Considerations for Design Criteria to Minimize MOISTURE WITHIN WALLS

By Colin Murphy, FRCI, RRC

Introduction

The necessary factors for successful design, construction, and long-term performance of building envelope systems often are summarized (see *Figure 1*) by the four Ds: deflection, drainage, drying, and durability (or decay resistance).[1] In recent years, however, there has been an increased worldwide focus on the mechanisms of moisture exchange between components within a wall (or roof) assembly.

Many common building materials are "hygroscopic"; i.e., initially dry samples will absorb moisture from the air until they reach an equilibrium moisture content ("EMC") corresponding to ambient conditions.[2] Typically, the EMC level is considered a function of relative humidity ("RH");[3] that is, an increased RH level will result in increased EMC level for each material, and vice versa. Thus, changes in ambient conditions, particularly RH, cause the construction materials to undergo "hygrothermal" interactions with their surroundings, resulting in an ongoing process of moisture exchange (gain or loss) within the wall and roof assemblies. The rates of these hygrothermal interactions typically are evaluated as a function of relative humidity;[4] that is, at increased RH levels, more moisture (liquid or vapor) can be exchanged, and vice versa.

These advancements in understanding require us to evaluate more closely the design, function, and positioning of the typical moisture barriers within the wall assembly.

History

The development of the standard "vapor retarder" installation dates back to the 1920s:

- "One of the first researchers to recognize the need of vapor retarders and air leakage control was Barrett in 1923. By the 1930s, a range of insulations and building papers were (sic) available."[5]
- "In the late 1920s, with the advent of refrigeration, Dr. Frank Rowley (from the University of Minnesota) ...recommended cold-side ventilation in frame construction and called for vapor barriers, after conducting a research project with the National Mineral Wool Association."[6]

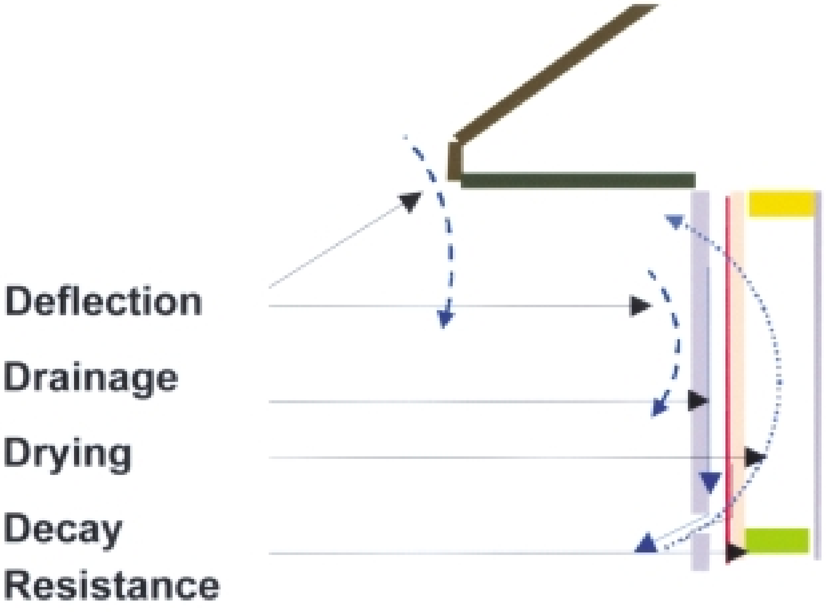

Figure 1: The four Ds of wall design.

