Condensation in Wall Assemblies: Can Vapor Diffusion Through Highly Permeable Air Barriers Increase the Risk?

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**ABSTRACT**

Blindside waterproofing provides challenges that can be addressed using prefabricated polymer-modified bitumen sheet membranes. Benefits of a fully adhered system, such as preventing lateral water migration on the interior side of the membrane, will be presented, along with ways of taking advantage of the concrete curing process for an intimate bond between the concrete and membrane. Blindside waterproofing systems based on modified-bituminous sheets and accessories meet the expectations of designers for soil conditions and contaminants and gas permeability of membranes, while providing contractors the ease of installation and detailing. They allow a cost-effective solution to accomplish watertight structures.

**SPEAKERS**

**JEAN-FRANÇOIS CÔTÉ, PHD — SOPREMA INC.**

JEAN-FRANÇOIS CÔTÉ joined Soprema in 1999 as a research chemist and has been the company’s director of strategic development since 2009, coordinating the activities related to product and systems development. He is co-chair of the ASTM D08-04 Subcommittee and is an active member of various technical committees in organizations such as ARMA, SPRI, CSA, and ULC.

**HANK STARESINA — SOPREMA INC.**

HANK STARESINA is Soprema’s technical specialist for building envelope solutions. He has been a part of the Canadian construction industry since 1980. Hank has been involved with a number of high-level manufacturers, providing him with a vast knowledge of industry practices. He serves on the board of directors of the Building and Concrete Restoration Association and is past president of the Sealant Waterproofing Association of Ontario.
INTRODUCTION

Vapor diffusion is the process of water molecules moving through porous materials (e.g., wood, insulation, plastics, concrete, etc.) driven by differences in vapor pressure. It is one of the many mechanisms that move water through wall assemblies. Vapor diffusion itself isn't the cause of moisture problems; rather, it is the moisture deposited by this and other processes that may create moisture concerns, such as mold, wood decay, and corrosion. To minimize these problems, building codes attempt to provide some level of vapor diffusion control.

Some materials can block vapor diffusion and are called vapor-impermeable or vapor retarders, such as polyethylene or asphaltic membranes. Other materials freely allow water diffusion and are called vapor-permeable, like fiberglass batt insulation. Most other materials fall somewhere in between these extremes.

All components of wall assemblies serve one or more important purposes. Wall membranes installed behind the cladding are primarily used to protect the assembly from wetting during construction and provide a water-resistive barrier (secondary plane of water protection). In many modern wall assemblies, this membrane may also become part of the air barrier system and therefore form an integral component to the vapor control system.

Today's offering of air barrier membranes is quite extensive. They may be mechanically fastened or adhered sheet membranes, or liquid-applied membranes that are rolled, sprayed, or brushed onto the sheathing. There are dozens of products available on the market, made from a number of different materials, from organic fibers to synthetic plastics with material properties featuring an extensive range of values.

Among these properties, water vapor permeance is no exception. Air barrier membranes can be found with permeance ranging from zero (in the case of air/vapor barriers) to above 75 U.S. perms (highly permeable). The appropriate selection (and positioning) of all components is critical to ensure proper moisture management in wall assemblies. However, some misunderstandings persist within the industry that highly permeable membranes are superior to less permeable alternatives. This is not always the case.

Ideally, all moisture sources should be controlled, thus eliminating any concerns of moisture damage. Most building assemblies include some materials that are moisture-sensitive. These are materials that may lose their functionality or pose health risks to the building occupants if subjected to elevated amounts of moisture. However, eliminating all moisture sources over the service life of a building is difficult. Consequently, walls should be designed to allow for drying of incidental moisture accumulation or construction defects.

Wet materials in a wall assembly will naturally dry by diffusion in the directions of lower water vapor pressure. When a polyethylene vapor retarder is used behind the interior drywall, the greatest amount of drying occurs to the exterior, and so the drying rates of the wall assembly benefit most from highly permeable exterior membranes. While a very permeable membrane will permit the greatest amount of drying, there are diminishing returns. A plot of normalized drying times, based on Fick's Law of diffusion, is shown in Figure 1. The normalized drying rate is the percent efficiency of a membrane to an infinitely permeable membrane. For instance, a 10 U.S. perm membrane is roughly 90% effective, whereas a 50-perm membrane is 98% effective. Consequently, changing a 10-perm membrane to a 50-perm membrane only improves the drying times by about 8%; increasing a 50-perm membrane to a 100-perm membrane only improves the drying times by about 1%.

