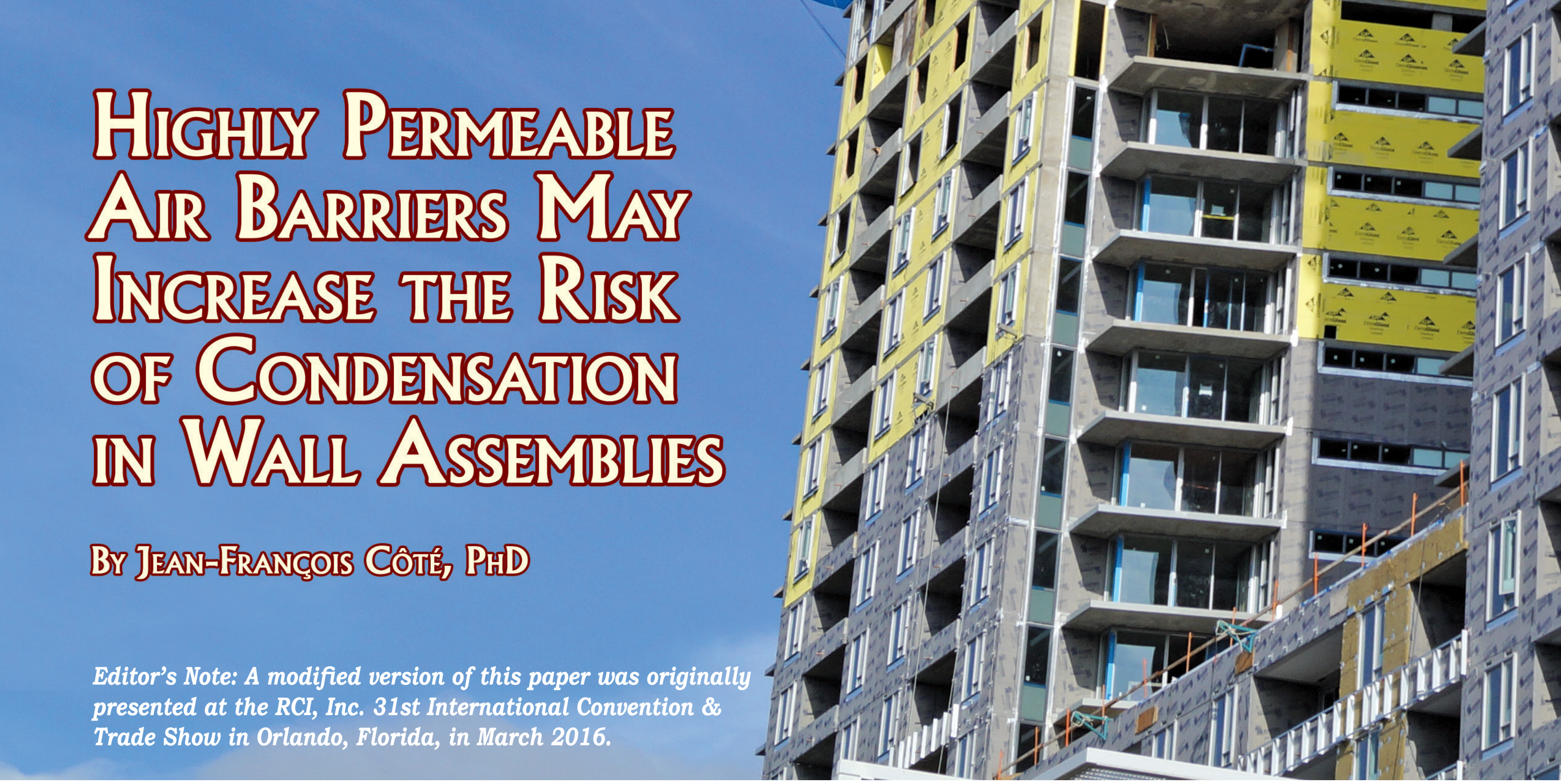

HIGHLY PERMEABLE AIR BARRIERS MAY INCREASE THE RISK OF CONDENSATION IN WALL ASSEMBLIES

BY JEAN-FRANÇOIS CÔTÉ, PHD

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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.