- "In 1948, Dr. Rowley revised the issue of vapor control, and demonstrated that the introduction of plywood to replace board sheathing increased airtightness, and thus increased indoor relative humidity and created the need for the new measures of vapor barriers and attic ventilation. Around 1950, a new material, 'polyethylene,' was introduced into construction."[7]
- "In 1948, the U.S. Housing and Home Finance Agency (a forerunner of the current Federal Housing Administration) held a meeting attended by representatives of building research organizations, home builders, trade associations, and mortgage finance experts on the issue of condensation control in dwelling construction. The focus of the meeting was on vapor diffusion in one- and two-family frame dwellings in cold weather climates. The consensus and result of that meeting was the Prescriptive Rule to place a vapor barrier (now called a vapor retarder) on the warm side of the thermal insulation in cold climates. The meeting also established that a vapor barrier (retarder) means a membrane or coating with a water vapor permeance of one Perm or less."[8]

Note that the formal industry-wide emphasis in 1948 on the importance of vapor retarders did not bring similar attention to the critical role and function of air barriers.

"The 1948 rule was based on the assumption that diffusion through envelope materials and systems is the governing mechanism of moisture transport leading to condensation in and eventual degradation of the building envelope. Since 1948, and particularly since about 1975, research conducted in this country and abroad has brought recognition that infiltration of humid air into building wall cavities and the leakage of rainwater are significant, in many cases governing mechanisms of moisture transport. Accordingly, the original simple rule with a limited scope has been expanded to include air infiltration and rainwater leakage, and to cover other climates and building and construction types. The current, expanded prescriptive rules can be summarized as follows:

- Install a vapor retarder on the inside of the insulation in cold climates,
- Install a vapor retarder on the outside of the insulation in warm climates,
- Prevent or reduce air infiltration,
- Prevent or reduce rainwater leakage, and
- Pressurize or depressurize the building so as to prevent warm, moist air from entering the building envelope."[9]

"The current expanded rules have greatly increased the validity and usefulness of the prescriptive rules. However, the rules still do not fully recognize the complexities of the movement of moisture and heat in building envelopes. For example:

- The emphasis on either including or omitting a separate vapor retarder is misplaced, and the contribution of the hygrothermal properties of other envelope materials on moisture flow are not considered. In fact, incorrectly placed vapor retarders may increase, rather than decrease, the potential for moisture distress in building envelopes.
- Climate as the only determining factor is inadequate to establish whether a vapor retarder should or should not be installed. Indoor relative humidity and the moisture-related properties of all layers must also be considered.
- The two climate categories 'cold' and 'warm' have never been adequately or consistently defined, and large areas of the contiguous United States do not fall under either cold or warm climates."[10]

Thus, over the past half-century, industry efforts to control moisture movement have "progressed" from the development of the vapor retarder (originally designed to prevent moisture condensation resulting from the migration of warm, humid interior air into the cooler wall and roof cavities found in cold weather climates) to the additional widespread use of felt, "building paper," or "housewrap" (materials with widely varying permeance and hygroscopicity) to control and channel infiltration of exterior moisture at the cladding.

We also now witness the common use of structural sheathing systems, including multi-layered assemblies of both engineered wood and exterior gypsum panels (again, materials with widely varying permeance and hygroscopicity), that produce greatly increased airtightness (and decreased vapor permeance) of the exterior wall, further limiting moisture exchange (both inward and outward).

- Review of published product data indicates, at standard levels of RH and ambient moisture, both plywood and OSB have roughly comparable vapor "permeance" (permeability divided by thickness) values of 0.45 to 1.45 "perms"[11], more or less, depending on specific product composition.
- A typical published value for the permeance of 1/2" exterior gypsum sheathing is 40 perms;[12] however, gypsum sheathing has significantly less moisture storage capability (i.e., the ability to store moisture during "wet" periods for later release during "dry" conditions) than plywood or OSB.[13]
- As noted above, as the moisture content of plywood or OSB panels increases, there are exponential (and significantly differing) increases in their moisture exchange properties;[14] thus, simple comparisons of typical published perm "ratings" for plywood, OSB, and gypsum sheathing do not provide acceptable design guidance.

Figure 2: Severe deterioration at unvented "cold wall" clad with stucco on both sides.

Furthermore, many of the new sheathing products are designed to provide even greater resistance to moisture exchange from the exterior to the interior.

