the smart vapor retarder would not be affected because of the buffering action of interior finishes.

Conclusion

A holistic approach to building design is the best way to address moisture and air flow. As architects and builders affect one area like thermal performance, the flow of air and moisture are also impacted. Moisture in the wall is unavoidable, so it is important assemblies are designed with the potential to dry. By incorporating adaptable solutions like smart vapor retarders, occupant comfort can be managed and buildings set up for long-term structural success. **CS**

Notes

[1] For more information on these tests online, visit www.youtube.com/watch?v=wulHes6Dm9E.

ADDITIONAL **INFORMATION**

Author

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Abstract

The tight-envelope construction techniques to which architects and builders are now required to adhere have led to a steep reduction in air movement through walls. This means moisture gets trapped inside wall cavities without sufficient means for it to escape, leading to reduced drying potential for a wall's interior. Therefore, the airtight standards for energy efficiency have created new challenges for moisture management that cannot be neglected. This so-called "moisture sandwich" is occurring with increasing frequency as architects design walls and incorporate newer insulation practices to enhance the energy efficiency of buildings.

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Vapor retarder
Wall cavity

Exploring Air and Water-resistive Barriers

Part Three

Understanding Heat, Air, and Moisture Control

BY SARAH K. FLOCK, CDT, AIA AND CAROLE CEJA, NCARB, RRC

Understanding **Heat, Air, and Moisture Control**

The gaps between design and performance

Photo © BigstockPhoto

MANY DESIGNERS AND SPECIFIERS UNDERSTAND CONTROLLING AIR, VAPOR, AND THERMAL TRANSFER HELPS MITIGATE MOISTURE PROBLEMS WITHIN THE BUILDING ENVELOPE. MOISTURE ACCUMULATION IS A PERFORMANCE ADVERSARY THAT CAN LEAD TO STRUCTURAL DETERIORATION, FINISH DAMAGE, ORGANIC GROWTH, AND REDUCED BUILDING LONGEVITY (FIGURE 1, PAGE 20). HOWEVER, NAVIGATING FUNDAMENTALS, CODE REQUIREMENTS, AND INDUSTRY TRENDS RELATED TO THESE TRANSFER MECHANISMS CAN BE COMPLEX.

The 2015 *International Codes* (*I-Codes*) were recently released; as of this writing, six states have adopted the 2015 *International Energy Conservation Code* (*IECC*) and *International Building Code* (*IBC*), with many more expected to join in the months to come. Even when designs meeting current codes are achieved, moisture issues can result. This article explores the impact of recent code changes, highlights various provisions' potential limitations, and presents examples of "gaps" between codes and real-world performance as they relate to the topics of air, vapor, and thermal control.

Thermal transfer

To incorporate the concept of thermal control in design, the fundamentals of heat transfer must be understood. Heat can transfer in various ways, such as conduction, convection, or radiation; it moves from areas of high to low temperatures independent of orientation.

Conduction is the most familiar mode and is the flow of heat through solid materials, such as window frames or metal studs. The amount of heat transfer via conduction depends on the material's conductivity, mass, and configuration.

Convection is the transfer of heat through a gas or liquid, such as air, and can occur either naturally or by force. Natural convection occurs in the wake of differing densities, exemplified in the old adage of hot air rising. Forced convection is based on similar principles, but may deal with increased rates of air movement generated by forces from outside (*e.g.* wind) or inside (*e.g.* HVAC systems).

Thermal radiation is the movement of heat energy from a warm object to a cooler item through space. A common example involves an occupant standing in front of a window and experiencing cold during the winter. In this instance, one's body is radiating heat to the cooler window surface.

The importance of limiting heat transfer is not only to promote energy efficiency and occupant comfort, but also to reduce the potential for condensation within building assemblies. When moist air comes into contact with nonporous surfaces below the dewpoint, water can condense and create frost or water droplets (Figure 2).

Insulating materials are categorized by their resistance to heat flow, otherwise known as R-value. The higher the R-value, the greater the resistance to heat transfer. Another measure associated with heat transfer is the U-factor, typically associated with opaque assemblies or fenestration products. The smaller the U-factor, the better the product limits heat transfer.

Air transfer

The new codes include major changes regarding air transfer—not only because of a desire for increased energy efficiency, but also because air movement is often a large contributor to moisture migration.

Air has a natural tendency to move from high to low pressure (Figure 3). Sources of pressure differentials at a building envelope are diverse. For example:

- wind can create shifting positive and negative pressures on the enclosure;
- stack effect can exist with differences in atmospheric pressure between the top and bottom of the building; and
- fan pressure created by the HVAC system can also result in positive or negative pressure, depending on mechanical system design and operation.

Figure 1

Example of damage that can result from moisture accumulation.

Images courtesy Raths, Raths, and Johnson

Figure 2

Water and frost at a window frame below dewpoint.

Air carries moisture in the form of vapor, which can then encounter surfaces below the dewpoint and cause condensation. For air transfer to occur, there must be a path or a hole between two areas of differing pressure—either exterior to interior, or between varying interior conditions.

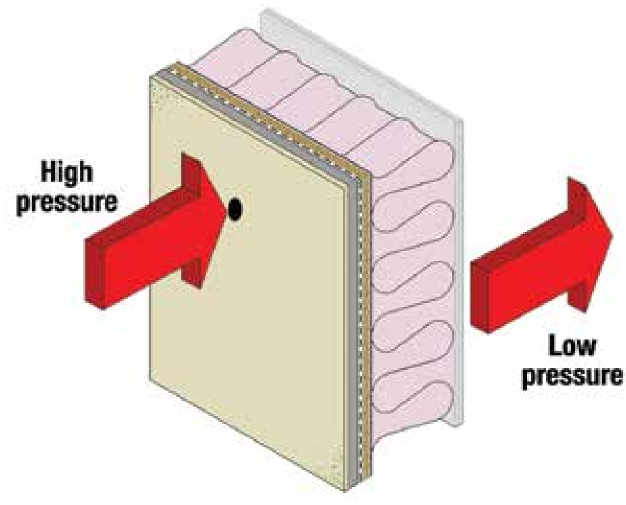
Air permeance is defined as the rate of airflow through a unit area of material under a given pressure difference. The performance of the air barrier materials is measured in L/(s•m^2) (cfm/sf) of air leakage. Air barrier systems require complete continuity as any gap, hole, or crack allows for air transfer.

Vapor transfer

While often considered a less impactful transfer mechanism due to the quantity of moisture moved, vapor transfer should not be ignored. Small amounts of moisture in the form of water vapor can pass directly through the exterior enclosure materials by a process called diffusion. The amount of vapor diffusion occurring in a building is partly determined by the force that pushes it, commonly known as the vapor pressure differential, as well as the material's vapor permeance. The lower the vapor permeance (measured in perms), the less diffusion occurs through the material.

Similar to air transfer, vapor migration also moves from high to low vapor pressure. High vapor pressure can be caused by numerous things, including an increase in relative temperature or mechanical pressurization. Most materials cannot eliminate vapor diffusion, but there are options to significantly slow the process.

Figure 3



Air moves from high to low pressure when a path is present.