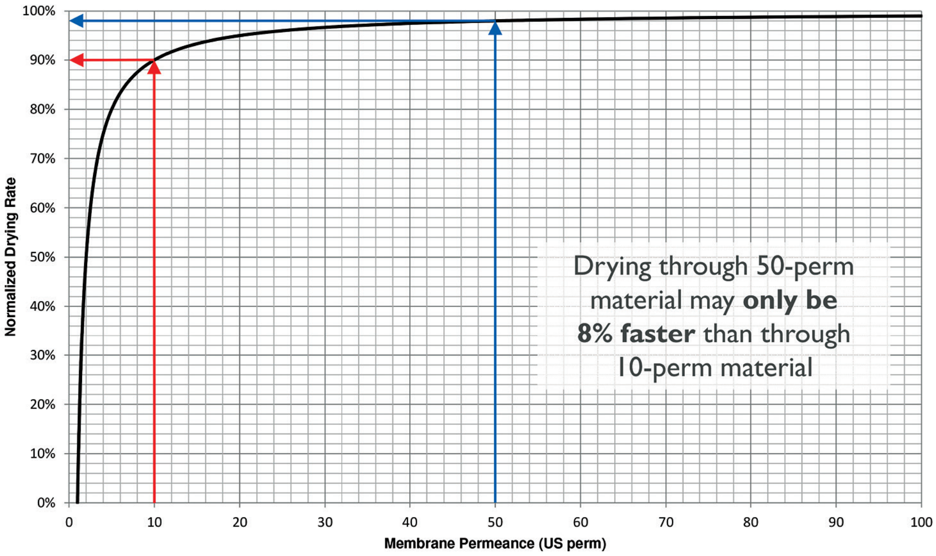
Some materials, termed vapor-impermeable or vapor retarders, such as polyethylene or asphaltic membranes, can block vapor diffusion. Other materials, termed vapor-permeable, like fiberglass batt insulation, freely allow water diffusion. Most other materials fall somewhere in between these extremes.

All components of wall assemblies serve one or more important purposes. Water-resistive barriers (WRB) installed behind the cladding are primarily used to protect the assembly from wetting during construction and to provide a secondary plane of water protection in service. In many modern wall assemblies, the WRB membrane may be designed as part of the air barrier system and also 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 US perms (highly permeable). The appropriate selection (and positioning) of all components is critical to ensure proper moisture management in wall assemblies. However, some misconceptions 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.



Drying through 50-perm material may **only be 8% faster** than through 10-perm material

Figure 1 – Theoretical relationship between normalized drying rate and permeance.

Wet materials in a wall assembly will naturally dry by diffusion in the direction 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. However, while a very permeable membrane will allow the greatest amount of drying, there are diminishing returns. A plot of theoretical 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 US perm membrane is roughly 90% effective, whereas a 50 US perm membrane is 98% effective. Consequently, changing a 10-perm membrane to a 50-perm membrane may only improve the drying times by about 8%; increasing a 50-perm membrane to a 100-perm membrane may only improve the drying times by about 1%. But what does this mean in real life?

PERMEANCE TESTING AND REPORTING

Water vapor permeance of building materials is most often measured using one of the test methods found in the ASTM E96 standard, entitled *Standard Test Methods for Water Vapor Transmission of Materials*. These methods are the "desiccant method" or "dry cup," where desiccant is placed in the test cups, leaving an air space at 0% relative humidity (RH); and "water method" or "wet cup," where distilled water is placed in the test cups, leaving an air space at 100% RH.

When testing is performed 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.

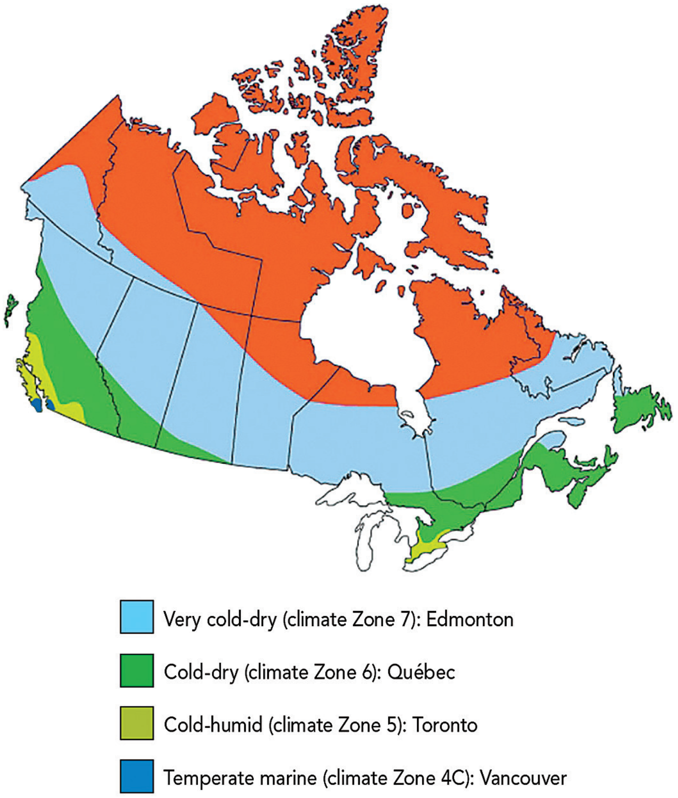


Figure 2 – Cities selected for the hygrothermal simulations and their ASHRAE climate zones.