In this study, water vapor permeance measurements were performed using two different methods on five self-adhered air barrier sheet membranes. Typical permeance values obtained in this study were used in hygrothermal modeling in order to quantify the level of risk associated with condensation, water accumulation, and mold growth in typical wall assemblies.

EXPERIMENTAL

Water vapor permeance testing was conducted on all membranes in accordance with ASTM E96 – 2010, Standard Test

The determination of water vapor permeance of materials (in this case, the self-adhered membranes) by ASTM E96 uses an apparatus called a cup. Both methods of E96 were used in this study:

- Desiccant Method, or "dry cup," where desiccant is placed in the cups, leaving an air space at 0% RH
- Water Method, or "wet cup," where distilled water is placed in the cups, leaving an 100% RH

In both methods, the material being tested was used to seal the opening of the cup, like a lid, such that it separates the interior of each cup from its surroundings. The cups were then placed in a climate chamber under controlled temperature and relative humidity conditions at 23±0.2°C (73.4±0.4°F) and 50±2% RH. These conditions are commonly referred to as "Procedure A" for the Desiccant Method and "Procedure B" for the Water Method in ASTM E96. The vapor pressure gradient created between the water/desiccant in the cups and climate chamber conditions (1,400 Pa or 0.203 psi) results in water vapor either entering the cups (when using the Desiccant Method) or leaving the cups (when using the Water Method) by diffusion through the test material.

The filled and sealed cups are then weighed at regular intervals using a laboratory scale. Water vapor diffusion (leaving or entering the cup) can be calculated when successive weight measurements, plotted on a graph, indicate that the rate of weight gain or loss has attained a steady state. Permeance is then expressed as the weight of water vapor diffusing through the material as a function of time, per unit area and vapor pressure difference. Both methods were completed in triplicate.

Membranes were also tested for water vapor transmission rate using another test method, ASTM F1249-13, Standard Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor.

Testing was conducted at 23°C (73.4°F) using the PERMATRAN-W 3/33 Water Vapor Permeability Instrument by MOCON. This instrument uses two diffusion cells for simultaneous duplicate testing. Each diffusion cell has two halves separated by the material to be tested. In one half, a test gas containing water vapor flowed (the test gas used was moisture-saturated air, 100% RH). In the second half, a carrier gas flowed (dry nitrogen, 0% RH), creating a water vapor pressure difference of 2,800 Pa or 0.406 psi across the tested material. The carrier gas swept constantly across the "dry" side of the material and collected all water vapor diffusing through it.

Carrier gas containing the permeating water vapor was brought to a pressure-modulated infrared (IR) detector at a rate of 100 cc/min. This detector measures infrared energy absorbed by water vapor and produces an electrical signal. The amplitude of the signal is proportional to the water vapor concentration. The amplitude is then compared to the signal produced by the measurement of a calibration film of known water vapor transmission rate. With a known test film area and the measured water vapor, the transmission rate for the test material can be determined and expressed in units of weight per unit area per day. This number was then converted to permeance by using the vapor pressure difference between the cell halves.

PERMEANCE RESULTS

Results of the experimental testing performed on the five membranes are shown (as averages) in Table 1. Membrane E could not be measured using ASTM F1249, as the vapor transmission rate exceeded the range of the test equipment. The same applied to a sixth membrane (A, not shown here) for which ASTM E96 results will be known later.

Results are generally in agreement with manufacturer-published data, except for Membranes E and F (higher permeance). Variability around the average was low for all membranes in all test methods, except Membrane D, for which variance was significantly higher, exceeding 47% in the Water Method, for example.

Because the ASTM E96 methods are performed with air at different RH values in the cup, and ASTM F1249 is performed with nitrogen at 100% RH, it is not shocking to observe different permeance results for a given air barrier membrane, depending on the method used. The general trend, however, is respected for all test methods.

Building codes have grouped materials into classes depending on their water vapor permeance:

- Class I vapor retarder: <0.1 U.S. perm
- Class II vapor retarder: 0.1 to 1.0 U.S. perms
- Class III vapor retarder: 1.0 to 10 U.S. perms (semipermeable)
- Vapor permeable: >10 U.S. perms

All air barrier materials tested in this study exhibited permeance results (as per ASTM E96 Water Method) in the "high permeance" category (from 10 to 76 U.S. perms).