Codes and design

With respect to air, vapor, and thermal control for the exterior enclosure, many changes and updates have been incorporated into not only the 2015 *I-Codes,* but also the 2013 American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) 90.1, *Energy Standard for Buildings Except Low-rise Residential Buildings*. These standards and codes contain both prescriptive and performance paths for compliance. This article primarily focuses on the updates and additions associated with the latest prescriptive requirements, which can be more universally implemented. This discussion provides an overview of provisions typically referenced for enclosure design, but not all changes are included—one should also consult the codes for any changes potentially affecting the specific design.

Thermal

Updated thermal control provisions are provided in the 2015 *IECC* and 2013 ASHRAE 90.1. Each document requires all envelope surfaces, both opaque and fenestration products, meet specific thermal values based on location and structure composition. Compliance for opaque thermal envelopes is shown prescriptively through R-values for insulation products or U-factors for assemblies, which were made more stringent in some instances in the recent code updates.

Some U-factors and solar heat gain coefficients (SHGC) for fenestration products were also tightened in recent editions. A few other notable changes in the 2015 *IECC* for the opaque wall thermal requirements include a method to determine the effective R-value for steel stud wall assemblies, as well as new criteria for mass walls.

While not new to the recent code updates, it is important to note a few limitations to R-value and U-factor testing. Opaque walls can be assigned R-values derived in accordance with ASTM C518, *Standard Test Method for Steady-state Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus*, or U-factors determined through ASTM C1363, *Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of Hot-box Apparatus*.

While both test methods involve measuring thermal transfer between cold and hot planes, ASTM C518 measures transfer through materials, whereas ASTM C1363 measures transfer through the assembly, including components that may produce thermal bridging. However, there might be deviations between test conditions and proposed built details, which the project team may need to consider.

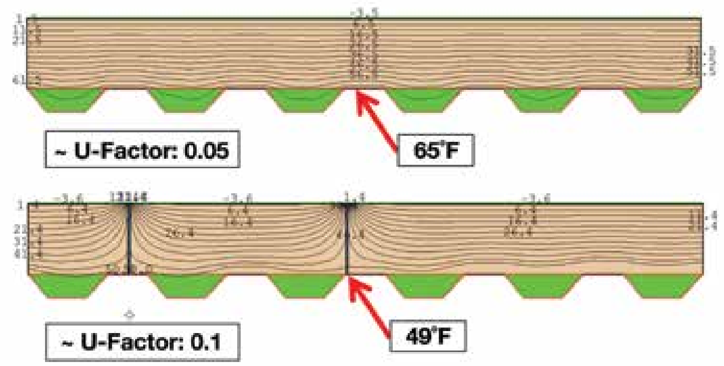
For example, whether for opaque walls or for fenestration products, test methods are conducted with a prescribed set of boundary conditions—such as −18 C (0 F) exterior and 21 C (70 F) interior—that may or may not align with the conditions experienced by a given building. The project team must understand the test conditions to evaluate the results' applicability to individual designs.

Air

Both ASHRAE 90.1 and 2015 *IECC* have similar air control provisions calling for a continuous air barrier throughout the building envelope. The 2015 *IECC* also stipulates the air barrier can be placed on the inside or the outside, as further explored later in this article.

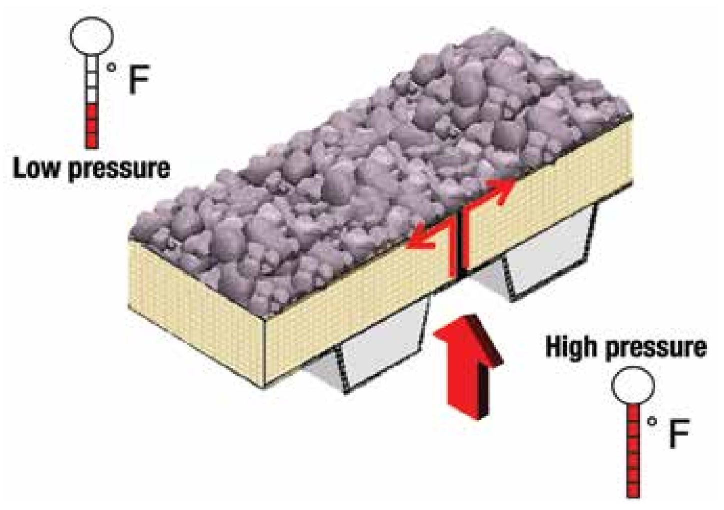
Beyond the presence of a continuous air barrier, there are further prescriptive provisions mandating the air barrier materials not exceed an air permeance of 0.02 L/(s•m^2) @ 75 Pa (0.004 cfm/sf @ 1.57 lb/sf) when tested in accordance with

Figure 4



Thermal models of roof assemblies with and without fasteners.

Figure 5



Example of low-slope roof assembly with mechanical pressurization driving conditioned air through the insulation from the interior.

ASTM E2178, *Standard Test Method for Air Permeance of Building Materials*, and assemblies not exceed 0.2 L/(s•m²) @ 75 Pa (0.04 cfm/sf @ 1.57 lb/sf) per ASTM E2357, *Standard Test Method for Determining Air Leakage of Air Barrier Assemblies*.

In lieu of compliance with the materials and assemblies air leakage rates, *IECC* stipulates the air barrier system, or whole building, be tested in accordance with ASTM E779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*, with a not-to-exceed rate of 2 L/(s•m²) @ 75 Pa (0.4 cfm/sf @ 1.57 lb/sf). The whole-building air performance is determined not only by the materials selected, but also by the constructed assembly or collection of one or more of those materials. A material itself may limit air transfer to extremely small amounts, but once this component is assembled with other materials, the acceptable air leakage rate is increased. Other industry standards, such as the U.S. Army Corps of Engineers (USACE) or the 2012 *International Green Construction Code* (*IgCC*), provide varying and more stringent thresholds for recommended whole building air leakage.

It is important to note all these code-referenced test methods quantify the amount of air leakage, but do not identify the location or specific source(s) of leakage. Therefore, if air leakage testing fails to meet requirements, then other standards (*e.g.* ASTM E1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*) would need to be utilized to identify deficiencies in the air barrier system.

The 2015 *IBC* also addresses air transfer in specific building assemblies in colder zones with certain operating conditions. For example, it limits use of air-permeable insulation materials in unvented cathedral ceilings and provides placement information for such materials.

Vapor

As of 2009, the code provisions related to vapor transfer were moved from *IECC* to *IBC*. During this time, there were more detailed vapor retarder classifications also added. Historically, a vapor retarder had a permeance of 1 perm or less—a common example was a polyethylene sheet. In the 2015 *IBC*, the classifications for vapor retarders include:

- Class I vapor retarder: 0.1 perm or less;
- Class II vapor retarder: 1.0 perm or less or greater than 0.1 perm; and
- Class III vapor retarder: 10 perms or less or greater than 1.0 perm.

Therefore, the traditional polyethylene sheet is now a Class I vapor retarder.

Common examples of a Class II vapor retarder are unfaced polystyrene or plywood, whereas a Class III example is gypsum board or some water-resistive barriers (WRBs).

To determine a material's vapor permeance and subsequent compliance with code, there are two test methods within ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*. It is important to understand which method may be applicable to the specific design because the results can vary. In the water method, the material sample is adhered to a test dish containing water so water vapor “flows” from the wet side through the test specimen and into the dry chamber—a condition similar to winter with humidified interior space. The desiccant method is similar to the performance of vapor transfer in a heated, dry structure during rain; it measures the inward drive into the building.