Brick cladding	Water storage capacity: 34kg/m^2 (7 lbs. per sq. ft.) Cavity ventilation rate: 5 air changes per hour
Fiber cement cladding	Water storage capacity: 5.2kg/m^2 (1 lbs. per sq. ft.) Cavity ventilation rate: 100 air changes per hour
Exterior insulation types	Permeable: Rockwool (3.1 US perm) Impermeable: XPS (0.2 US perm)
Exterior insulation R-values	0 / R-6.5 / R-18
Air barrier permeance	0.01 to 50 US perm

Table 1 – Hygrothermal study parameters and values.

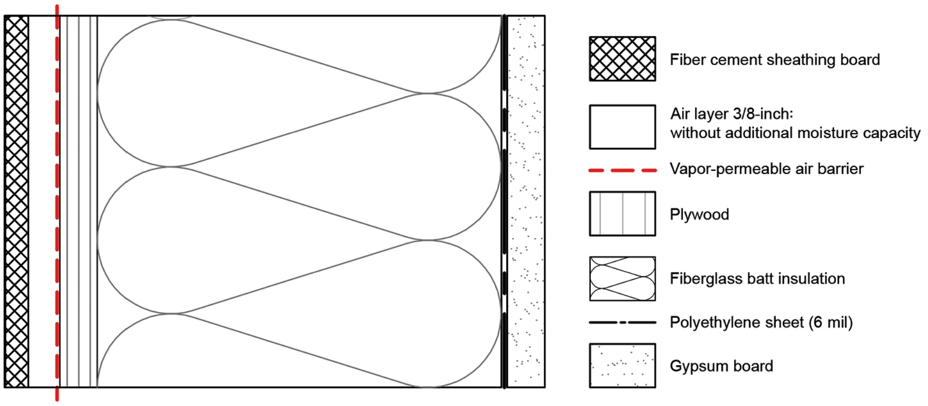


Figure 3 – Fiber cement cladding, no exterior insulation wall assembly.

When testing a given material, permeance results obtained using different standards or different methods within the same standard vary considerably. Because the ASTM E96 methods are performed with air at different RH values in the test cup, it is not shocking to observe different permeance results for a given material, depending on the method used. Test conditions dictate the behavior of these membranes and, consequently, results cannot be compared among test methods. However, general trends (the increasing order of permeance, for example) are generally respected for all test methods.

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 performed for four different ASHRAE 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 (see *Figure 2*).

