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AIR BARRIER EDUCATION TRACKS FOR THE CONSTRUCTION INDUSTRY

Evaluating the Effects of Air Barriers with Variable Vapor Permeance in Hygrothermal Analysis

Jodi Knorowski, P.E.

WDP & Associates Consulting Engineers, Inc.

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Jodi Knorowski, P.E.

jknorowski@wdpa.com

(434) 245-6117

www.linkedin.com/in/jodi-knorowski-38040032

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Learning Objectives

- Discuss the theory of transient hygrothermal analysis and the effect of variable vapor permeance
- Review the standardized testing procedures to measure vapor permeance of materials
- Discuss the testing conditions as they relate to installed conditions
- Assess the impact of the vapor permeance of an air barrier on a defined wall assembly

Outline

- Basic Moisture Movement Concepts
- Review of ASTM E96
- Hygrothermal Analysis
- Product Data for Air Barriers
- Case Study

Basic Vapor Movement Concepts

Hygrothermal Analysis

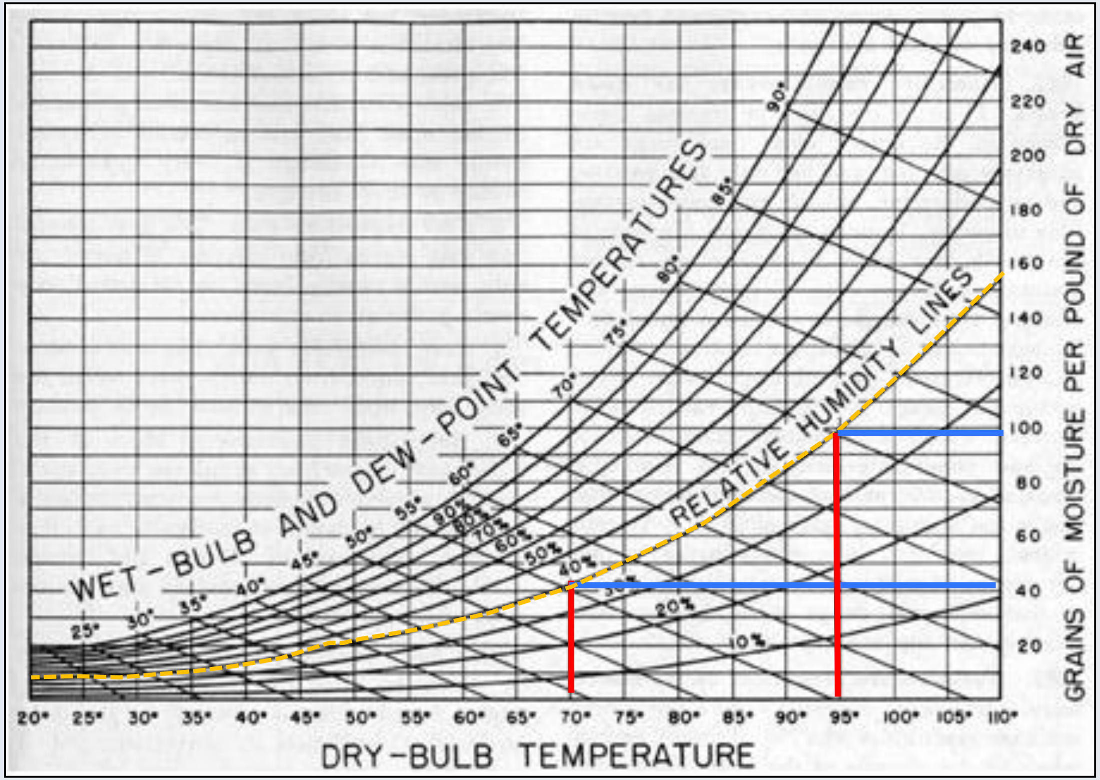
Study of how **heat** and **moisture** move *simultaneously* across a building envelope assembly

Ideal Gas Law

$$PV = nRT$$

P = *Pressure*
V = *Volume*
n = *Number of Moles*
R = *Universal Gas Constant*
T = *Absolute Temperature*

