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DYNAMIC WATER VAPOR PERMEANCE OF BUILDING MATERIALS AND THE BENEFITS TO BUILDINGS

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ABSTRACT

Knowledge of building materials' water vapor transmission properties is critical to proper building design. The standard version of ASTM E96 does not adequately describe water vapor transmission properties of building materials. Simple modifications to the current standard can be made that allow for measurement of water vapor permeance over a range of relative humidity.

Information on the benefits of building materials that have a variable vapor permeance in typical exterior-wall assemblies will be provided. Examples of wall assemblies in various climate zones to help validate the benefits of variable vapor permeance when exposed to different relative humidity levels will be explained.

SPEAKER

MARYSUSAN COUTURIER — W.R. GRACE & Co.

MARYSUSAN COUTURIER is a senior research chemist with W.R. Grace. She has over 20 years of experience working in research and development with polymers. Her work has included structural adhesives for the automotive and construction industry, sealants for the food packaging industry, and air barriers for the construction industry. She received her B.A. in chemistry from Regis College, completed her master's in plastics engineering at the University of Massachusetts, and is a member of the Society of Plastics Engineers. She holds two patents on polymer compositions.

CRAIG BOUCHER — W.R. GRACE & Co.

CRAIG BOUCHER has worked in the construction product industry for over 10 years. He has witnessed ASTM E96 testing and several other building material tests at third-party labs and participates in the ASTM committees that developed the standards. He is on the technical committee and board of directors of the Air Barrier Association of America and participates in the Underwriters Laboratories of Canada Committee on Air Barrier Materials and Systems. Mr. Boucher has made presentations on building materials at CSI and AIA meetings and trade shows. He has a B.S. in civil engineering from Worcester Polytechnic Institute and is a LEED Accredited Professional.

DYNAMIC WATER VAPOR PERMEANCE OF BUILDING MATERIALS AND THE BENEFITS TO BUILDINGS

BACKGROUND

The use of air barriers to prevent air leakage, moisture problems, and energy loss is becoming accepted in the construction industry. Air barriers minimize hot air leaking into the building in the warmer summer months due to thermal gradients, as shown in *Figure 1*. Air barriers also limit warm air from leaking out of the building in the colder winter months, as shown in *Figure 2*.

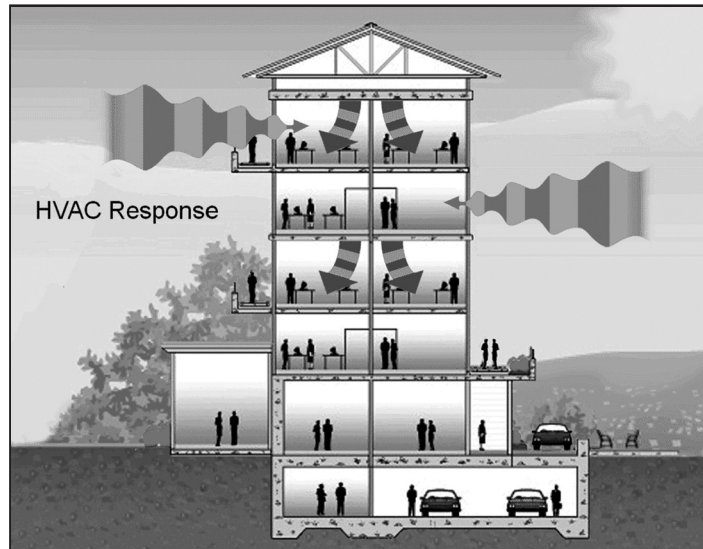


Figure 1 – Air leaking into building.

Measurement of air resistance of air barrier materials and assemblies is pretty straightforward, with the most common methods being ASTM E2178 and ASTM E2357. Depending upon the type of material being used, air barriers can have varying water vapor permeance, from impermeable to permeable. Understanding the water vapor permeance of the air barrier being used in a building envelope is very important to ensure the building envelope does not trap moisture in undesirable locations or materials that can lead to moisture damage of the building envelope.