Placement of a vapor retarder within an assembly becomes particularly important given that more than one material within an assembly may now qualify as some class of vapor retarder. Caution must be dedicated to these situations to not trap or allow unwanted moisture to migrate between layers of vapor retarders within a given assembly.

The 2015 *IBC* definition of a roof assembly hints at the intended location of the vapor retarder inboard of thermal insulation, but other provisions within that code are more specific. For exterior walls, the vapor retarder location is specified to be on the interior side of frame walls in Zones 5 through 8 and Marine 4. The code does permit an exception with accepted engineering practice for hygrothermal analysis. Special case assemblies, such as unvented cathedral ceilings, include provisions that actually limit the use of Class I vapor retarders, but require a Class II material with airtight insulation.

Codes and performance

Despite meeting all the provisions discussed in this article, compliance may not guarantee performance, and subsequently creates “gaps” between design and the built world. However, many tools and upfront services are available to the project team to better understand and help anticipate performance prior to construction.

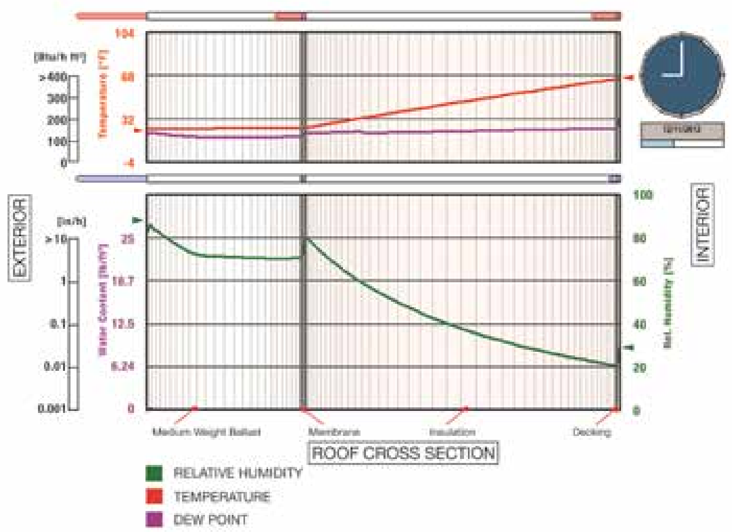
Continuous insulation

Continuous insulation (ci) is often required to meet prescriptive code requirements. However, current codes and standards recognize insulation penetrated by fasteners as “continuous.” ASHRAE 90.1 identifies continuous insulation as:

Insulation that is uncompressed and continuous across all structural members without thermal bridges other than fasteners (*i.e.* screws and nails) and service openings.

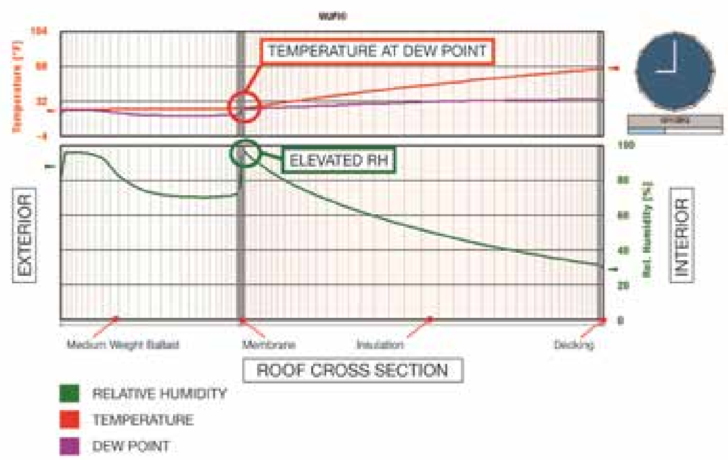
Therefore, it may be important for the project team to understand any potential overall or localized effects fasteners or service openings may have on the overall thermal performance of an assembly.

Figure 6



Model without an air change source.

Figure 7

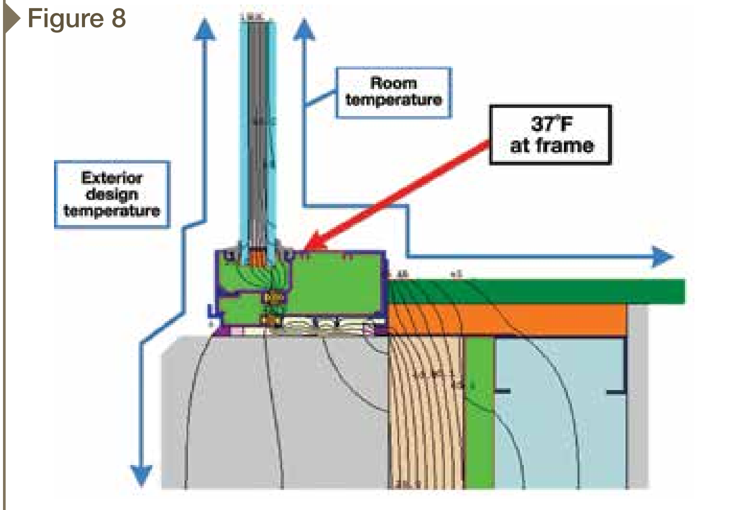


Model with an air change source.

One method of upfront analysis is to utilize various computer simulations to estimate thermal transfer. It is important to note two- and three-dimensional thermal models exist and may yield varying results. Utilizing a two-dimensional analysis, Figure 4 depicts a thermal model of a roof assembly where the insulation is continuous per the code and the fasteners are not included. The surface of the metal decking is well above dewpoint for most typical interior operating conditions, and the U-factor of the assembly meets code.

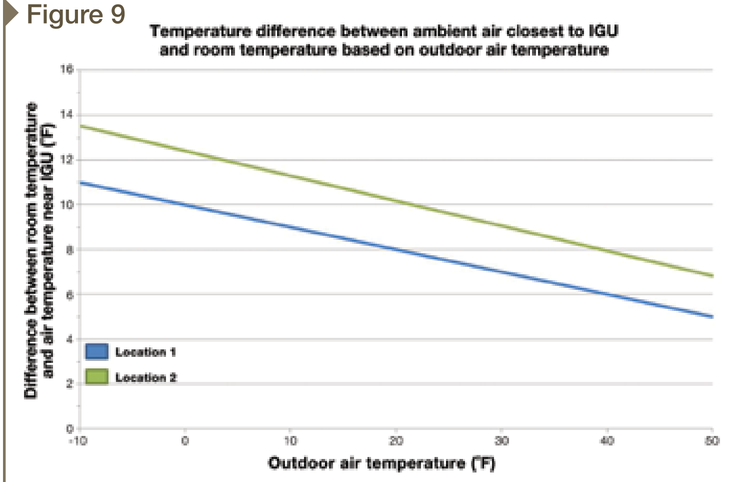
However, once metal fasteners that penetrate the decking are modeled, the temperature of the metal

Figure 8



Thermal simulation with interior boundary condition as room temperature.

Figure 9



Monitored temperature difference between the room and microclimate.

decking is altered locally at the fasteners, as well as the assembly's overall U-factor.

The fasteners direct heat away from the metal decking as they bridge to cold exterior conditions. This increases the risk for localized condensation on the metal deck, depending on interior operating conditions. Therefore, the designer may wish to evaluate the impact of thermal bridging in the early stages of the design process to understand whether or not changes or specific detailing to eliminate thermal bridging is warranted.