Psychometric Chart



70°F + 40% RH

=

~40 grains of moisture

95°F + 40% RH

=

~100 grains of moisture

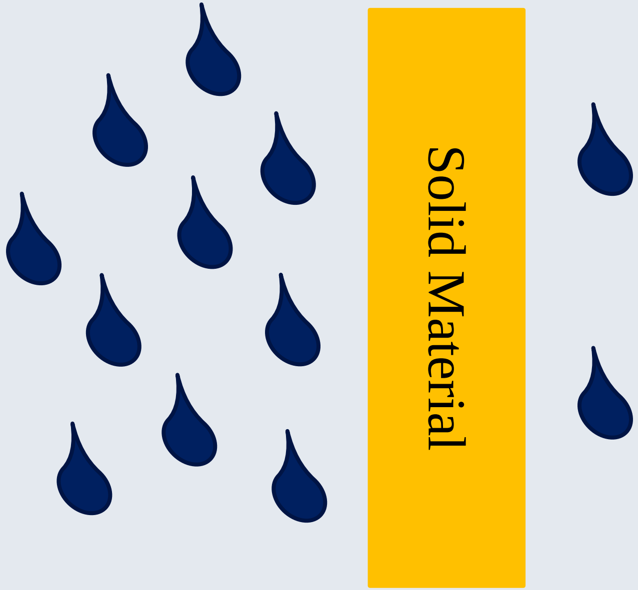
Relative Humidity is a function of temperature and moisture

Differences in temperature and moisture create a vapor pressure differential

What is “Vapor Diffusion”

- Rate of diffusion is function of the material’s vapor permeance
- Materials with **high permeance**, such as air or batt insulation, will **readily allow** water vapor to pass through
- Materials with a **low permeance**, such as metal, will **not readily allow** vapor to pass through

Vapor Diffusion

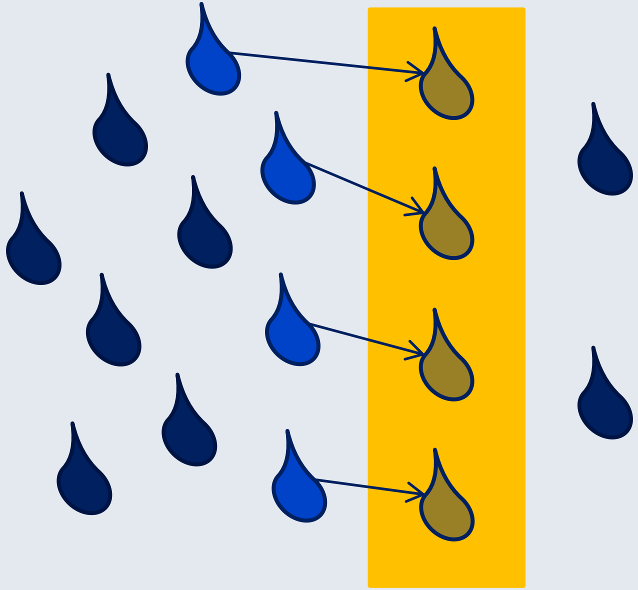


TIME: ZERO
Concentration on left = 10 molecules/volume of air
Concentration on right = 2 molecules/volume of air

A difference in concentration of molecules across a material creates a pressure difference

(Assuming equal temperature and volume)

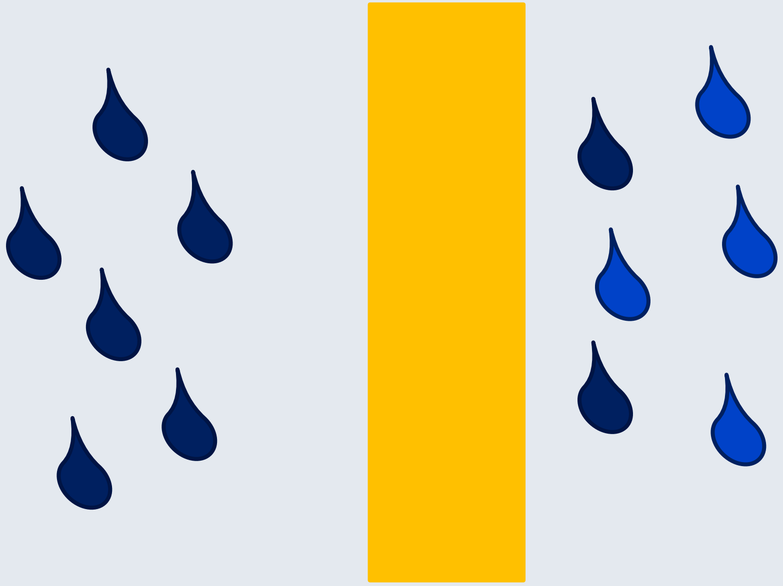
Vapor Diffusion



TIME: ZERO through FINAL
Concentration on left = decreasing
Concentration on right = increasing

Over time, the pressure difference forces the molecules from the area of high concentration to the area of low concentration through the pores of the solid material.