Water vapor permeance is calculated from the water vapor transmission rate (WVTR) through a material and is not as straightforward a property to measure as it would appear. McCullough¹ compared five standard test methods for measuring WVTR of materials: ASTM E96B, ASTM E96BW, JSL 1099, ASTM F1868, and ASTM F2298. She concluded that although there were some correlations within the test results, the data from one test to another are not comparable, and the reason why the differences exist is not clearly understood. For the most part, the building science industry tends to use ASTM E96 for measuring WVTR of building materials. In simple terms, this method measures the rate of water vapor transmitting through a material when exposed to a vapor drive.

ASTM E96 basically uses a dish with the material being evaluated sealed to the top of the dish. As shown in *Figure 3*, ASTM E96 provides six test conditions that can be used to evaluate the material. Each test condition may not provide similar results for a material. There is a wide range in temperature and relative humidity (RH) that can greatly affect gas transport properties of materials.

In the Desiccant Method, the RH varies from 0% to 50%, and the vapor drive is into the cup. For the Water Method (or wet cup), the RH varies from 50% to 100%, and the vapor drive is out of the cup. Conditions C, D, and E use either the Desiccant or Water Methods with elevated temperatures. Increasing the temperature for polymeric materials may cause a change in the thermal expansion, gas diffusion, and solubility coefficients. Therefore, results from one temperature and material type will not correlate with another test condition or material.

er test condition or material.

The 2009 International Building Code (IBC)² provides three levels of classification for vapor retarders and permeance, based on ASTM E96A, the Desiccant Method. Type I has water vapor permeance of ≤ 0.1 perms. Type II is >0.1 and ≤ 1 perms, and Type III is

Figure 2 – Air leaking out of building.



Method	Basic Identifier	Basic Test Conditions	Temperature
A	Desiccant	Cup 0% RH, Outside 50% RH	73.4F
B	Water	Cup 100% RH, Outside 50% RH	73.4F
BW	Inverted Water	Water in direct contact with test specimen	73.4F
C	Desiccant	Cup 0% RH, Outside 50% RH	90 F
D	Water	Cup 100% RH, Outside 50% RH	90 F
E	Desiccant	Cup 0% RH, Outside 50% RH	100F

Figure 3 – ASTM E96 test conditions.

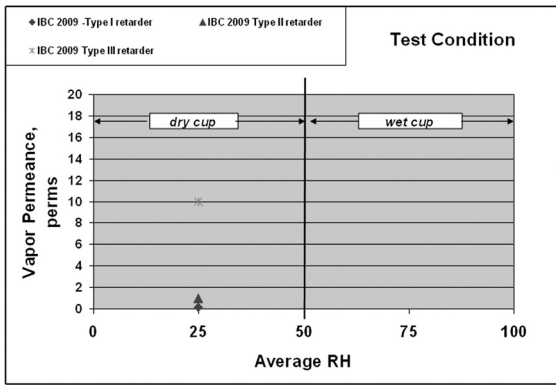


Figure 4 – 2009 IBC classifications for water vapor permeance and test conditions of vapor retarders.

ASTM E96: Air velocity	Cup RH	Chamber RH	Average RH	Water vapor
E 96 A Desiccant	CaCl ₂ (anh.) 0%	Room 50%	25%	Into the Cup
E 96 B Water	Water 100%	Room 50%	75%	Out of the Cup
Experimental	CaSO ₄ (anh.) 0%	CaCl ₂ ·6H ₂ O 32 %	16%	Into the Cup
Experimental	CaCl ₂ ·6H ₂ O 32 %	Room 50%	41%	Into the Cup
Experimental	NaCl 75%	NaBr 58%	66.5%	Out of the Cup
Experimental	KCL 84%	NaCl 75%	79.5%	Out of the Cup
Experimental	Water 100%	KCL 84%	92%	Out of the Cup

Figure 6 – Salt solutions and relative humidity conditions used in the experiment.

>1 and ≤10 perms. The 2009 IBC also defines a vapor permeable membrane as a membrane that permits the passage of moisture vapor and has a permeance greater or equal to 5 perms based on ASTM E96A, the Desiccant Method. As shown in Figure 4, classifying based on the dry cup will not always reveal the material's behavior under conditions of high relative humidity, which may be the more critical condition. With some materials, one datum point will not provide sufficient information as to how the material will behave over the entire relative humidity range it will be exposed to in a building.