Interior boundary conditions were estab-

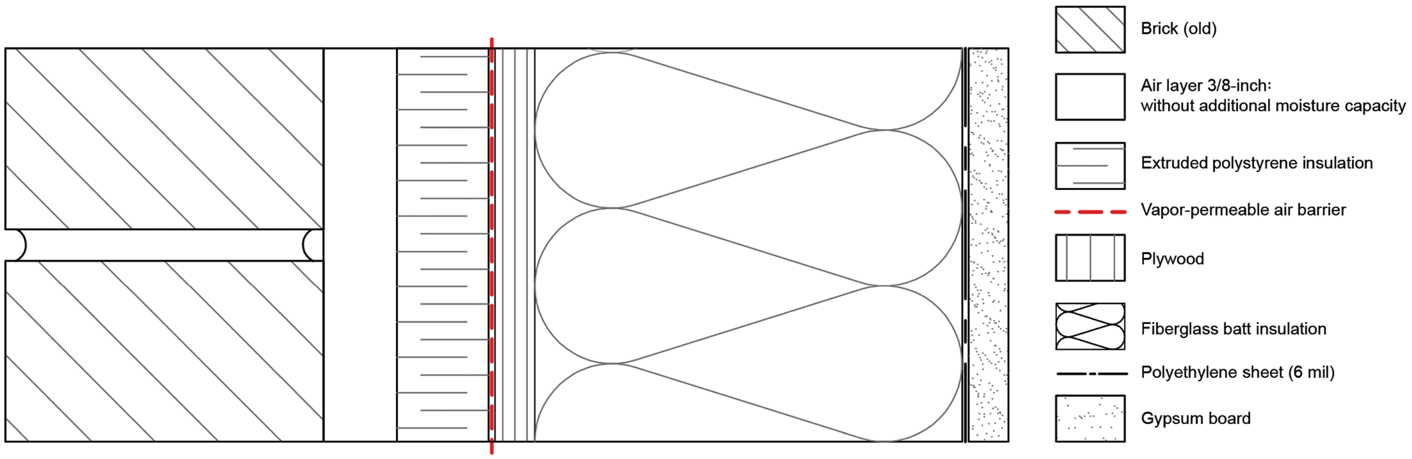


Figure 4 – Brick cladding, XPS exterior insulation wall assembly.

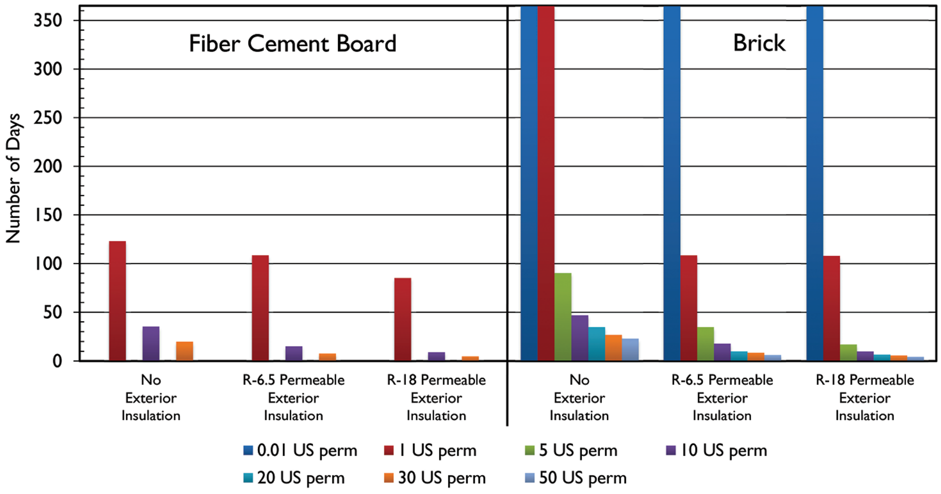


Figure 5 – Days required to dry plywood sheathing to 20% MC in Edmonton – Zone 7.

lished by assuming a high indoor moisture load representative of a residential building with low outdoor ventilation rates and high moisture production (in accordance with EN 15026, *Hygrothermal Performance of Building Components and Building Elements. Assessment of Moisture Transfer by Numerical Simulation*). 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, *Criteria for Moisture-Control Design Analysis in Buildings*, 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-gray 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 1*.

The simulations considered the impact of two cladding materials with different water storage capacities (storing more or less water when exposed to rain—namely brick and fiber cement panels, respectively). Water storage capacities of these cladding materials used in the simulations were taken 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 various levels, from 0.01 to 50 US perms. Cross sections of typical wall assemblies used in simulations are shown in *Figures 3* and *4*.

In the first series of simulations, drying rates were calculated by setting the wood sheathing moisture content (MC)—the moisture content at which fungal deterioration can occur—to 28%, 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 in *Figures 5* to *8*. Walls with

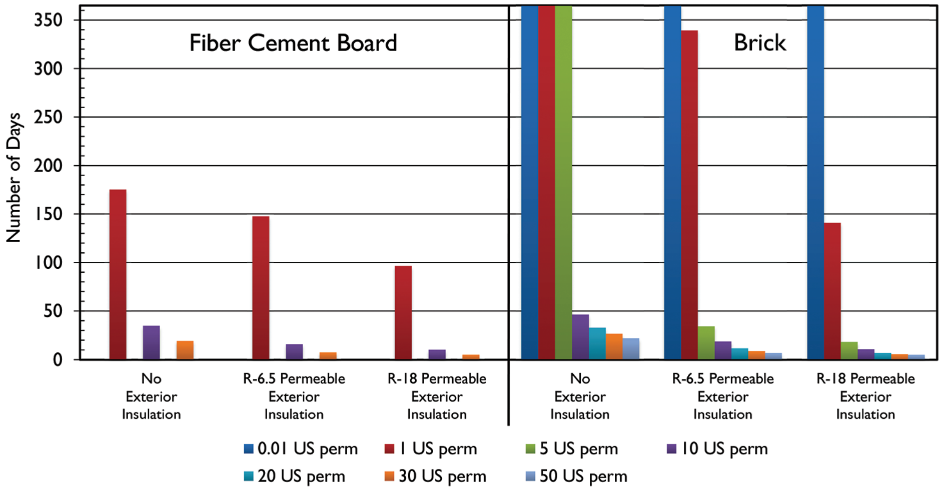


Figure 6 – Days required to dry plywood sheathing to 20% MC in Québec City – Zone 6.