Vapor Diffusion



Once the concentration on one side is equal to the concentration on the other side, the pressure difference is resolved.

TIME: Final
Concentration on left = 6 molecules/volume of air
Concentration on right = 6 molecules/volume of air

What is "Water Vapor Permeance"

"The time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions"

$$\boxed{1\,perm = \frac{1\,grain\,of\,H_2O}{hr * ft^2 * inHg}}$$

Volume of Water

Vapor Permeance (Perms)	$\frac{\text{mL of Water}}{\text{1 hr * 1 ft}^2\text{ * 1 psi vapor pressure differential}}$
0.1	0.00132
1.0	0.13195
5.0	0.65976
10.0	1.31951
30.0	3.95853

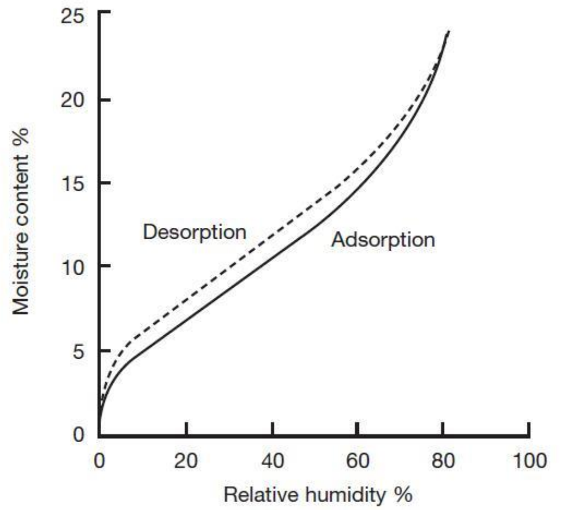
Hygroscopic Materials

- “Water Attracting” materials
- As relative humidity increases, hygroscopic material tend to take on moisture through a process called “sorption”
- Increase in moisture content of materials could impact vapor permeance of the material

Sorption Isotherm Curves

- **Show relationship between relative humidity and moisture content at constant temperature**

- **Developed by incrementally adjusting moisture level surrounding material and measuring actual moisture content at each change (ASTM C1498)**



A typical sigmoid (S-shaped) moisture sorption isotherm illustrating hysteresis

"Water Sorption Isotherm." *Food Network Solution*, Mar. 2008.

This International standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: E96/E96M – 16

Standard Test Methods for Water Vapor Transmission of Materials[1]

This standard is issued under the fixed designation E96/E96M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

Review of ASTM E96

1. Scope

1.1 These test methods cover the determination of water

plaster products, wood products, and plastics. The test methods are limited to specimens not over 1¼ in. [32 mm] in thickness except as provided in Section 9. Two basic methods, the Desiccant Method and the Water Method, are provided for the

C1809 Practice for Preparation of Specimens and Reporting of Results for Permeance Testing of Pressure Sensitive Adhesive Sealed Joints in Insulation Vapor Retarders

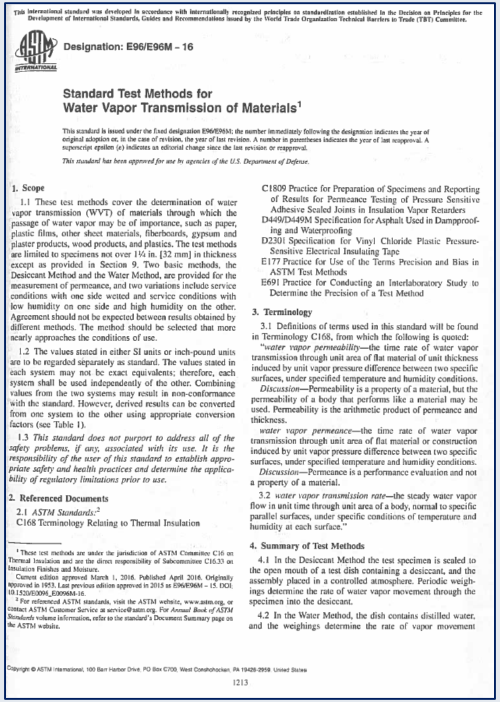
D2301 Specification for Vinyl Chloride Plastic Pressure-Sensitive Electrical Insulating Tape