In order to determine how different air barrier material technologies performed from low to very high relative humidity exposures, a set of experiments was conducted. The air barrier technologies evaluated were these:

1. Asphaltic-based peel-and-stick membrane
2. Nonasphaltic-based peel-and-stick membrane
3. Liquid, spray-applied air barrier

cup. The cups were placed in a chamber. The relative humidity of the chamber was controlled to create the relative humidity condition outside of the cup. By creating differing relative humidity conditions both inside the cup and outside of the cup (i.e., in the chamber), a number of varying test scenarios can be run.

ASTM E104 lists equilibrium relative humidity values for selected saturated aqueous salt solutions and provides guidance on how to make the solutions. Young⁵ and Dean⁶ are additional references for humidity control using saturated salt solutions. The standard Desiccant and Water Methods from ASTM E96 were used in conjunction with six additional experimental relative humidity conditions, ranging from

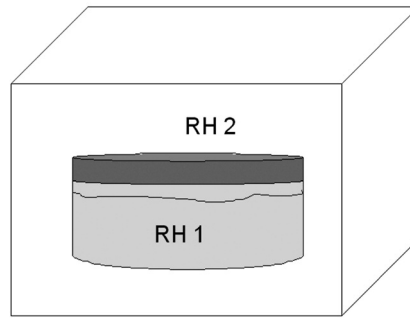


Figure 5 – Basic chamber conditions.

All of the testing was done under isothermal conditions.

TEST PROCEDURE

Simple modifications to ASTM E96 can be employed to measure the water vapor permeance of a material at different relative humidity exposures. The technique used for this evaluation is based on Timusk³ and Kuishan⁴, using saturated salt solutions to create differing relative humidity conditions inside and outside of the cup as shown in Figure 5. The saturated salt solutions were placed inside of the cup with the material being evaluated sealed to the top of the

low to high. The test conditions used are listed in Figure 6.

Since the hydrating reaction for these salts is exothermic, the salt solutions were created a minimum of one day prior to starting the tests. This was done to avoid confounding the results with temperature variations. The relative humidity inside the cup was measured using a blank cup with the same salt solution covered with an impermeable membrane, as shown in Figure 7.

It is important to note that the salt solutions can be corrosive, so the use of plastic or glass containers and not steel or aluminum is recommended to prevent corrosion in the cup that could impact the data. The process for measuring WVTR per ASTM E96 is to weigh the cups to determine if water vapor has exited or entered the cup. Introduction of corrosion to the testing could affect the weight measurements and, therefore, the WVTR data.

The cups and test chambers were stored in a laboratory controlled at 70°F (21°C) and 50% RH. For the test chambers, standard plastic coolers or ice chests were used. A small, 5-cfm fan was mounted within the coolers to maintain adequate air circulation as prescribed in ASTM E96, between 0.066 and 1 ft/second, as shown in Figure 8. The temperature and relative humidity inside the chamber were monitored using a Dickson data logger. This allowed for continual measurement of temperature and relative humidity for the duration of the experiments. The cups rested on a plastic rack in

the cooler above the saturated salt solution. The cups were weighed twice a day, and water vapor permeance was calculated as prescribed in ASTM E96. The weight loss was plotted over time, and the slope of the line was