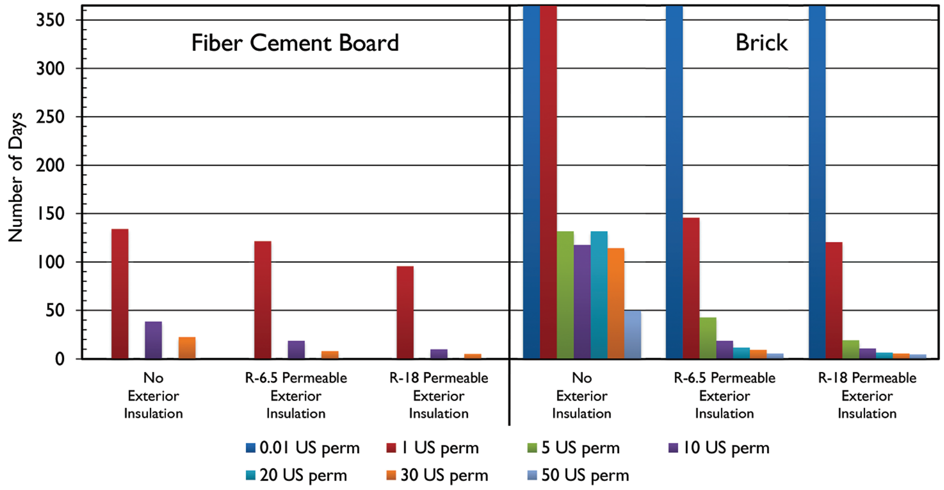


Figure 7 – Days required to dry plywood sheathing to 20% MC in Toronto – Zone 5.

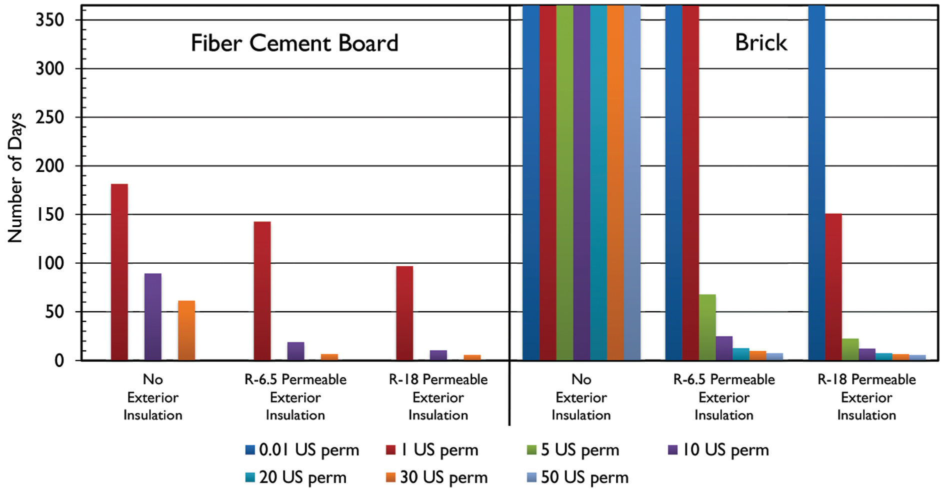


Figure 8 – Days required to dry plywood sheathing to 20% MC in Vancouver – Zone 4C.

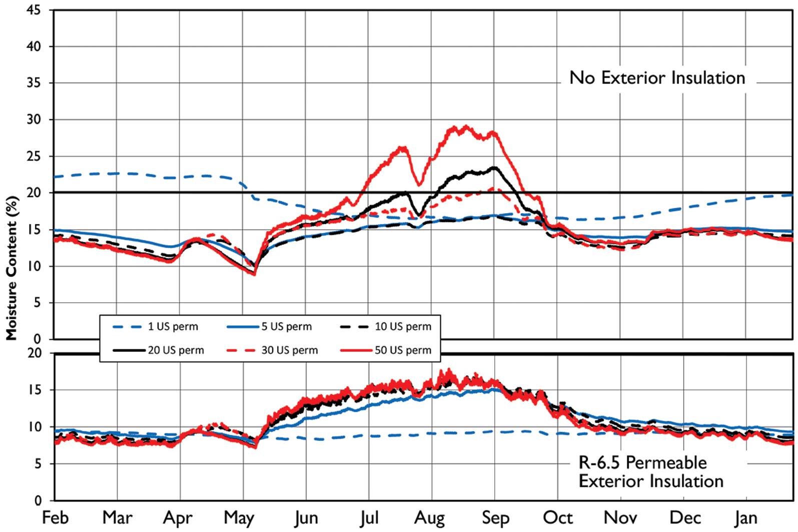


Figure 9 – Annual evolution of sheathing MC in Edmonton – Zone 7.