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

ASTM E96

“Standard Test Methods for Water Vapor Transmission of Materials”

- **Determine water vapor transmission (WVT) of materials**
- **Two basic methods:**
  - **Desiccant Method (Procedure A/Dry Cup)**
  - **Water Method (Procedure B/Wet Cup)**



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1. Scope

1.1 These test methods cover the determination of water vapor transmission (WVT) of materials through which the passage of water vapor may be of importance, such as paper, plastic films, other sheet materials, fiberboards, gypsum and plaster products, wood products, and plastics. The test methods are limited to specimens not over 1¼ in. [32 mm] in thickness except as provided in Section 9. Two basic methods, the Desiccant Method and the Water Method, are provided for the measurement of permeance, and two variations include service conditions with one side wetted and service conditions with low humidity on one side and high humidity on the other. Agreement should not be expected between results obtained by different methods. The method should be selected that more nearly approaches the conditions of use.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. However, derived results can be converted from one system to the other using appropriate conversion factors (see Table 1).

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation

C1809 Practice for Preparation of Specimens and Reporting of Results for Permeance Testing of Pressure Sensitive Adhesive Sealed Joints in Insulation Vapor Retarders

D449/D449M Specification for Asphalt Used in Dampproofing and Waterproofing

D2301 Specification for Vinyl Chloride Plastic Pressure-Sensitive Electrical Insulating Tape

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 Definitions of terms used in this standard will be found in Terminology C168, from which the following is quoted:

"*water vapor permeability*—the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

Discussion—Permeability is a property of a material, but the permeability of a body that performs like a material may be used. Permeability is the arithmetic product of permeance and thickness.

water vapor permeance—the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

Discussion—Permeance is a performance evaluation and not a property of a material.

3.2 *water vapor transmission rate*—the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface."

4. Summary of Test Methods

4.1 In the Desiccant Method the test specimen is sealed to the open mouth of a test dish containing a desiccant, and the assembly placed in a controlled atmosphere. Periodic weighings determine the rate of water vapor movement through the specimen into the desiccant.

4.2 In the Water Method, the dish contains distilled water, and the weighings determine the rate of vapor movement

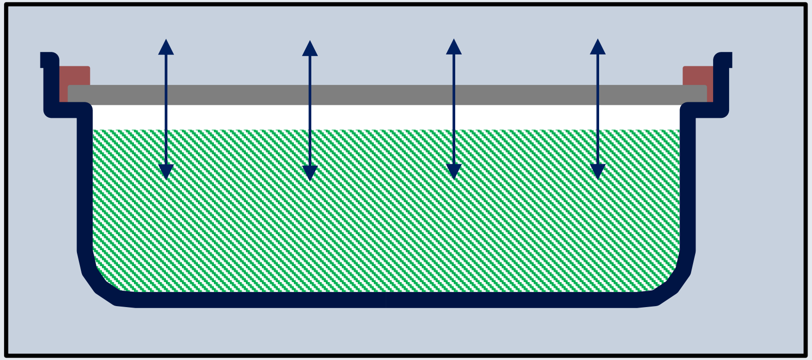
[1] These test methods are under the jurisdiction of ASTM Committee C16 on Thermal Insulation and are the direct responsibility of Subcommittee C16.33 on Insulation Finishes and Moisture.

Current edition approved March 1, 2016. Published April 2016. Originally approved in 1953. Last previous edition approved in 2015 as E96/E96M – 15. DOI: 10.1520/E0096_E0096M-16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Procedure

- Seal test specimen to a dish
- Create a vapor drive across the specimen
- Monitor the change in weight of the dish over time
- Determine rate of change in moisture in dish over time, area, and pressure difference