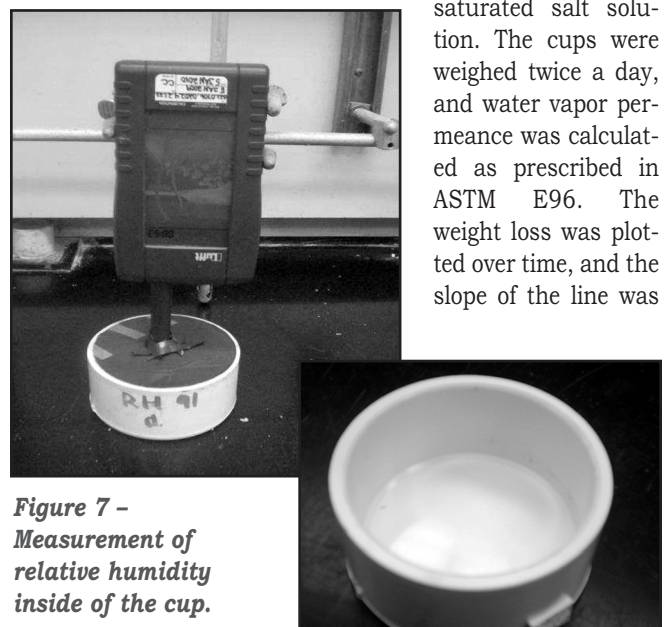
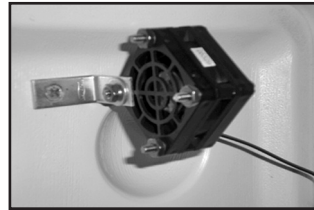
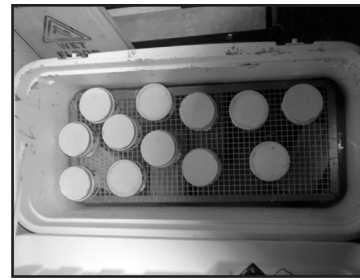


Figure 7 – Measurement of relative humidity inside of the cup.

used to calculate the water vapor transmission rate.

For some materials, a change in slope with time existed. When this occurred, the final slope was used for the water vapor permeance calculations. Reasons for the change in slope will be discussed later in the paper. The water vapor permeance is calculated by dividing the WVTR by the product of the saturation water vapor pressure times the change in relative humidity.



ASTM E96: Air velocity over specimen - Between 0.066 to 1 ft/sec

Figure 8 – Test chambers and fan used inside test chambers to maintain proper air circulation in accordance with ASTM E96 requirements.

RESULTS

Results of water vapor permeance vs. relative humidity for three air barriers are shown in Figure 9. Not all air barriers perform the same as they are exposed to different relative humidity conditions. Depending upon the material type, either a static or dynamic response can be obtained. Static materials exhibit a linear response to relative humidity, and dynamic materials exhibit a nonlinear response to relative humidity in the case of material 3 (liquid, spray-applied air barrier), an exponential response to relative humidity.

DISCUSSION

For static-type materials, water vapor permeance is based solely on Fickian diffusion. Measuring permeance under dry cup conditions will give a fairly accurate prediction under wet cup or other relative humidity conditions. Materials that show a dynamic response to relative humidity exhibit both a diffusion and solubility interaction coefficient. Gretton⁷ and Chang⁸ also discuss this non-Fickian behavior. Materials that contain polar groups will exhibit molecular attractions with the water vapor. This dual effect is the explanation for the slope change in the WVTR mentioned earlier in the paper; one is for diffusion, and the other is for solubility. This solubility or interaction coefficient changes with the amount of water vapor present and is dependent upon the chemistry of the material. In this situation, basing performance upon dry cup results could result in inaccurate

recommendations for humid conditions.

For example, Figure 4 shows the classification and test methods for vapor retarders in the 2009 IBC. Figure 10 shows vapor permeance testing results for 1) asphaltic-based, self-adhered air barrier and 2) nonasphaltic-based, self-adhered air barrier, in addition to the 2009 IBC classification and test methods for vapor retarders. Basing the vapor retarder classification of the materials shown in this example solely on water vapor permeance using the Desiccant Method of ASTM E96 is acceptable for these materials that have a static response to relative humidity.

For static materials, using the Water Method or Desiccant Method of ASTM E96 is acceptable because the water vapor permeance does not change drastically with relative humidity. However, the same is not true for materials that have a dynamic water vapor permeance response to relative humidity. Referring to Figure 11, using the Desiccant Method of

ASTM E96 to characterize a material's performance would not be accurate. In this example, under 2009 IBC, the air barrier material is characterized as a Type II vapor retarder with a permeance of >0.1 and <1. However, under conditions of high humidity, this air barrier material is not a vapor retarder, but permeable to water vapor. At an average RH of 75%, the water vapor permeance is 12 perms, and at 90% RH, the water vapor permeance is around 30 perms. Clearly, this is not a vapor retarder, but quite the

opposite at high levels of relative humidity. Characterizing a material's behavior under conditions of low relative humidity appears to be of much less importance than under high relative humidity conditions. It is under high moisture conditions where vapor drive and building design are critical.