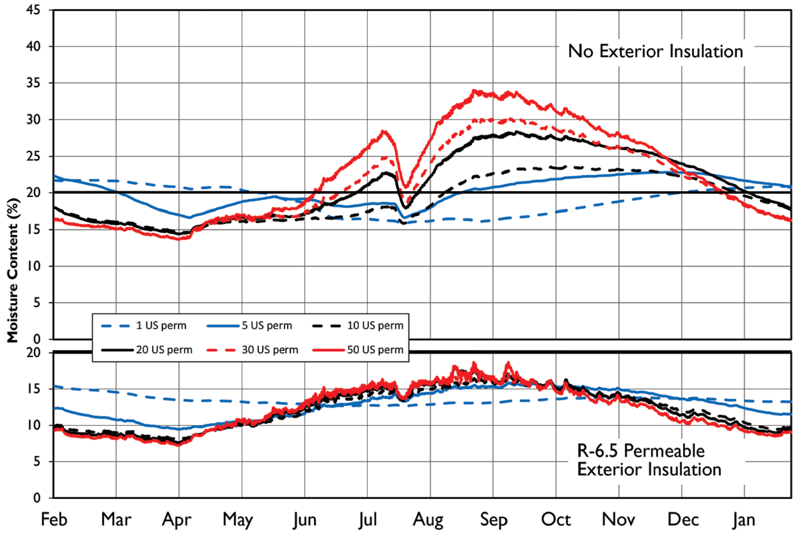


Figure 10 – Annual evolution of sheathing MC in Québec City – Zone 6.

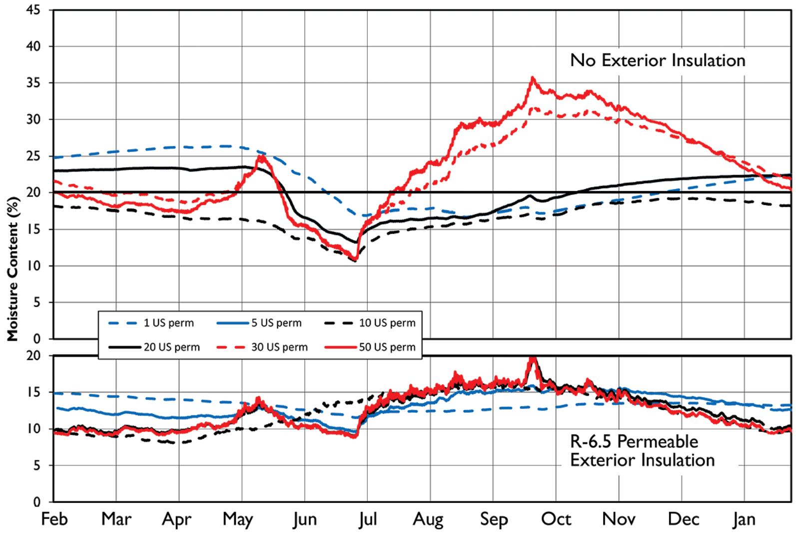


Figure 11 – Annual evolution of sheathing MC in Toronto – Zone 5.

impermeable exterior insulation (not shown) are double vapor retarders; according to the simulation results, they do not dry within a one-year period, regardless of the membrane permeance. They were therefore excluded from the remaining portions of our study.

Results indicate that adding permeable insulation to any wall assembly accelerates the drying time, irrespective of the cladding material and climate zone. Insulated walls are kept at a higher temperature than their noninsulated counterparts at all times. Because water vapor pressure increases with increasing temperature, moisture in insulated walls will escape faster by diffusion.

With the exception of the Vancouver simulation without exterior insulation, results indicate that wall assemblies had measurable differences in drying rates, correlated to the vapor permeance of the air barrier membrane. As expected, the greater the permeance of the membrane, the higher the drying rate. However, although membrane permeance has a large impact on the drying rates below 5 US perms, improvements achieved by increasing membrane permeance above 10 US perms are small. In some assemblies without exterior insulation, the difference in drying time between a 10-US-perm and 50-US-perm membrane is as little as two extra days.