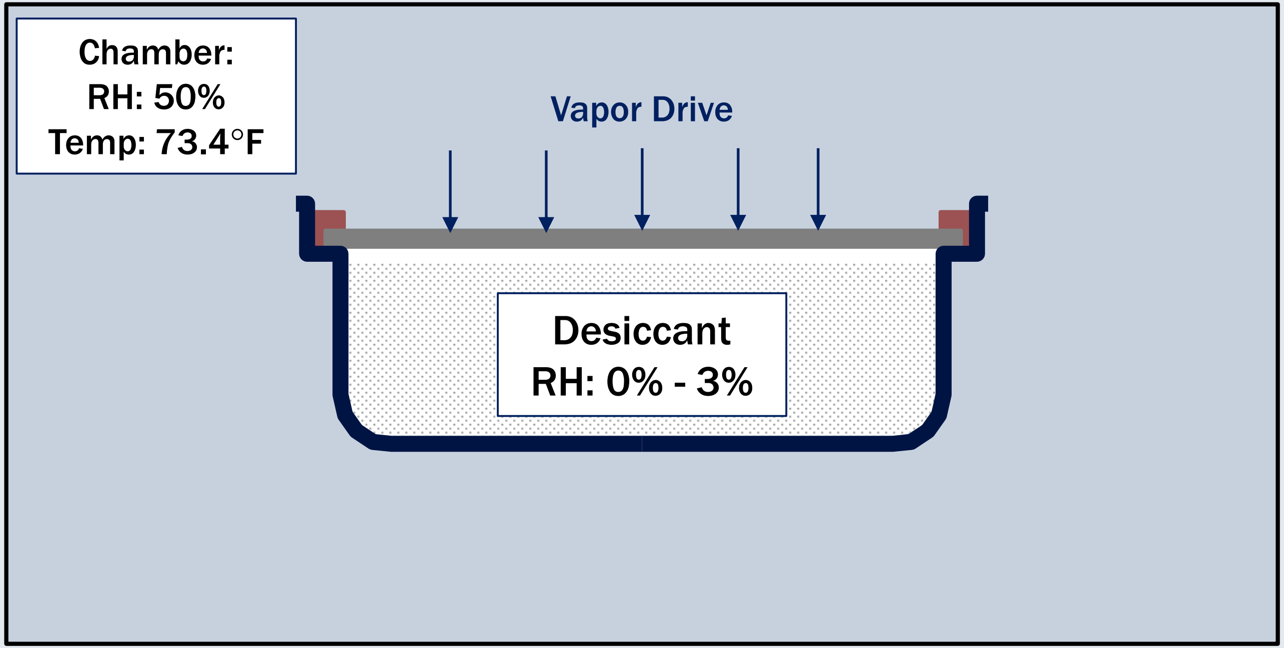


Calculating Vapor Permeance

$$Water\ Vapor\ Transmission = \frac{Slope\ of\ Line\ (\frac{grains}{hr})}{Test\ Area\ (ft^2)}$$

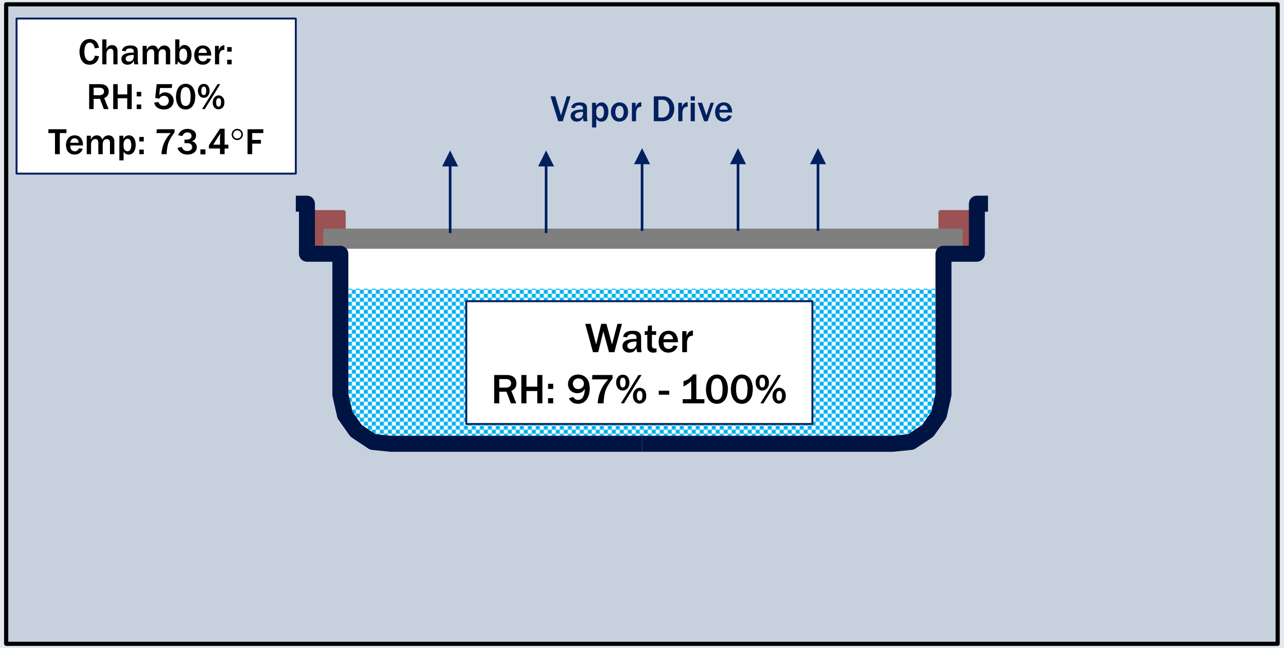
$$Permeance = \frac{WVT\ (\frac{grains}{hr * ft^2})}{\Delta P\ (in\ Hg)}$$