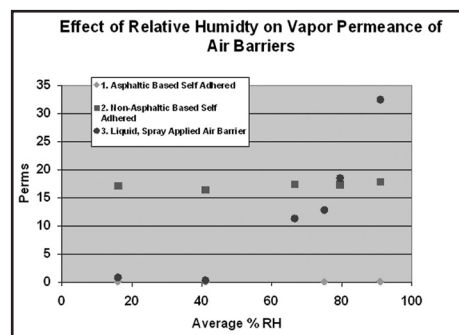


Figure 9 – Results of water vapor permeance vs. relative humidity testing for three types of air barrier materials.

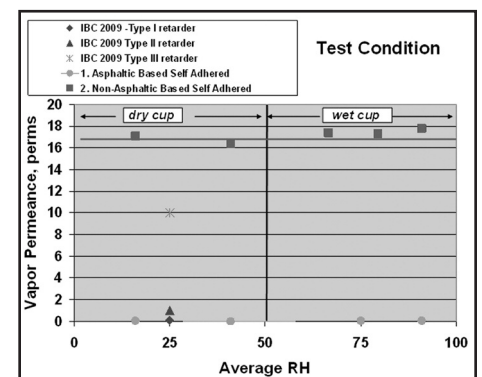


Figure 10 – Examples of static response to relative humidity.

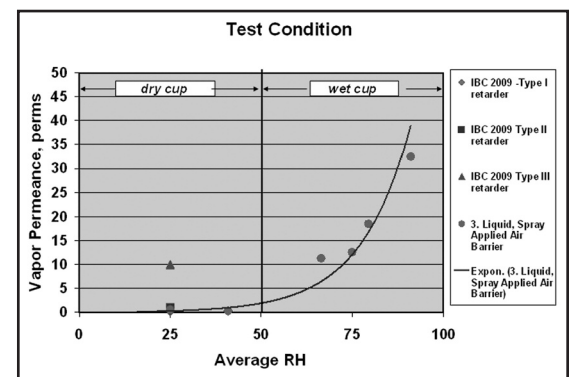


Figure 11 – Example of potential incorrect characterization of a material's water vapor permeance when only one datum point is evaluated.

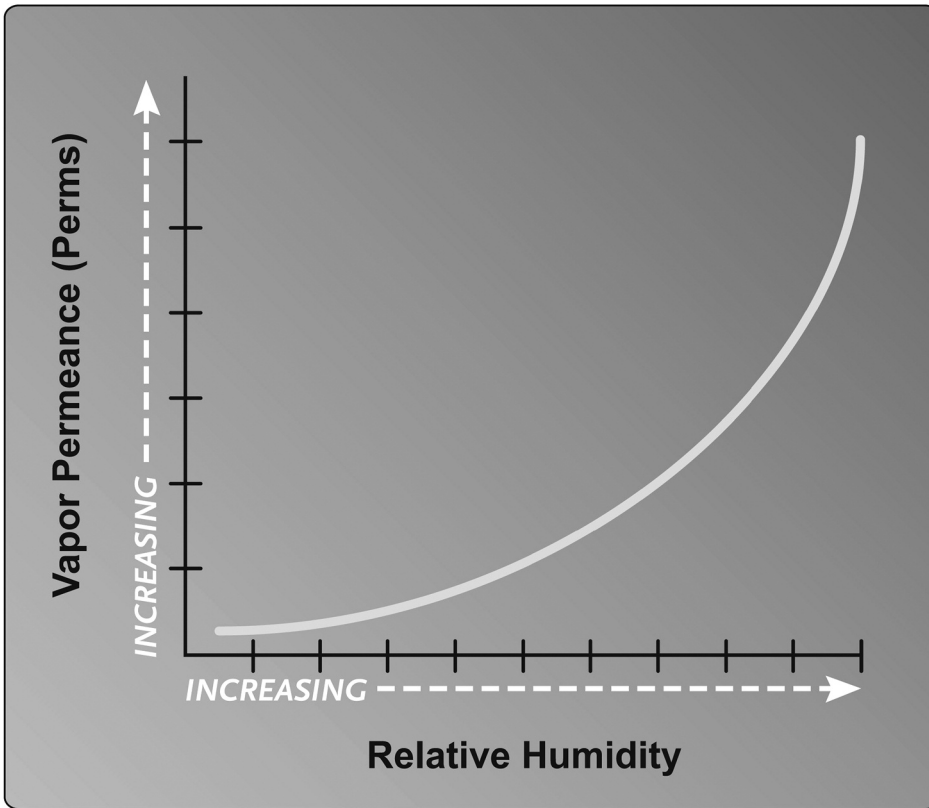


Figure 12 – Typical water vapor permeance of a material with a dynamic response to relative humidity.