- Published data[15] indicate standard 5/8" type "X" exterior gypsum sheathing has 260% more vapor permeance potential than G-P Gypsum 5/8" Dens-Glass Gold Fireguard® sheathing. A similar perm rating decrease is reported by U.S. Gypsum for its "Aqua Tough" Fiberock® sheathing.[16] Both companies, of course, are focused on the value of erecting even stronger barriers to moisture infiltration from the exterior.
- Note that the increasingly common practice of taping the sheathing joints also results in a significant decrease in moisture exchange performance, both inward (which is good) and outward (which can result in trapping moisture within the wall).

Similarly, the permeance values for the typical "self adhering membranes" commonly used to seal wall penetration perimeters and other wall transitions are very low, effectively blocking any moisture exfiltration from the wall at these joints, an area at which there typically is less insulation and a varying dew point.

In addition, "new" wall systems, such as EIFS, have resulted in reduced vapor permeance at the exterior face.

- "EIFS are (sic) relatively vapor impermeable (the combined permeance of the finish coat, base coat, and 50 mm of EPS insulation can be less than 60 metric perms)."[17] (60 metric perms equal one U.S. Perm.)

At the same time, increases in insulation usage and performance have significantly affected typical wall cavity temperatures, potentially increasing the temperature differentials that can drive moisture movement.

A motivating force for all of these developments has been an "Energy Code" focus on minimizing heat loss from the interior. For example, the state of Washington, like many of the nations' local and state governing bodies, requires: "Vapor retarders shall be installed on the warm side (in winter) of insulation as required by this section."[18] There are only limited exceptions to this mandate, even though the climate extremes in the state, like the United States, range from desert to temperate rain forest.[19]

The end result is a typical modern "cold wall" comprised of external layers of relatively tight, reduced-permeance materials sandwiching substrate components that, due to changes in construction methods and declines in construction quality, often are wet at the beginning of the wall's service life and commonly suffer additional localized infiltration of rainwater and vapor. Moreover, once this moisture has infiltrated the interior components of the wall assembly, it cannot be efficiently exfiltrated due to weakened moisture exchange mechanisms brought about by modern wall designs.

Note the deterioration in *Figure* 2 of an unvented "wing wall" clad on both sides with stucco installed over exterior gypsum sheathing and 60-minute paper. This is a true "cold wall," detached from any interior heat source to help drive moisture to the exterior. Unless venting provisions are designed into this wall, any infiltration of rainwater or solar-driven vapor will result in severe deterioration; yet, such installations are not uncommon.

In effect, while our current typical wall assemblies are designed theoretically to improve moisture deflection and drainage, it is another of the above noted 4 Ds — drying performance — that often has been sacrificed to achieve these gains. In many cases, the trapped moisture results in significant decreases in wall durability or decay resistance.

Note that Section 502.1.1 of the 2000 *International Energy Conservation Code* also requires the vapor retarder to be installed on the "warm-in-winter" side of the insulation; however, a much greater range of exceptions is allowed, including: "hot and humid climates" and "where other approved means to avoid condensation in unventilated framed wall, floor, roof, and ceiling cavities are provided."[20]

Discussion - Air Barriers and Vapor Retarders

The primary functions of air barriers and vapor retarders[21] often are confused, yet the distinctions are critical:[22]

- A **vapor retarder** is designed to impede moisture vapor diffusion (i.e., the natural force that drives individual moisture vapor molecules from areas of high concentration toward areas of low moisture concentration). Note that localized deficiencies in the vapor retarder installation will not greatly increase rates of vapor diffusion.
- An **air barrier** is designed to limit airflow, which transports quantities of moisture vapor via convection (i.e., it is air movement due to air pressure differentials that physically conveys the moisture vapor). Similar in concept to a balloon, a breach in the air barrier can result in significant movement of air and moisture; thus, the overall integrity of an interior air barrier is critical.
- "The differences in the significance and magnitude of vapor diffusion and air-transported moisture are commonly misunderstood. Air movement as a moisture transport mechanism is typically far more important than vapor diffusion in many (but not all) conditions...The quantity of vapor diffusing through a building component is a direct function of the surface area. For example, if 90% of the area of an envelope wall is covered with a vapor retarder, then the vapor diffusion retarder is 90% effective. A punctured polyethylene film with several tears will act as an effective vapor retarder, whereas, at the same time it is a poor air retarder."[23]
- While the air barrier and the vapor retarder requirements can be addressed in the same material application (e.g., taped and sealed sheets of 6-mil polyethylene), the installations may be better designed as distinctly separate layers within the wall assembly.