Air barrier placement

According to the 2015 *IECC*, the air barrier can be placed at the interior, exterior, or within the wall/roof assembly. However, the mechanical pressurization can significantly complicate air control strategies and should have an impact on the barrier's placement for optimal performance.

In this example, a typical low-slope roof assembly was designed to include (from exterior to interior) medium-weight ballast, fully adhered roofing membrane, and polyisocyanurate (polyiso) insulation over metal decking. The building was located in a heating climate, and the interior space was to be humidified to approximately 30 percent, with positive pressurization at the interior spaces (Figure 5, page 22). The metal decking was specified to function as the vapor retarder, and the fully adhered roofing membrane (toward the exterior) was identified as the air barrier. The splices, joints, and ends of the metal decking were not detailed for continuity.

A computer simulation evaluated the proposed roofing assembly's hygrothermal performance with only heat and moisture considered. An additional evaluation was then undertaken to include the effects of an air change source. By comparing the two models, the project team could grasp the potential effects of uncontrolled airflow within the roofing assembly.

In this instance, the applied air change source was from the interior to mimic the positive pressurization specified for the mechanical system. Simulating the assembly without air transfer (Figure 6, page 23), the model indicated the roof assembly would not accumulate moisture or result in a sustained relative humidity (RH) above 80 percent—the lower boundary for organic growth—for extended periods. However, once the air change source was applied to simulate the building mechanicals pushing air into the enclosure, the model output indicated the assembly's moisture content increased in comparison to the model without the air change. The surface temperature reached the dewpoint at the underside of the roofing membrane (Figure 7, page 23), and the RH was maintained above 80 percent for longer than 30 days during the heating months.

Therefore, conditions in the model with air changes were conducive to organic growth and other potential damage to materials and components. As a result, the designer revised the project criteria to include a continuous air barrier at the interior and developed specific termination details to ensure continuity with adjacent assemblies.

Microclimates

The 2015 *IECC* stipulates interior design conditions used for calculations to be a maximum of 22 C (72 F) for heating. Therefore, whenever thermal simulations are undertaken for the exterior enclosure, a temperature of approximately 22 C is often applied as the interior boundary condition. However, does this temperature correlate with conditions adjacent to the exterior wall? The authors' research and experience has yielded interesting findings regarding microclimates in operation versus design criteria.

Thermal simulations can provide valuable information prior to construction, but data collection after construction can also be an important tool for validation. In this study, a thermal simulation, as shown in Figure 8, was performed with an interior temperature in concert with 2015 *IECC*. Given the proposed interior operating conditions of 22 C and 25 percent RH, the surface temperatures were above the dewpoint of 1 C (34 F).

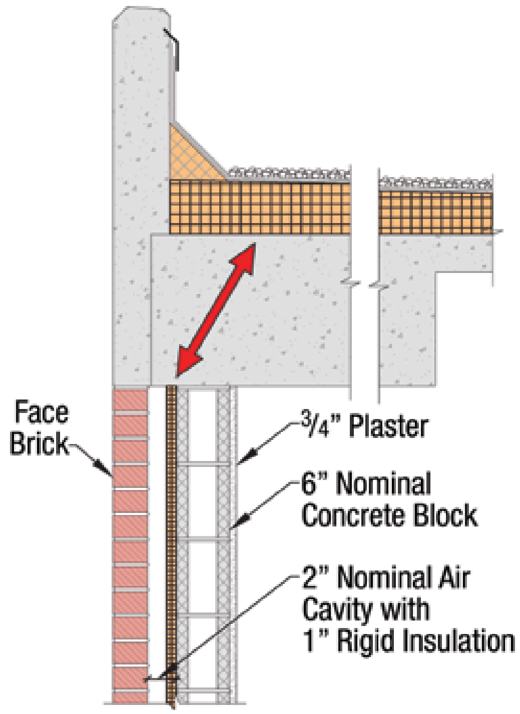
However, instrumentation was also enlisted to monitor the conditions following substantial completion. The frame surface temperatures from the instrumented data were compared to thermal simulations and found to be considerably lower than those predicted, prompting a closer look at the adjacent microclimate. The results indicated the temperature at the exterior wall can be significantly different (*i.e.* 5.5 to 8 C [10 to 15 F]) than the adjacent room temperature, as shown in Figure 9, and sometimes greater depending on the project details.

Once the temperature of the microclimate was applied as the interior boundary condition in the thermal simulation, the frame temperatures were indicative of the instrumented data. Further study indicated the microclimate's behavior could be impacted by the placement of the window, air leakage, and adjacent materials. Therefore, these may be important considerations for the project team when trying to estimate built behavior during the design phase.

Parapets

Parapets are another source of envelope moisture issues. The code does not define the parapet as part of the roofing or of the exterior wall, therefore the designer is left without clear direction. Consequently, the parapet is often overlooked when it comes to code-compliance and is not fully detailed as a part of either. The parapet is located where two envelope systems meet, often with dissimilar materials, structural interference, and construction sequence challenges. Failure to maintain continuity

Figure 10



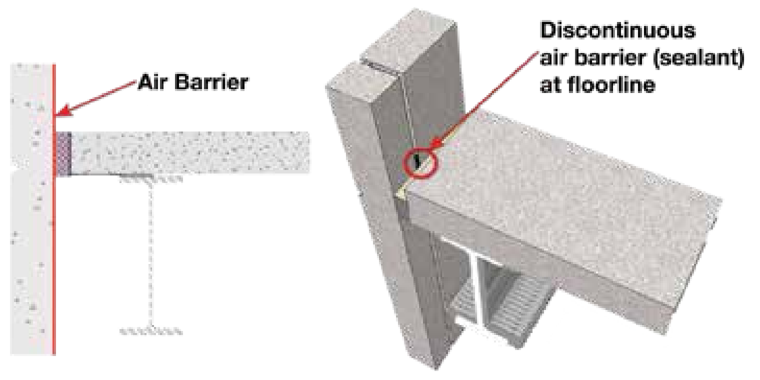
Thermal discontinuity at a parapet.

of air and thermal control planes can lead to moisture issues.

Parapets are often supported on projecting or upturned structural slab elements. These structures commonly define the edge of the thermal barrier of either the wall or the roofing. A thermal discontinuity between the roof and wall can be readily noted in Figure 10. However, this connection is easily overlooked during the design process. Peer review by various building system specialists can bring new perspective and expertise to assist with identification and resolution.

Air barrier continuity can be equally challenging at parapets where dissimilar materials, competing manufacturers, and different construction trades meet and attempt to integrate. Therefore, material compatibility must be considered where walls and roofs meet. While many common roofing materials have been in use for decades, new products are continually developed and proprietary air barrier systems are being marketed to keep pace with the new code mandates. The chemical compatibility between varying materials can be identified sooner with manufacturer involvement during design and resolved through additional specified testing or detailed language for warranties.

Figure 11



Two-dimensional section in comparison to three-dimensional detail.

Even when continuity is specifically checked during design and dissimilar materials are resolved, geometries where vertical and horizontal elements meet can create hidden locations for moisture issues to propagate. As seen in Figure 11, a quick three-dimensional model of a simple parapet in two dimensions can highlight the need to further evaluate in-plane detailing. The typical building section detail is inadequate to show the special consideration needed at joints between parapet panels. Given this, the project team may wish to consider peer review and three-dimensional modeling early in the design process to assist with identifying and resolving performance gaps before they are constructed.