Using one datum point at low relative humidity can lead to improper material choice. Materials with variable water vapor permeance are not new to the industry; plywood and Kraft paper are typical examples. Kumaran⁹ has published an extensive report on hygrothermal properties of building materials. However, knowledge of these properties and inputting them into the modeling software are critical to achieving proper building design.

APPLICATION OF INFORMATION

Basing building design solely upon dry cup results for dynamic materials could result in inappropriate material selections for building envelopes. For example, if an air barrier material with a dynamic response to relative humidity, as shown in *Figure 12*, is chosen as a water vapor barrier for a hot, humid-exterior climate based solely on the ASTM E96 Method A, Desiccant Method, there may be issues in the building. If the air barrier is installed on the exterior side of a moisture-sensitive insulation or other moisture-sensitive building components, then those moisture-sensitive building components may become exposed to moisture. As the exterior climate becomes more humid, the air barrier material is exposed to higher levels of relative

humidity and may allow excess water vapor to diffuse into the building. This excess moisture may lead to moisture damage in the building over time.

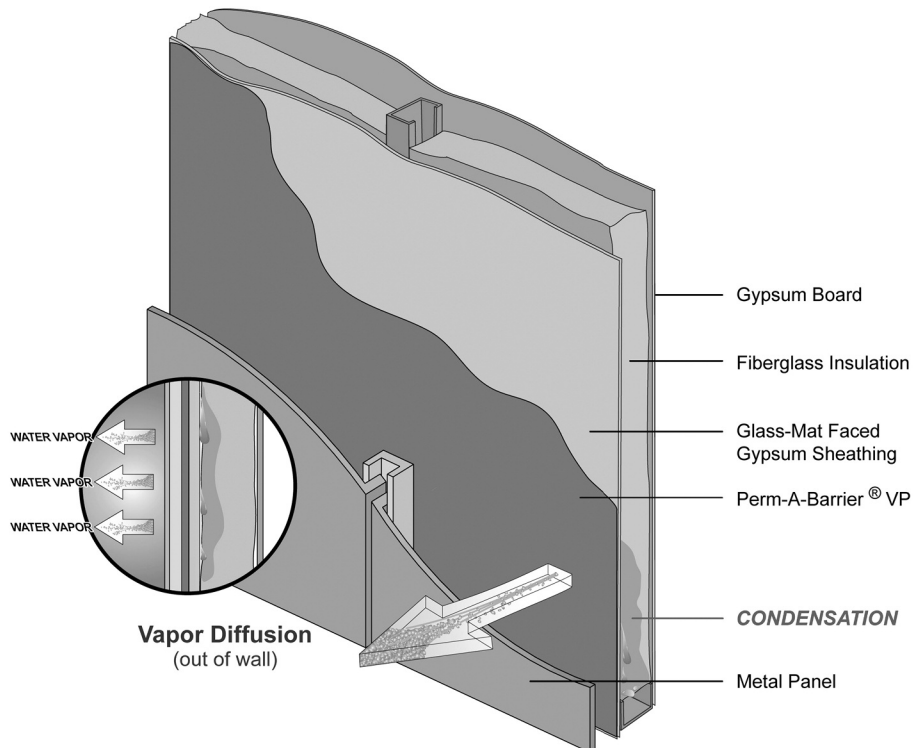


Figure 13 – Air barrier with a dynamic water vapor permeance allowing condensation moisture to diffuse out of a wall.

For static materials, using one datum point for water vapor permeance, such as ASTM E96 Method A, Desiccant Method, or Method B, Water Method, may provide as much information as needed because the water vapor permeance does not change drastically with relative humidity. However, the same is not true for dynamic-type materials.