Note that the air convection process exchanges moisture vapor via air pressure differentials (high to low), while moisture diffusion occurs from wet to dry and warm to cold. Depending on conditions, the direction of these various forces within the wall assembly may be opposing or complementary.

As a recent Building Science Corporation publication[24] points out, these moisture exchange forces are universally governed by the Second Law of Thermodynamics, which describes the inevitable entropic tendency for all matter and energy in the universe to devolve from more to less.

Clearly, the simple Energy Code requirement to install a vapor retarder on the warm side (in winter) of the insulation does not begin to address the complexities of the issue. The potentially fatal flaw for a typical vapor retarder installation in "cold" climates is its fundamental assumption that the vapor drive (from more to less) always occurs from the interior toward the exterior. Yet, scientific analysis and common sense inform us of many situations in which the direction of the vapor drive can be from the exterior to the interior, creating the potential for excessive condensation at the back side of the vapor retarder. For example:

- "Moisture trapped in or behind the cladding can be transported into the enclosure by solar-driven diffusion, especially in air-conditioned buildings. Rather than control vapor diffusion, a 6-mil vapor retarder close to the interior may, in many instances, exacerbate wetting and greatly retard drying."[25]
- "It is clear that any wet material (which will have an RH of 95% to 100%) that is heated by the sun will generate large inward vapour drives."[26]

In summary, while installation of an air barrier to conserve energy and control convective moisture exchange certainly is both hygroscopically and economically sound, the similar installation of a vapor barrier (or retarder) can be problematic unless: a) we are certain which side of the vapor retarder is subject to moisture condensation, and/or b) we have introduced design features to mitigate the reduced drying performance of our typical modern wall.

"The key point that needs to be made is that although air barriers are a good idea everywhere, vapor barriers are not."[27]

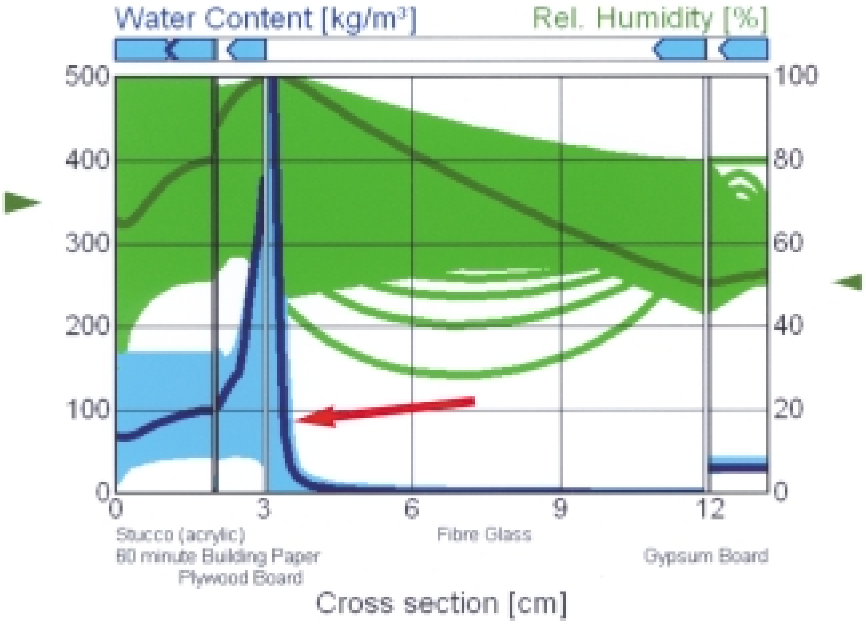

Figure 3: WUFI/ORNL/IBP analysis for March 2002 of south-facing wall assembly (stucco cladding and plywood sheathing) at Seattle structure with no interior vapor retarder. Note (see arrow) the condensation (in blue) at the interior face of the plywood sheathing (Layer #3).