Conclusion

As codes advance and higher performance is expected from building assemblies, the control of moisture within and through the exterior envelope is critical to the success of any project. Good design anticipates the transfer of air, vapor, and heat under various conditions. However, understanding the fundamental nature of these properties is frequently insufficient to achieve success when considering the code-required performance or construction practices. To complicate matters, even when the code is satisfied, optimal performance may not always be achieved.

It is important to consider options and activities that can be done early in the design process to better understand and estimate the potential performance issues. Due diligence can also continue beyond the design process and provide a benefit to the overall project performance. In other words, every effort to identify potential performance risks or issues prior to completion is a benefit to project success. **CS**

ADDITIONAL **INFORMATION**

Authors

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Abstract

The 2015 *International Codes* (*I-Codes*)—with their changes to air, vapor, and thermal control—have been adopted in several states and continue to be implemented and enforced across the nation in the months to come. However, even when compliance is achieved, performance is not guaranteed. This article explores the impact of recent code changes, examines potential limitations of the various compliance approaches, and offers examples of gaps between codes as they relate to design and performance in the built world.

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07 21 00–Thermal Insulation
07 26 00–Vapor Retarders
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B2010–Exterior Walls

Key Words

Division 07
ASHRAE 90.1
Air barriers
IBC
IECC
Insulation
Modelling
Vapor retarders

Our rugged Construction Tapes and Flashings team up with TYPAR® Building Wraps, which boast unbeatable durability. And the facts to back them up.

CHECK OUT OUR STRENGTHS

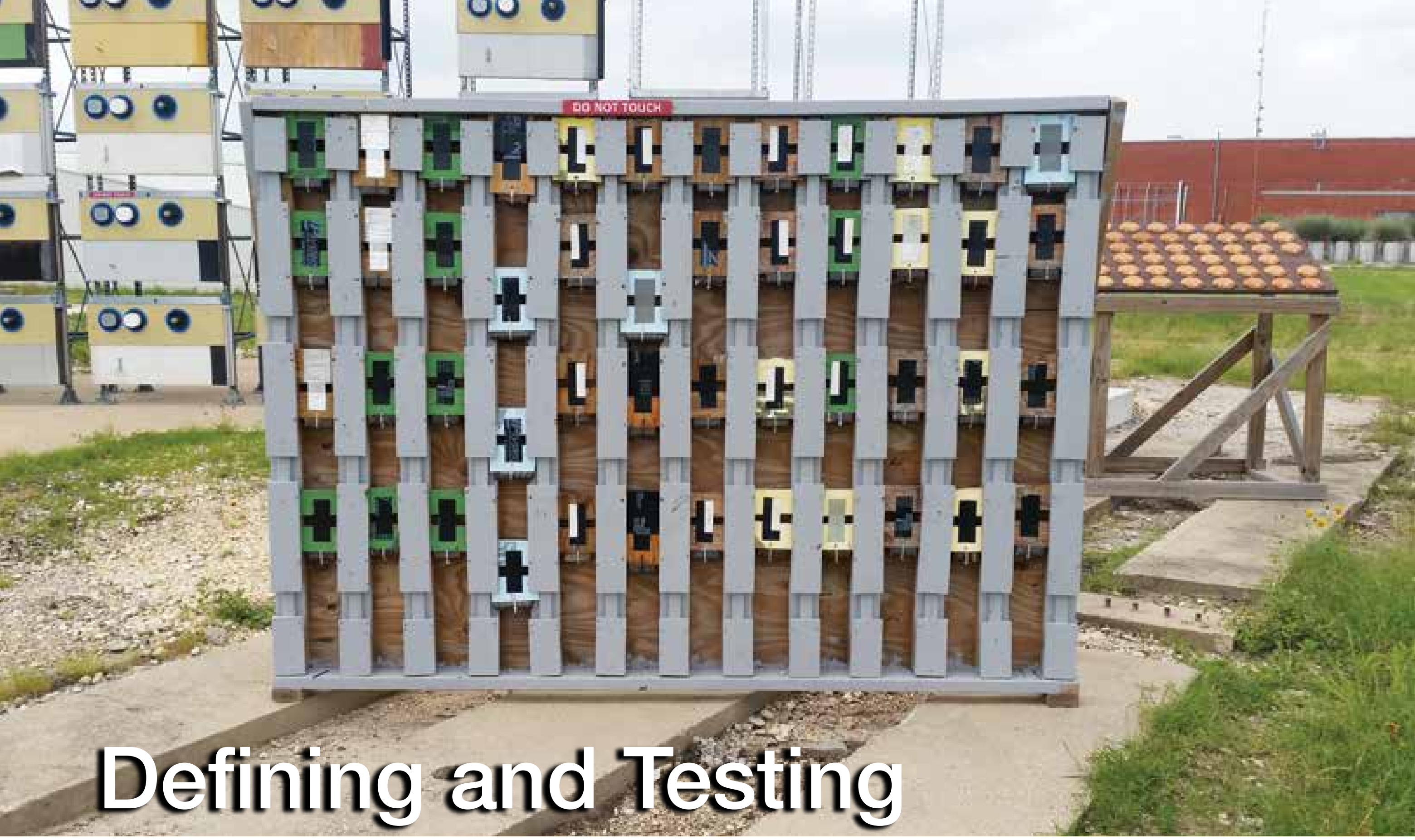
*Based on published results for tear strength according to ASTM D5733-99 testing.

Exploring Air and Water-resistive Barriers

Part Four

Defining and Testing Construction Tape and Flashing Durability

BY ANTHONY M. GARCIA, PE, AND JORGE M. BLANCO



Defining and Testing Construction Tape and Flashing Durability

All images courtesy Building Diagnostics Inc.

CONSTRUCTION TAPES AND FLASHINGS ARE USED TO SPAN JOINTS AND GAPS, TYPICALLY IN CONJUNCTION WITH A PRIMARY WATER-RESISTIVE BARRIER (WRB) OR AIR BARRIER. SINCE THEY ARE CONCEALED BEHIND CLADDING, IT IS IMPORTANT TAPES AND FLASHINGS ARE DURABLE. WILL THEY REMAIN ADHERED IN HARSH CONDITIONS? CAN THEY ACCOMMODATE MOVEMENT FOR THE DESIGN LIFE OF THE BUILDING? THIS ARTICLE'S AUTHORS PERFORMED HUNDREDS OF TESTS TO EVALUATE DIFFERENT TAPE ADHESIVE CHEMISTRIES AND DURABILITY ON A VARIETY OF SUBSTRATES.

Most construction professionals are familiar with traditional rubberized asphalt self-adhered flashing (*i.e.* peel and stick), but acrylic and butyl tapes are increasingly popular. Construction tapes and self-adhered membrane flashings (collectively referred to as "tapes" in this article) are used to span gaps and transitions in materials, such as at window perimeters, sheathing joints, and other complex geometries.

Tapes are common accessories in WRBs and air barriers such as sheet membranes, liquid membranes, and building wraps. These assemblies are crucial to a building's performance and durability. Since tapes are used at junctions critical for keeping the exterior out, proper selection and installation are paramount to avoid water infiltration and air leakage that may lead to tenant discomfort—or worse.