The testing discussed above provides a significant amount of information about the building materials' water vapor permeance over a broad range of conditions. This information can be used to make better exterior building envelope design decisions.

EXAMPLES OF BENEFITS OF DYNAMIC WATER VAPOR PERMEANCE

The following couple of paragraphs provide some examples of how a material with a dynamic water vapor permeance may be beneficial in building envelope construction. This paper does not provide examples of the benefits of static water vapor permeance materials. However, past experience and successful performance of static water vapor permeance materials have shown that those types of materials are fit for use in building enclosures. Material with dynamic and static water vapor permeance attributes can be used in building enclosures to achieve the desired performance.

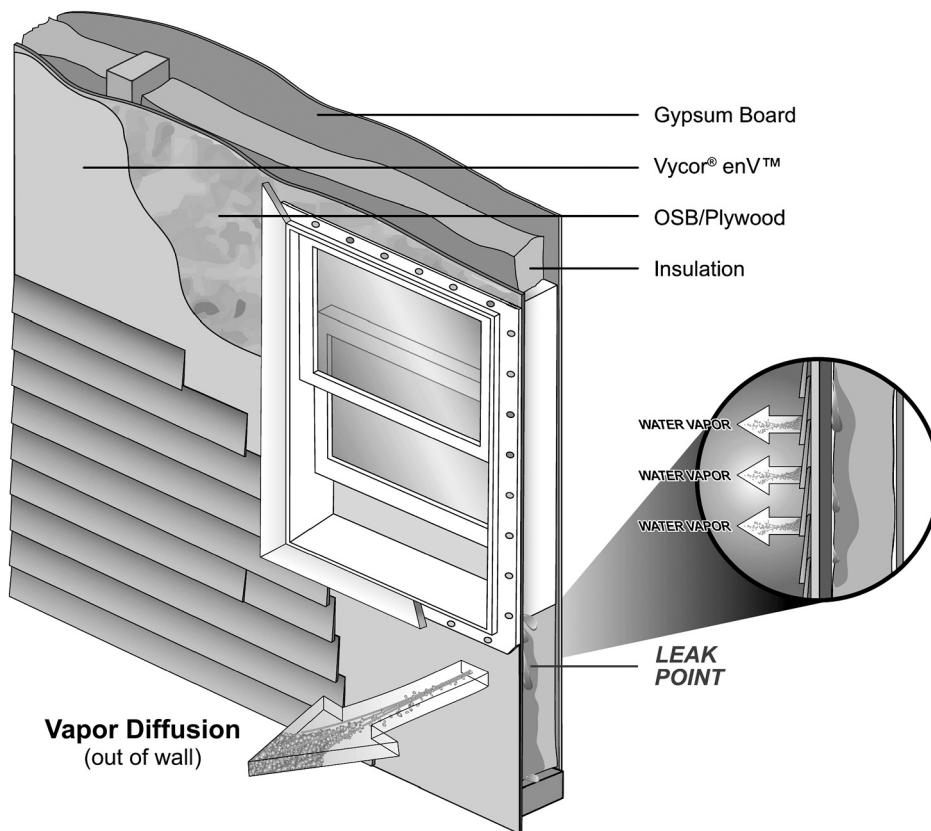


Figure 14 – Air barrier with a dynamic water vapor permeance allowing moisture from a water leak to diffuse out of a wall.

Understanding the attribute of the material with respect to water vapor permeance is important to ensure the material chosen is suitable for the building envelope design.

For the first example, consider a building in Minnesota. In the winter months, most of Canada and the United States, including Minnesota, will experience weather conditions in which the exterior of the structure is colder and less humid than the interior. These differences in temperature and relative humidity can lead to air and moisture drive from the interior of a building toward the colder and drier exterior conditions.

If there is a small air leak in the air barrier assembly, at an exterior outlet box or light fixture, for example, then air will leak out of the building. As warm, moist air moves from the interior toward the exterior, the air may cool down as it passes through air-permeable insulation materials and may potentially reach its dew point. If the dew point is reached in the wall assembly, then water in the air will condense at the interior surface of the gypsum sheathing as shown in *Figure 13*. If the gypsum sheathing gets saturated by the condensation, then an air barrier applied onto the exterior surface of the gypsum sheathing will be

exposed to a high level of relative humidity – effectively 100% RH.