Furthermore, this summary becomes more complex when we consider the issue of "indoor air quality." Even when the probability of an inward vapor drive is acknowledged, designers still may require an interior vapor retarder to avoid the possibility of unacceptable interior RH levels that might promote unhealthy mold growth. In other words, a decision is made to increase the risk of deterioration of the wall assembly to lessen risks to the occupants' health.

Design Solutions

It is clear there are no simple solutions to the vapor retarder issue; however, as a first step, the use of available computer software that allows simple assessment of the hygrothermal characteristics and potential performance of the specific wall assembly is vital. The most advanced program that can be freely downloaded from the Internet is the "research and education" version of WUFI-ORNL/IBP.[28] It is important to note the WUFI software does not evaluate moisture exchange by air convection because the program is not designed to evaluate the effects of installation deficiencies.

"Since airtightness is an essential property of a building wall, air convection is in practice only found in unplanned cases of defective parts or inappropriate building components."[29]

The WUFI program, which also can be purchased in a "professional" version, allows comparative evaluation of the long-term moisture exchange performance of various wall designs under localized climatic conditions; thus, for a Seattle-area structure, one can specifically compare the hygroscopic effects of the installation of plywood vs. gypsum sheathing (which, as noted above, has significantly less moisture storage capacity than plywood or OSB) under stucco cladding over a two-year period, and explore the potential consequences of removing, repositioning, or respecifying the vapor retarder.

For example, *Figure 3* represents an analysis using the WUFI program of wall performance over a two-year period of a theoretical, south-facing stucco-clad wall (with plywood sheathing) in a Seattle, Washington, structure with high levels of interior moisture. The wall assembly has no vapor barrier installed on the warm side of the fiberglass batt insulation. There is also no interior finish (e.g., latex or PVA paint) on the interior drywall to reduce diffusion of interior vapor into the wall cavity. Thus, the system's only vapor retarder is the plywood sheathing on the cold side of the insulation. The result (in blue) during winter months is extreme condensation at the interior face of the plywood and saturation of the sheathing.

Further analysis reveals this condensation can be eliminated in a variety of ways, including reducing the interior moisture application of latex paint on the interior drywall, or installation of a polyethylene vapor retarder. Note that in many cases, the use of a polyethylene vapor retarder can be detrimental to overall performance of the wall system. "The results clearly depict the detrimental effect of the use of polyethylene as an interior vapor-control strategy when interior relative humidity is kept within a healthy range of 30-60%."[30]

Given the necessity (even if only for code requirements) for installation of a vapor retarder on the warm side of the insulation, designers can approach the issue of improving wall drying performance from several directions:

- Design the vapor permeance of the inner layers of the wall at a level that is "high enough to allow inward drying while still controlling outward-acting wintertime diffusion condensation."[31]
- Increase the overall vapor permeance of the exterior cladding, sheathing, and "weather resistive barrier" system. Note, for example, that compared to 15# felt, 60-minute asphalt-saturated building paper provides a superior range of vapor permeance. "At low relative humidities, the 15-lb building paper is quite impermeable, making any kind of vapor diffusion through it very slow."[32]
- Install a hygroscopic vapor retarder product. Unlike polyethylene, many vapor retarder products, ranging from kraft paper to the new "Smart Vapor Retarder" inspired by the WUFI program (see *Figure 4*)[33] can absorb significant quantities of moisture while providing greatly increased permeance at high RH levels. Thus, in "dry" conditions, the vapor retarder can serve as a barrier to moisture diffusion from the interior; however, if the wall becomes excessively "wet" or suffers solar-driven vapor from the exterior, this moisture can be partially released to the interior; however, if the wall becomes excessively "wet" or suffers solar-driven vapor from the exterior, this moisture can be partially released to the interior.