Defining the tapes

To define "tape" and its function in construction, the authors reviewed numerous codes and standards, including the 2015 *International Building Code* (*IBC*) and 2015 *International Energy Conservation Code* (*IECC*).

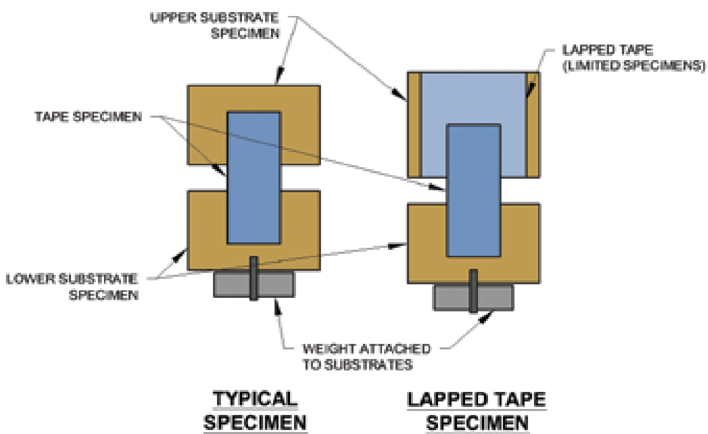
Regarding WRBs, *IBC* requires:

[n]ot fewer than 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, shall be attached to the studs or sheathing, with flashing as described in Section 1405.4,

Figure 1

Fishmouths can develop spontaneously in some tapes even when properly applied. It is important to ensure compatibility of materials and use primer when required. Some tapes also require applying sealant, mastic, or liquid membrane over uncaptured edges.

Figure 2



A schematic diagram of the typical tape test specimens is on the left, and a tape-to-tape specimen is on the right. The top substrate piece is fixed, and the lower piece can move vertically from gravity.

in such a manner as to provide a continuous *water-resistive barrier behind the* exterior wall veneer.[1]

Flashings, as defined by *IBC*:

prevent moisture from entering the wall or to redirect that moisture to the exterior", and "shall be installed at the perimeters of exterior door and window assemblies, penetrations and terminations of *exterior wall* assemblies…[2]

IBC does not require or define an air barrier. However, *IECC* calls for an air barrier to be "continuous" and "provided throughout the building thermal envelope."[3] For the air barrier, *IECC* also requires:

joints and seams shall be sealed, including sealing transitions in places and change in materials…Joints and seals associated with penetrations shall be sealed in the same manner or taped or covered with moisture vapor-permeable wrapping material.[4]

(The code specifically mentions "tapes" as part of the air barrier.)

As *IECC* recognizes tapes will be stressed during their service life, it requires sealing materials to be "securely installed around the penetration so as not to dislodge, loosen, or otherwise impair the penetrations' ability to resist positive and negative pressure from wind, stack effect, and mechanical ventilation."

In addition to codes and standards, previous research and laboratory testing on WRBs informed the study discussed in this article.[5] During the construction of the WRB specimens for testing, manufacturers' accessory tapes were installed at many details; this experience helped develop tape testing methodology and provided a basis for product selection. Ongoing WRB testing will continue to inform future tape testing.

For this study, tapes were defined as broadly as possible, while keeping *IBC*, *IECC*, and colloquial definitions in mind. The requirements for inclusion in the testing were purposely flexible.

Tapes typically consist of similar components, including a carrier sheet (*i.e.* facer or scrim)—often made of polyethylene, polypropylene, or aluminum—and an adhesive layer. A release paper (protective liner) is used on some products; one of the most challenging aspects of engineering a sticky tape is keeping it from adhering to itself on the roll.

The adhesives used in tapes consist of long-chain polymers that interact with substrates under pressure. The polymers create physical bonds that must be very strong in the dynamic and critical applications of building tapes.[6]

Generally, the market is dominated by a few adhesives and their specific uses:

- traditional modified asphalt self-adhered flashings (*i.e.* peel-and-stick);
- thick butyl tapes that typically complete with modified asphalt as flashings; and
- thin acrylic "seam" tapes, which are often used to bridge gaps or cover seams and laps in WRB, and are thus less flexible but very sticky.

Why test tapes?

Experience in forensic investigations indicates tapes are prone to failure, which can be discovered due to water infiltration or the consequential structural damage. Tapes require careful installation, but manufacturers' requirements vary, including rolling with a hand tool, limited effective temperature ranges, use of primers, treating the tape edges with sealant, or other specific procedures. Despite these requirements, tapes are often installed by untrained laborers that have never read the installation instructions or product information.

Tapes must adhere to a variety of substrates, which may be dusty or wet due to construction activities. The tapes must remain uncovered until the building is clad, exposing their free edges to abrasion, ultraviolet (UV) light, and weathering—harsh conditions that may cause curling, wrinkles, "fishmouths" (Figure 1), or other failures.

Additionally, it is common to see one manufacturer's tape used to flash an opening by adhering to another manufacturer's WRB. Although not an approved assembly, tapes must often stick to products other than the manufacturer's own. Incompatibility between tapes and substrates may cause leaks at the openings, penetrations, or, worse, at concealed locations within walls. Repairs are not trivial, since the products are concealed by cladding, requiring costly demolition and reinstallation. The WRB, including tape accessory products, must last for the design life of the building.

Due to the importance of tapes in building envelopes, specifiers must have confidence in their performance under a variety of circumstances. Manufacturers' product information is often incomplete, offering only general information—actual conditions may not meet the requirements provided by manufacturers.

How to test tapes

A variety of test methods and requirements published by ASTM and the Air Barrier Association of America (ABAA) were considered for this research. It would be ideal to test tapes' ability to perform a variety of functions, including:

- accommodate movement;
- span joints and gaps;
- provide a seal to both air and water;
- adhere to a variety of substrates;
- remain durable in adverse conditions; and
- install with ease.

It is extremely difficult to include all possible variables in a single test, so an initial procedure was developed to look at the performance of construction tapes in a multifaceted way.

The pull-off adhesion test, often called the "puck test," is often used in-situ to test membranes, including tapes. A pull-off adhesion of 110.3 kPa (16 psi) is required by AABA,[7] but pull-off adhesion (*i.e.* tension) may not reflect actual behavior in construction, where tapes usually have to resist movement in plane.

By analogy, consider separating an Oreo—it is most difficult to pull the cookies off the frosting in straight tension (and the cookies usually break). Instead, it is easier to pull cookies apart by twisting (*i.e.* torsion, which does not relate to typical construction) or by sliding (*i.e.* shear, as in ASTM D3654, *Standard Test for Shear Adhesion of Pressure Sensitive Tapes*).[8] These different directions of force application yield drastically different strength values. However, they are measuring the same adhesive property, so higher values from direct tension may give a false sense of security—and misleading information about durability. The authors believe shear adhesion is the appropriate way to measure the adhesive strength of construction tapes.

The selected initial test method is based on the ASTM D3654 procedure for measuring adhesion in shear, and was modified based on experience to include:

- outdoor exposure facing solar south to be subjected to high solar radiation (in addition to wind and rain); and
- a larger contact area than specified, to allow for less specimen modification with a consistent tape width. (The increased contact area also lengthened the time to failure, which prevents most tapes from immediately failing before meaningful results could be obtained.)