Functionally, the difference between selecting a “high” permeability or “very high” permeability membrane has a lesser impact on the drying time of the wall than other design considerations, such as the type of cladding or use of exterior insulation.

SEASONAL MOISTURE VARIATIONS

In a second series of simulations, the long-term moisture performance was assessed by running the model for several years until annual equilibrium was reached; that is, repeatability between successive seasons is achieved. These simulations were intended to validate the impact of inward vapor drive into wall assemblies and the relative importance of this phenomenon versus drying rate. Assemblies with fiber cement cladding were not included in this portion of the study, as inward vapor drive of these assemblies is not significant due to a low moisture storage capacity.

To examine the yearly impacts of the climate on the sheathing performance in these systems, the sheathing moisture content of assemblies with and without exterior insulation is plotted for a complete year in *Figures 9* to *12*. Note that the 20% moisture level is emphasized on these plots, and that any assembly for which sheathing moisture content is above that 20% mark is subject to mold growth if the temperature is between 4°C (39.2°F) and 35°C (95°F). It is, therefore, highly desirable to maintain moisture content of the sheathing below 20% at all times.

Assemblies Without Exterior Insulation

Analysis of the annual plywood moisture content of assemblies not using exterior insulation reveals that, with the exception of Edmonton, moisture content of the plywood remains above 20% for at least half of the year, regardless of membrane permeance. In the Edmonton climate, the risk of mold growth caused by inward vapor

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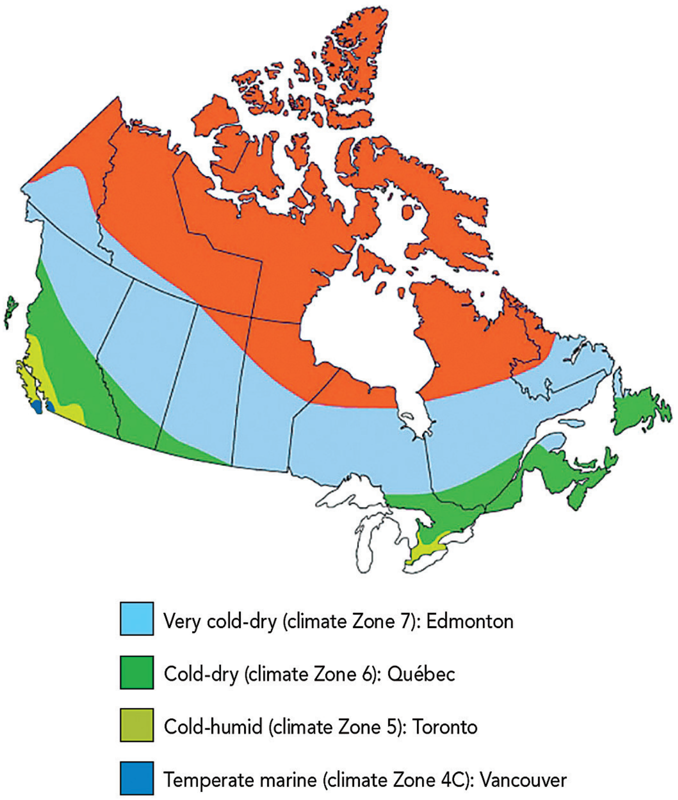


Figure 2 – Cities selected for the hygrothermal simulations and their ASHRAE climate zones.

drive is significantly reduced, as most curves remain below 20% for a greater part of the year or even the complete year. Interestingly enough, assemblies with highly permeable membranes (20 US perms and above) are the worst performers when used in these assemblies, with plywood moisture content very commonly reaching above 30%. Assemblies with membranes of permeance below 5 US perms are also at greater risk.

In all climate zones, assemblies constructed with the 10-US-perm membrane offer the best performance and lowest moisture contents. In Toronto and Edmonton, these assemblies maintain plywood moisture content below 20% throughout the year without any additional insulation.

The perception that higher-permeance materials are always best performers because they allow faster drying is proven wrong. When inward vapor drive can be expected, higher-permeance membranes not only allow faster drying, but also faster wetting. The entire wetting and drying capacities of these assemblies must be taken into account to predict their behavior over long periods.