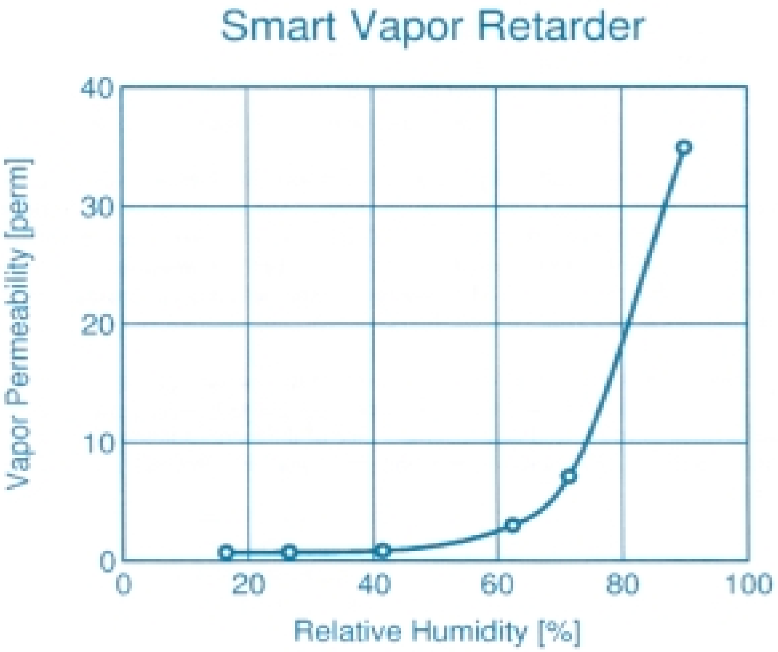

Figure 4: Vapor permeability of "smart" vapor retarder as a function of relative humidity

- Provide ventilation behind the cladding: "The heat capacity of air is so limited that little heat can be carried out of the air space by ventilation (unless there are very large and fast air flows)...Very small air flows can, however, transport significant quantities of moisture if they act for long enough. Because the air space in many walls is usually warmer and contains more moisture than the outdoor air, even small ventilation flows over many days have the potential to remove useful amounts of moisture."[34]

- Evaluate the use of insulation on the outside of the sheathing. An EIFS installation, for example, provides a significant temperature control mechanism for the inner wall, resulting in lessened temperature differentials than can drive moisture exchange.
- Install reflectance barriers on the outside of the sheathing to reduce the potential for solar-driven vapor drive.
- Eliminate thermal bridges (e.g., by installing "insulating sheathing" panels) within the wall assembly.
- Use more vapor permeable flashing materials, produced from PVC and TPO, that function to block free water infiltration while allowing exfiltration of trapped vapor.
- Avoid dark-colored cladding if solar gain is a concern.
- Use low permeance insulation materials, similar to many roofing assemblies, to provide the required vapor retarder.

"In roofing, the use of closed cell foam is very common, and this foam can provide the vapor resistance required to control diffusion even in very cold climates (as always, an air barrier system is still required)...Many closed-cell, spray-applied foams are sufficiently vapor resistant to obviate the need for a special vapor control layer. Structural insulated panel systems (SIPS) are another example of an enclosure system that almost never require a vapor barrier because of the combination of thickness and moderate permeability of the insulating material."[35]

Conclusions

Vapor retarders and low permeance building materials and systems are key components of many modern wall assemblies; yet, insufficient design attention has been paid to ameliorating the resulting loss of drying performance of the wall. In addition, many members of the building industry do not recognize the critically different functions of air barriers and vapor barriers.

Designers must recognize that a primary result of most of the past half-century's wall design advancements has been to shuffle the moisture exchange problem from one area of the wall assembly to another. Each new advance is loudly proclaimed as the final solution to a specific condition; however, the voices of those who analyze the overall moisture exchange effects of this "advance" are often overwhelmed by the cheerleaders for the new product or system.