Numerous tapes made with different types of adhesive were tested on a variety of substrates. The rack can hold 48 specimens to be tested at a time, allowing for data collection on a large number of combinations. Other variables tested included using or omitting recommended primers, using mechanical rollers or hand pressure, and varying the "rest" time before

Figure 3

Products with significant market share were prioritized. The products were purchased or provided by manufacturers for testing at The Durability Lab at The University of Texas at Austin. The rack shown allows testing of multiple specimens. After failure, the specimens could be exchanged quickly.

Figure 4

An example of tape failure.

Figure 5

As illustrated by the photos above, the failure modes include vertical sliding and complete disbonding of the adhesive.

exposure. Since pressure-sensitive adhesives often take time to develop full strength, researchers wanted to determine if these variables affected tape performance.

The test procedure is summarized as follows:

1. Select tape and substrate combinations; make a minimum of three replicates for every combination.
2. For each specimen, cut two pieces of the selected substrate to fit within the test apparatus, 76 mm (3 in.) tall x 127 mm (5 in.) wide.
3. Apply primer to the substrate (if required, per the tape manufacturer's product literature).
4. Carefully unroll a strip of tape, ensuring the adhesive is not compromised with dirt, moisture, or other contaminants. Cut the strip with a razor blade to measure 127 mm long x 50 mm (2 in.) wide.
5. Install tape with 258-mm^2 (4-si) contact area, with 50 mm (2 in.) of length on each substrate piece.
6. Apply pressure to the tape with an appropriate roller to promote optimal adhesion.
7. Allow the specimen to rest indoors before installing on the rack outdoors; store the specimens. Rest periods ranged from 24 to 72 hours.
8. Attach a weight to the lower substrate piece to reach a combined mass of 0.45 kg (1 lb) for the substrate, tape, and weight. The final configuration is shown in Figure 2 (page 30).
9. Install specimen on the test rack (Figure 3, page 31); record the date and time of exposure.
10. Record the date and time of failure (when tape disbonds from substrate). If failure does not occur after 30 days, remove the specimen and record the date and time (Figure 4).

What were the results?

So far, testing on this rack has included 360 specimens with seven acrylic, five butyl, and six rubberized asphalt tape products from eight manufacturers, in various combinations on the following substrates:

- CDX plywood sheathing (plywood);
- smooth side of oriented strand board (OSB) sheathing;
- rough side of OSB sheathing;
- OSB with integral WRB;
- glass mat-faced gypsum sheathing; and
- extruded polystyrene (XPS) insulation boards.

In addition to sheathing substrates, tape-to-tape adhesion was tested to evaluate lap performance, since all tapes will be adhered to themselves at certain details. The authors were surprised when failure occurred at the interface between the tapes (Figure 6) more than twice as often when compared to other substrates at the same location.

The carrier sheet played a prominent role in the durability of the tapes under loaded and exposed conditions. The authors observed two failure modes:

- carrier sheet separated from the adhesive and slid vertically (Figure 5); and
- adhesive disbonded from the substrate (Figure 5)

The data collected is extensive; averaged results are shown in Figure 7. The following conclusions are of particular interest.

1. Only 95 specimens (26 percent) reached the cutoff time of 30 days without failure. Almost half the specimens reaching this point were acrylic tapes. Still, the average time of failure for all acrylic tape tests was much lower, as shown in Figure 8 (Page 34).
2. Across all combinations, butyl tapes had an average time to failure of 10 days; rubberized asphalt tapes had an average time to failure of six days. (See Figure 9, page 34)
3. Modified asphalt tapes performed best on XPS insulation, with an average time to failure of 11 days.
4. Butyl tapes performed the best on gypsum sheathing, with an average time to failure of 13 days.
5. The rough side of OSB was the most challenging substrate for all adhesive types, with an average time to failure of seven days. In contrast, the average time to failure on the smooth side of OSB was nine days. (See Figure 10, page 35)

The 30-day limit was imposed after analysis of preliminary results and with a desire to collect data rapidly. Most specimens failed within the 30-day limit, but some well-performing specimens during the preliminary tests were removed from the rack (without failure) at approximately one year of exposure. If a specimen exceeded the 30-day limit, it would generally reach the 180-day exposure limit imposed by most manufacturers' literature.

What are the next steps?

At the time of writing, this testing was ongoing. Based on experience with construction failures and knowledge gained from the study so far, additional combinations were planned, including the following additional substrates:

- polyisocyanurate (polyiso) insulation;
- vinyl (to simulate the window flanges on typical multifamily construction);
- aluminum (to simulate common window frame and flashing materials);
- various type of steel with and without corrosion (to simulate lintels, flashings, and other common construction details); and

Figure 6

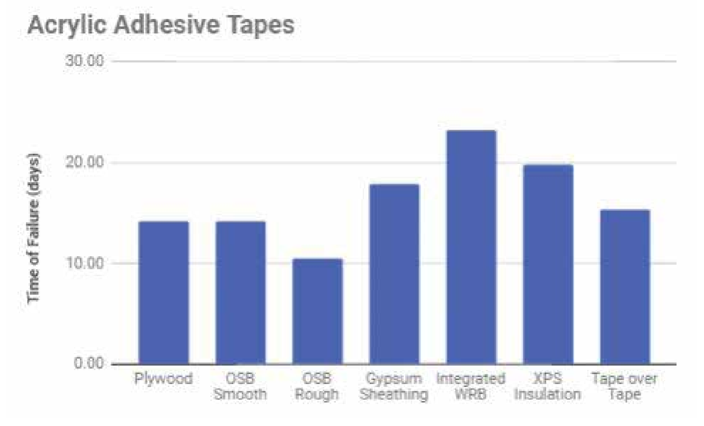
Failure of a tape-to-tape lap.

Figure 7

ADHESIVE	SUBSTRATE	AVERAGE TIME OF FAILURE* (DAYS)	REACHED CUT-OFF
Acrylic	Plywood	14.22	42.90%
	OSB Smooth	14.19	42.90%
	OSB Rough	10.54	33.30%
	Gypsum Sheathing	17.93	50.00%
	Integrated WRB	23.24	71.40%
	XPS Insulation	19.8	44.40%
	Lapped Tape	15.36	41.70%
Butyl	Plywood	11.11	20.00%
	OSB Smooth	7.74	6.70%
	OSB Rough	7.42	0.00%
	Gypsum Sheathing	13.06	20.00%
	Integrated WRB	Not Tested	-
	XPS Insulation	10.4	0.00%
	Lapped Tape	9.16	0.00%
Modified Asphalt	Plywood	7.11	20.00%
	OSB Smooth	4.14	6.70%
	OSB Rough	0.08	0.00%
	Gypsum Sheathing	7.68	13.30%
	Integrated WRB	Not Tested	-
	XPS Insulation	11.43	10.00%
	Lapped Tape	3.26	0.00%