The previous portion of this paper identified materials, such as air barriers, that have a dynamic water vapor permeance when exposed to different levels of relative humidity. An air barrier with a dynamic water vapor permeance that increases as relative humidity increases may be beneficial for the condition shown in *Figure 13*. As the gypsum sheathing gets wet due to condensation, the air barrier will increase its water vapor permeance to allow the moisture to diffuse out of the wall. This attribute of the air barrier may help dry the exterior wall assembly in the short term, but an air leak that results in condensation in the wall assembly must be repaired to ensure the building does not experience excessive moisture damage.

Another benefit of an air barrier with a dynamic water vapor permeance is facilitating a dry wall assembly, should there be a water leak into the structure. Bulk water intrusion into the wall assembly may occur at a defect in window installation, as shown in *Figure 14*, or other penetrations through the wall. If the fiberglass insulation and OSB or plywood get wet due to a water leak in the wall, then the water vapor permeance

of an air barrier, which increases in water vapor permeance as relative humidity levels increase, will increase to help dry out the wall. The air barrier at this point will allow water vapor to diffuse out through the wall to facilitate drying of the wall. Facilitating rapid drying of the wall could help prevent mold growth, rot, and decay of moisture-sensitive elements within the wall assembly if the water leak is repaired quickly.

It is important to point out that water vapor diffusion, even at high water vapor permeance levels, is relatively slow in terms of moving large quantities of moisture. Water vapor diffusion will not remove enough moisture from the wall cavity to keep up with a liquid water leak into the building envelope. The liquid water leak will allow far more moisture and water to enter the wall cavity in the example shown in *Figure 14* than water vapor diffusion will be able to remove under normal conditions. Therefore, as indicated in the paragraph above, the water leak will need to be repaired quickly to prevent significant damage in the building envelope.

CONCLUSION

Materials used in the construction of building envelopes may have a dynamic or static water vapor permeance response when exposed to varying levels of relative humidity. Measuring the water vapor permeance of a material over a wide range of relative humidity levels is achievable. Understanding the water vapor permeance response of a material to different relative humidity levels is important in selecting materials for the building enclosure. 

REFERENCES

1. E. McCullough, M. Kwon, and H. Shim. "A Comparison of Standard Methods for Measuring Water Vapour Permeability of Fabrics," *Measurement Science and Technology*, 14: 1402-1408. 2003.
2. ICC International Building Code, 2007 Supplement. IBC-4.
3. P.C. Timusk, K.D. Pressnail, and V.F. Striesky. "Moisture-Related Properties of Oriented Strand Board." *10DBMC International Conference on Durability of Building Materials and Components*, Lyon. 2005.
4. L. Kuishan, Z. Xu, and G. Jun. "Experimental Investigation of Hygrothermal Parameters of Building Materials Under Isothermal Con-

- ditions." *Journal of Building Physics*. Vol. 32, No. 4. 2009.
5. J.F. Young. "Humidity Control in the Laboratory Using Salt Solutions - A Review." *Journal of Applied Chemistry*. Vol. 17. 1967.
 6. J.A. Dean. *Lange's Handbook of Chemistry* (15th Edition). McGraw-Hill, Table 11.4. 1999.
 7. J.C. Gretton, D.B. Brook, H.M. Dyson, and S.C. Harlock. "A Correlation Between Test Methods Used to Measure Moisture Vapour Transmission Through Fabrics." *Journal of Coated Fabrics*, 25, pp 301-310. 1996.
 8. S.C. Chang, S. Sask, and N.B. Hutcheon. "Dependence of Water Vapor Permeability on Temperature and Humidity." National Research Council, Canada, Division of Building Research, *Research Paper No. 21*. 1956.
 9. M.K. Kumaran, J. Lackey, N. Normandin, D. van Reenen, and F. Tariku. "Summary Report from Task 3 of MEWS Project." Institute for Research in Construction, National Research Council, Ottawa, Canada, (NRCC-45369), pp 1-68. 2002.