At the fundamental level, designers must recognize that the tighter they make their walls, the more they need to design escape mechanisms for moisture (free water and vapor) that inadvertently breaches barriers. The most recent advances in materials and technology, such as the WUFI software, provide the knowledge and means to conclusively explore and resolve these issues.

Such analyses must factor in all physical properties, conditions, and forces (such as location, exposure, orientation,[36] the local "wind-driven rain coefficient,"[37] the "stack effect," and many others) that affect the moisture exchange performance of a wall system.

Designers must recognize both the similarities and differences between the moisture functions (exchange and resistance) of roof and wall systems. Even at the most fundamental level, such as the effects of gravity, the forces affecting horizontal or sloped roofs and vertical walls are quite distinct.

In the end, in the same manner that fire, "wind uplift," and other ratings are issued for designated wall and roof assemblies, the industry requires ratings for both moisture resistance and moisture exchange performance for specific wall assemblies in specific locations and conditions (interior and exterior). ■

Footnotes

1. D.G. Hazleden, "Designing for Durable Wood Construction: The 4Ds," *8th International Conference on Durability of Building Materials and Components,* Vancouver 1999. http://www.durable-wood.com/french/papers/The_4_Ds.doc
2. W. Simpson and A. TenWolde, "Physical Properties and Moisture Relations of Wood," *Wood Handbook,* Forest Products Laboratory, U.S.D.A., Madison, WI 1999. http://www.fpl.fs.fed.us/documents/FPLGTR/fplgtr113/Ch03.pdf
3. D. Burch and A. Desjarlais, *Water-Vapor Measurements of Low-Slope Roofing Materials,* National Institute of Standards and Technology, Gaithersburg, MD 1995. http://fire.nist.gov/bfrlpubs/build95/PDF/b95100.pdf
4. A. Karagiozis, "Impacts of Codes on Building Performance 'Moisture Control,'" Oak Ridge National Laboratory, 2001. http://www.energycodes.gov/news/2001_workshop/pdfs/karagiozis.pdf
5. J. Lstiburek, A. Karagiozis, and K. Ueno, "Feasibility of Establishing Criteria for Permeable Envelope and/or Non-Mechanical Ventilation for Detached Single One or Two Family Resident Construction," Building Science Corporation, Westford, MA 2002. http://www.admin.state.mn.us/buildingcodes/printouts/category%202/activity1.pdf
6. Ibid
7. Ibid
8. H. Treschel, ASTM Manual 40, *Moisture Analysis and Condensation Control in Building Envelopes,* ASTM International, 2001. http://www.astm.org/bookstore/MNL40PDF/Preface.pdf
9. Ibid
10. Ibid
11. One perm = 1.0 grain of water vapor transmitted per hour per square foot per 1.0 inch of mercury vapor pressure difference. One grain of water = 1/7000th of a pound.
12. http://www.commerce.state.mn.us/pages/Energy/Builders/pdfs/2000Stucco.pdf
13. See: A. Karagiozis and A. Desjarlais, *Building Enclosure Hygrothermal Performance Study, Phase 1,* Oak Ridge National Laboratory, Tennessee 2002.
14. Ibid
15. "Dry cup" testing per ASTM E-96. http://www.gp.com/gypsum/sheathing/codes.html
16. http://literature.usg.com/pdf/F135.pdf
17. J.F. Straube, "The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance," *Performance of Exterior Envelopes of Whole Buildings VIII,* ASHRAE, Florida 2001. http://www.buildingsolutions.ca/Downloads/
18. Washington Administrative Code, "WAC 51-11-1313 Moisture Control"