HYGROTHERMAL MODELING

The WUFI 5.2 Pro (WUFI) computer model was used to simulate the hygrothermal performance of wall assemblies in various configurations and climates. The simulations were repeated for four different climate zones. Major Canadian cities in each climate zone were selected from the WUFI climate file database representing 10th percentile cold or hot years over a 30-year period:

- Temperate Marine (Climate Zone 4C): Vancouver, British Columbia
- Cold-Humid (Climate Zone 5): Toronto, Ontario
- Cold-Dry (Climate Zone 6): Québec City, Québec
- Very Cold-Dry (Climate Zone 7): Edmonton, Alberta
Table 2 – Hygrothermal study parameters and values.

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<th>Variable</th>
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| Cladding Moisture Storage Capacity            | Nonstoring: 5.2 kg/m²  
Storing/Reservoir: 34.0 kg/m²  |
| Drainage Cavity Ventilation Rate              | Nonstoring: 100 ACH*  
Storing: 5 ACH                                                                 |
| Exterior Insulation Vapor Permeance           | Permeable: 178 ng/Pa·s·m² (3.1 U.S. perm)  
Impermeable: 1.15 ng/Pa·s·m² (0.2 U.S. perm)  |
| Exterior Insulation Thermal Resistance (R-value) | Thermal Resistance (IP)  
None/R-6.5/R-18                                                                  |
| Air Barrier Membrane Vapor Permeance          | 57.2/572/1716 ng/Pa·s·m²  
(1.0/10/30 U.S. perm)                                                               |

*ACH: Air changes per hour

Interior boundary conditions were established by assuming a high indoor moisture load representative of a residential building with low outdoor ventilation rates and high moisture production (EN 15026 approach). This model generated relatively high indoor humidity values and therefore established conservative estimates on drying rates and wall behaviors.

The rain load was determined using ASHRAE Standard 160P, with a rain exposure factor of 1.0 and rain deposition factor of 1.0. This established an upper limit to the degree of wetting of the cladding. To maximize solar radiation, the wall orientation was directed due south, with a short-wave absorptivity of 0.4 and long-wave radiative emissivity of 0.9. These values are approximate for a light-grey cladding, such as stucco or fiber cement siding. Explicit radiation balance was also included, with the default settings, to provide better resolution of the long-wave counter radiation with the environment.

The parametric study was based on a typical 2-x-6-in wood-framed wall with ½-in. plywood sheathing, with an interior polyethylene sheet vapor retarder and ½-in. gypsum wallboard. The wall was insulated with R-19 fiberglass batt insulation. The parameters and their values are provided in Table 2.

The simulations considered the impact of nonstoring cladding (materials that absorb or store relatively small amounts of water when exposed to rain such as vinyl siding or fiber cement panels) and reservoir, or moisture-storing cladding (materials such as brick and stucco that can hold significantly larger amounts of water). The respective water-storage capacities were used from internal WUFI property data. Also considered was the impact of additional exterior insulation (either vapor-permeable or impermeable) from R 0 to R 18. Air barrier membrane vapor-permeance variables were selected at three levels: 1, 10, and 30 U.S. perms.

Cross sections of one typical nonstoring and one typical storing/reservoir wall used in simulations are shown in Figure 2 and Figure 3, respectively.

Drying rates were calculated by setting the wood sheathing moisture content (MC) to 28%, the moisture content at which fungal deterioration can occur, and evaluating the time required for the sheathing to dry below 20% MC, the lower limit for fungal growth. The simulations were started at the beginning of February to mimic wintertime wetting, and drying times were measured for one year. Drying times in excess of a year were deemed to be at extremely high risk of moisture damage and decay.

Hygrothermal simulations assessing the time for saturated sheathing (i.e. 28% MC)
to dry below the safe level (i.e., 20% MC) are presented. Figure 4 shows simulation results for the Vancouver (Zone 4C) climate, and Figure 5 does the same for the Québec City (Zone 6) climate.

Wall assemblies—not including exterior insulation or including vapor permeable exterior insulation—had measurable differences in drying rates, correlated to the vapor permeance of the air barrier membrane. However, results show that although membrane permeance has a large impact on the drying rates between 1 and 10 U.S. perm, improvements achieved by increasing membrane permeance from 10 to 30 U.S. perm are small. The biggest differences were observed when no exterior insulation was present. In some assemblies, the faster drying time is as little as two extra days. In contrast, it can sometimes take weeks for mold growth to occur under ideal conditions. Functionally, the difference between selecting a high-permeability or “very high”-permeability membrane has a lesser impact on the moisture performance of the wall than other design considerations, such as the type of cladding or use of exterior insulation.