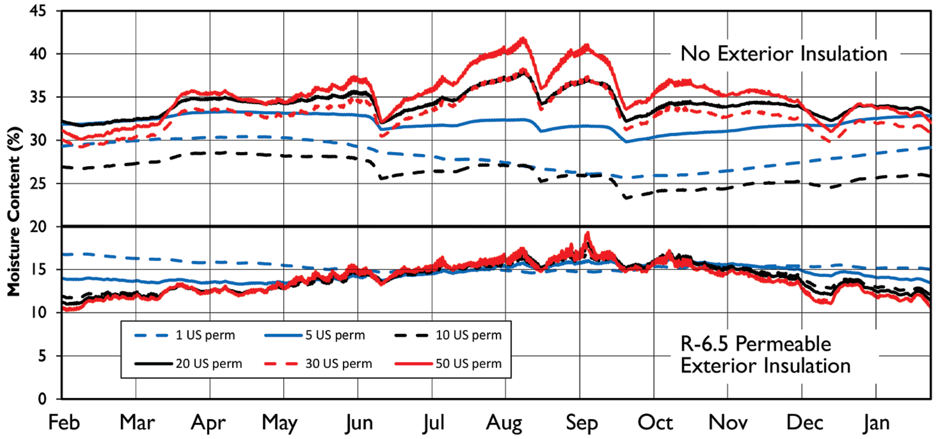


Figure 12 – Annual evolution of sheathing MC in Vancouver – Zone 4C.

Assemblies With Permeable Exterior Insulation

The addition of permeable exterior insulation—even only a small amount (R-6.5)—provides significant benefit to the hygrothermal behavior of these wall assemblies. In all climate zones, the use of R-6.5 permeable exterior insulation brings plywood moisture content below 20% at all times (with the exception of a few days in Toronto). With these assemblies, all curves are much closer to one another, indicating that membrane permeance has a negligible impact on the performance of these walls.

Not only is the use of continuous exterior insulation considered best practice for energy efficiency, it also provides tangible benefits to the hygrothermal behavior of wall assemblies like the ones studied here.

CONCLUSION

Prevention of moisture problems is the first and most important step to 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 bulkwater 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 bulkwater 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 contribute greatly.

The wetting and drying characteristics of exterior wall assemblies are complex, and there is no universal solution. As demonstrated, the thickness and type of exterior insulation and other materials, including the cladding and interior vapor control layer, will often have more impact on the hygrothermal behavior of exterior wall assemblies, leaving little influence to permeance of the materials used in these assemblies.

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 the right conditions are met. 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, membranes with permeance above 10 US perms are subject to diminishing returns, whereby increasing their permeance yields smaller and smaller benefits to drying.

Resorting to high-permeance membranes is not 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. But there are situations where wetting and drying regimes of assemblies will be better served by a "moderate" permeance membrane in the range between 5 and 20 US perms.

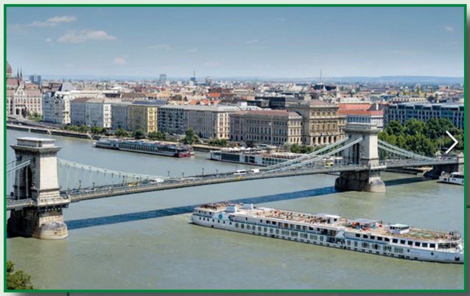
Consequently, specifying and positioning the vapor control layer must be done holistically with the design of the enclosure. That includes considering other properties of the vapor-permeable air barrier membrane, including the following:

- Adhesion performance
- Sealability around penetrations
- Resistance to UV
- Need for primer (and impact on permeance)

Jean-François Côté

Jean-François Côté holds a PhD in materials science from INRS-Université du Québec, obtained in 1998. In his current role, he represents Soprema on technical committees of industry associations (ARMA, PIMA, SPRI) and is actively engaged in various North American standards development organizations. He is chair of the CSA A123 technical committee on Bituminous Roofing Materials, and is co-chair of the ASTM D08.04 Subcommittee on Felts, Fabrics and Bituminous Sheet Materials.

— GREEN ROOF RIVER CRUISE IS A FIRST —



The first green roof terrace in the river cruise industry was installed on the *Crystal Mozart*, owned by Crystal Cruises. Sailing along the Danube River between Germany, Austria, Switzerland, and Hungary, passengers on the riverboat can now enjoy the living garden, installed by ANS Global and AD Associates. Installation took only three days to complete. The roof is made up of multiple individual ANS Grufekit green-roof modules, each containing everything needed, from a water reservoir and drainage layer to the soil and vegetation. The tiles clip together to make the system lightweight and easy to install. ANS Global planted alpine species of plants such as *Erica*, a low-growing evergreen shrub; and herbs such as Goldmoss stonecrop, a tufted perennial that forms mat-like stands.

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