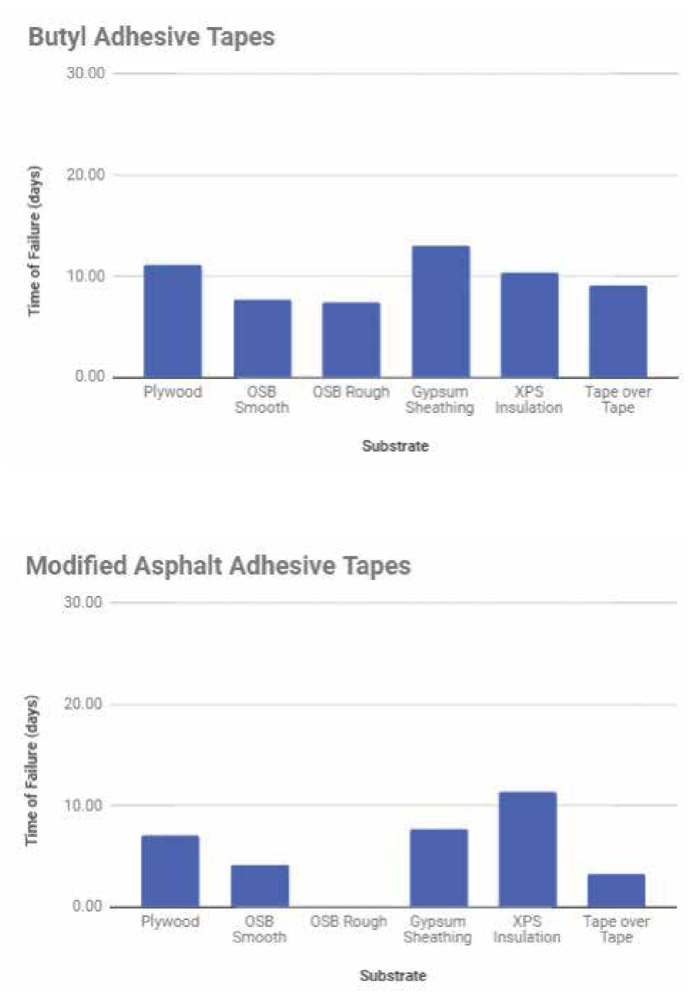
Summary of data, broken down by adhesive type and substrate. (This average time of failure includes the specimens removed at the cut-off time of 30 days.)

Figure 8



Average time to failure on each substrate for acrylic tapes.

Figure 9



Average time to failure on each substrate for butyl tapes (top) and rubberized asphalt tapes (bottom).

- common WRBs (including building wraps).

It is important to note numerous conditions can affect tape performance beyond the initial study's scope (although the conditions may be simulated during future testing). They include:

- adverse storage conditions—most tapes call for storage in a cool, dry location, which may not occur on construction sites;
- wet substrates of all varieties to simulate installation of tape during or shortly after rain; and
- dirty substrates to simulate installation of tapes on active construction sites.

In addition to the shear adhesion testing, long strips of tapes were installed on sheathing to observe how tapes behave with environmental exposure, as shown in Figure 11. Qualitative evaluations include shrinkage, bleeding, curling, and spontaneous development of fishmouths. Future testing will include pull-off adhesion per ASTM D4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*, and peel adhesion to compare the results to these shear adhesion tests.

Conclusions

Every layer matters in a building's water-resistive barrier or air barrier, so the importance of tapes cannot be overstated. Common in construction, tape failures lead to costly repairs. The testing confirmed typical field observations—when installed well, most tapes perform acceptably, a few are exceptional, but some perform very poorly.

The industry needs standard test methods reflective of tape conditions in the field. Most current methods load tapes in unrepresentative manner or are impractical to perform. The test developed for this study simulates the forces tapes experience in construction better than other methods.

A few techniques and best practices to improve the durability of tapes were illuminated by this study. Even if the best tapes are specified, installation is critical. One should use compatible primers when provided by the manufacturer, especially on OSB sheathing. Pressure should be applied with a roller in all situations. Tapes should only be used with the recommended substrates and WRBs.

Additionally, specifiers must be aware of performance limitations of tapes in WRB and air barrier applications, including their ability to adhere to substrates and adhesion to a tape's own carrier material. Where possible, one should specify the smooth side of OSB as outward-facing to optimize adhesion by tapes. **CS**

Notes

[1] This comes from the 2015 *IBC* Chapter 14, Section 1404, Paragraph 1404.2.

[2] See 2015 *IBC* Chapter 14, Section 1404, Paragraph 1454.4.

[3] Excerpted from 2015 *IECC* Chapter 4, Section C402, Paragraph C402.5.1.

[4] See 2015 *IECC* Chapter 4, Section C402, Paragraph C402.5.1.1.3.

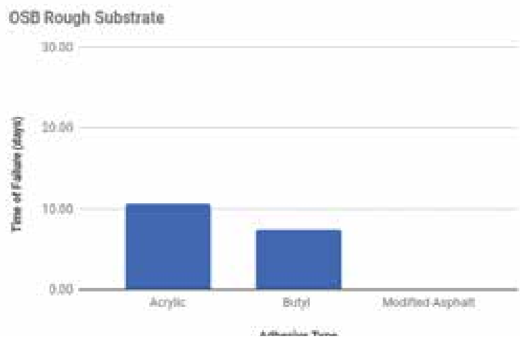
[5] For more information, see the February 2015 issue of *The Construction Specifier* for the article, "Durability of Water-resistive Barriers," by Beth Anne Feero, EIT, and David H. Nicastro, PE. Visit www.constructionspecifier.com/durability-of-water-resistive-barriers.

[6] The *Scientific American* article, "What Exactly is the Physical or Chemical Process that Makes Adhesive Tape Sticky?," can be read online at www.scientificamerican.com/article/what-exactly-is-the-physi.

[7] For more information, see Revision 14 (June 2015) of the Air Barrier Association of America's "ABAA Process for Approval of Air Barrier Materials, Accessories and Assemblies."

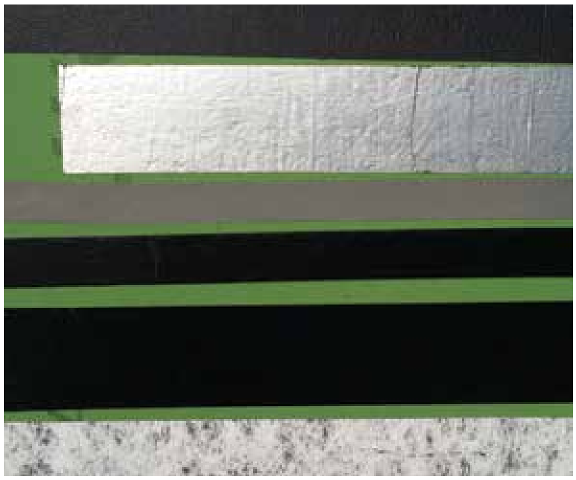
[8] The authors are grateful for the suggestion of this analogy by Dr. Christopher C. White, a research chemist with the National Institute of Standards and Technology (NIST).

Figure 10



The average time to failure of each type of tape when adhered to rough oriented strand board (OSB) sheathing substrates.

Figure 11



Testing of long strips demonstrates how tapes act over time when exposed to weather (in this photo, the color is desaturated to deemphasize branding). Exposure testing of tapes complements the shear adhesion testing described in this article, and water-resistive barrier (WRB) mockup panel and fastener sealability testing described previously. (See note 5.)

ADDITIONAL **INFORMATION**

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Abstract

Construction tapes and flashings are used in almost all construction to span joints and gaps, typically in conjunction with a primary water-resistive barrier (WRB). As they will be concealed behind cladding, it is important tapes and flashings are durable, remain adhered, and accommodate movement. To evaluate their performance, numerous construction tapes and flashings were tested on a variety of substrates. This article explains the trends observed during the testing, including adhesive chemistry, compatibility, and durability on specific substrates.

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