Walls with impermeable exterior insulation (not shown) are double vapor retarders; they do not dry within a one-year period, regardless of the membrane permeance.

**SEASONAL MOISTURE VARIATIONS**

The long-term moisture performance was assessed by running the simulations for several years until annual equilibrium was met; that is, repeatability between successive seasons was achieved. The metric for comparison was the number of hours with high risk of fungal growth or decay at the sheathing level, and these hours were called “critical hours for biodeterioration.” These critical conditions were temperatures between 4°C (39.2°F) and 35°C (95°F), and at sheathing moisture contents exceeding 20%. It should be noted that these simulations do not include incidental moisture leaks or air leakage. Figure 6 and Figure 7 show the impact of air barrier membrane permeance and exterior insulation on the number of critical hours for biodeterioration in a year, as obtained from simulations for various assemblies with brick cladding. Assemblies with fiber cement cladding (not shown) had very low numbers of critical hours of biodeterioration.

Of the modeled assemblies, the only wall types that are at risk of decay are those with 1.5 in. or no exterior insulation behind a reservoir cladding. Wall types without reservoir claddings are not at appreciable risk to decay regardless of membrane permeance, although simulations indicate that using a 10-U.S.-perm membrane is the...
least susceptible to cause risks (less susceptible than when using a 30-U.S.-perm membrane). Wall assemblies with 1.5 in. or no exterior insulation behind a reservoir cladding have a direct relationship between membrane permeance and hours of biodeterioration. In these cases, using a “very high” permeance air barrier membrane should be avoided.

To better examine the yearly impacts on the sheathing performance in reservoir-clad wall systems, the annual sheathing moisture contents were plotted for R-6.5-permeable exterior insulation and compared to assemblies with no exterior insulation. Figure 8 and Figure 9 present the annual evolution of sheathing moisture content for the Vancouver (Zone 4C) climate and the Québec City (Zone 6) climate, respectively.

Analysis of the annual plywood moisture content reveals that highly permeable membranes perform best when used in conjunction with permeable exterior insulation. However, the improvements compared to a 10-perm membrane are minimal. Overall, addition of exterior insulation has a more significant impact on sheathing performance than any variations in membrane permeance. In the absence of exterior insulation, it was found that medium-permeance air barrier membranes perform slightly better than either highly permeable or impermeable membranes in all of the simulated climate zones. In all instances, the use of a 10-perm membrane does not appreciably increase the risk compared to a 30-perm membrane.

CONCLUSION

Prevention of moisture problems is the first and most important step in ensuring the long-term performance of all wall assemblies. However, if leaks do occur, an assembly that can dry will invariably perform better than one that does not.

The main causes of moisture problems, in order of significance, are bulk water leaks, air leakage condensation, construction moisture, and lastly, water vapor diffusion. Proper rainwater management strategies and detailing of the water-resistive barrier are fundamental to minimize bulk water leaks, whereas continuous air barriers and exterior insulation are keys to managing condensation resulting from air leakage.

Construction moisture and vapor diffusion are managed by the proper placement and selection of vapor control layers and careful use of impermeable materials. Proper installation following good construction practices will also greatly contribute.

With regard to drying, a more permeable membrane will enable more drying than a less permeable one but will also allow more water vapor to enter the wall assembly through inward vapor drive when
a reservoir cladding is used. Furthermore, the membrane vapor permeance must be considered in conjunction with the adjacent layers in the wall assembly. A highly permeable membrane is not as effective if the vapor diffusion is already restricted by other layers in the assembly. In addition, highly permeable membranes are subject to diminishing returns, whereby increasing the permeability yields smaller and smaller benefits to drying.

The wetting and drying characteristics of wall assemblies are complex, and there is no universal solution. Resorting to high permeance membranes may not be the right approach in all instances; similarly, low-permeance membranes are not suitable for all applications. In many cases, the vapor permeance of the air barrier membrane has little or no influence on the performance of the wall assembly.

As demonstrated, the thickness and type of exterior insulation and other materials, including the cladding and interior vapor control layer also have an impact on the selection of the air barrier membrane vapor permeance; therefore, widespread industry recommendations cannot be made as to whether a lower or higher vapor permeance is better. Consequently, specifying and positioning the vapor control layer must be done holistically with the design of the enclosure.