19. See http://www.buildingscience.com/housesthatwork/#Hygro for informative rainfall and hygrothermal maps of North America published by the Building Science Corporation.
20. 2000 *International Energy Conservation Code,* International Code Council, Inc., Virginia 2001
21. Performance distinctions between "barriers" and "retarders" are well reviewed in: J. Lstiburek, "Understanding the Terms 'Barrier' and 'Retarder' for Vapor and Air," http://www.buildingscience.com/resources/walls/understanding_barriers.pdf
22. An excellent discussion of these issues is provided by J.F. Straube, "The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance," *Performance of Exterior Envelopes of Whole Buildings VIII,* ASHRAE, Florida 2001 http://www.buildingsolutions.ca/Downloads/ASHRAE%20Thermal8%20Vapor%20Barriers.pdf
23. J. Lstiburek, A Karagiozis, and K. Ueno, "Feasibility of Establishing Criteria for Permeable Envelope and/or Non-Mechanical Ventilation for Detached Single One or Two Family Resident Construction," Building Science Corporation, Westford, MA 2002. http://www.admin.state.mn.us/buildingcodes/printouts/category%202/activity1.pdf
24. http://www.buildingscience.com/resources/walls/air_barriers_vs_vapor_barriers.htm
25. J.F. Straube and E.F.P Burnett, "Drainage, Ventilation Drying, and Enclosure Performance," *Thermal Performance of Exterior Envelopes in Buildings VII,* Florida, 1998, pp 189-198. http://www.buildingsolutions.ca/Downloads/
26. J.F. Straube, "The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance," *Performance of Exterior Envelopes of Whole Buildings VIII,* ASHRAE, Florida 2001. http://www.buildingsolutions.ca/Downloads/
27. http://www.buildingscience.com/resources/walls/air_barriers_vs_vapor_barriers.htm
28. http://www.ornl.gov/ORNL/BTC/moisture/index.html
29. "Moisture Transport in Building Materials, Computer Simulation with the WUFI Model," http://www.hoki.ibp.fhg.de/wufi/grundl_ueberblick_e.html
30. A. Karagiozis and A. Desjarlais, "Building Enclosure Hygrothermal Performance Study, Phase 1," Oak Ridge National Laboratory, Tennessee 2002
31. J.F. Straube and E.F.P Burnett, "Drainage, Ventilation Drying, and Enclosure Performance," *Thermal Performance of Exterior Envelopes in Buildings VII,* Florida, 1998, pp 189-198. http://www.buildingsolutions.ca/Downloads/
32. Ibid
33. http://www.nibs.org/BETEC/Pres/Desjarlais.pdf
34. J.F. Straube and E.F.P Burnett, "Drainage, Ventilation Drying, and Enclosure Performance," *Thermal Performance of Exterior Envelopes in Buildings VII,* Florida, 1998, pp 189-198
35. J.F. Straube, "The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance," *Performance of Exterior Envelopes of Whole Buildings VIII,* ASHRAE, Florida 2001. http://www.buildingsolutions.ca/Downloads/
36. E.g., C.R. Crocker, "Influence of Orientation of Exterior Cladding," *Canadian Building Digest,* CBD-126. http://www.nrc.ca/irc/cbd/cbd126e.html
37. E.g., J.F. Straube and E.F.P Burnett, "Simplified Prediction of Driving Rain Deposition," *Proceedings of International Building Physics Conference,* Eindhoven, Netherlands 2000, pp. 375-382. www.buildingsolutions.ca

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Colin Murphy, RRC, FRCI, founded Trinity Group Fastening Systems in 1981. In 1986, he established Trinity Engineering, focusing primarily on forensic analysis of roof systems, materials analysis, laboratory testing, and long-term analysis of in-place roof systems. The firm, formally known as Exterior Research & Design, LLC, Trinity Engineering, is based in Seattle, WA. Colin joined RCI in 1986 and became an RRC in 1993. In 1996, he was honored with the Richard Horowitz Award for excellence in technical writing for *Interface.* In 1998, RCI granted Colin the Herbert Busching Jr. Award for significant contributions to the general betterment of the roof consulting industry. In 2001, he was made a Fellow of RCI.