Desiccant Method



Maximum RH Exposure: 50%

Water Method



Maximum RH Exposure: 100%

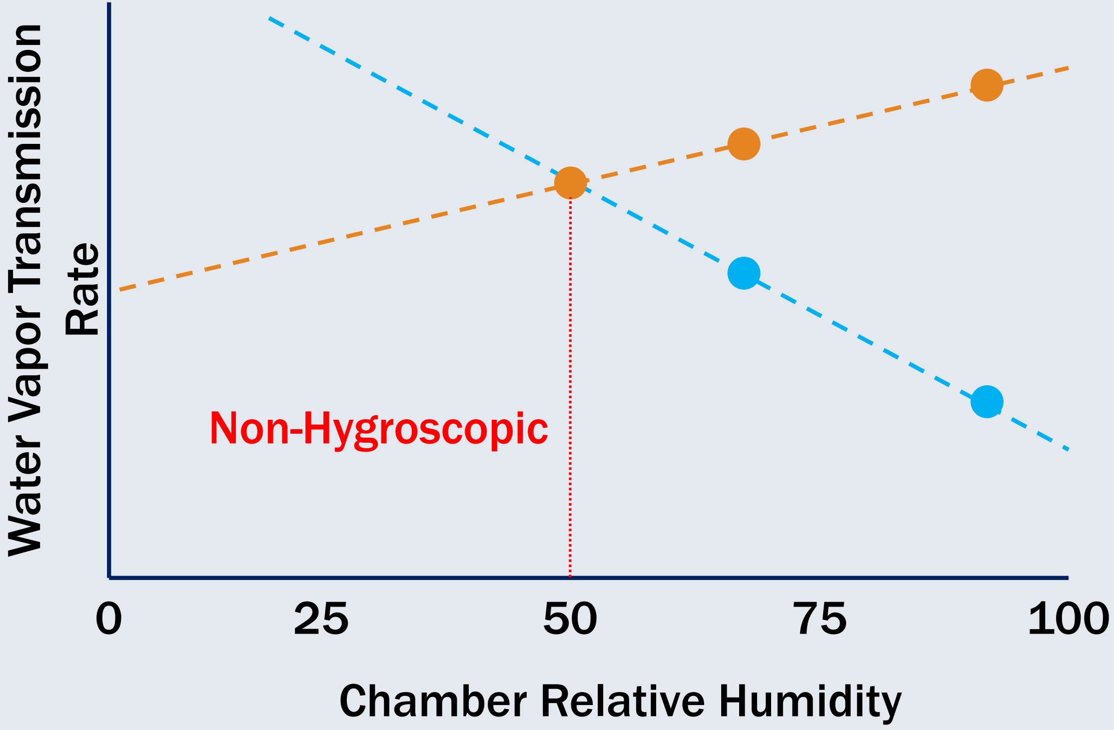
Desiccant vs. Water Method

*"Agreement should **<u>not</u>** be expected between results obtained by different methods. The method should be selected that **<u>more nearly approaches the conditions of use</u>**"*

Designation of Vapor Flow Direction

- *When a product is designated for use in only one position, [it] shall be tested…with the vapor flow in that direction*
- *When either side may face the vapor source, [it should be] tested with the vapor flow in each direction and so reported*

ASTM E96: Appendix X3
"Procedure to Calculate Dependency of Water Vapor Transmission Rate on Relative Humidity"



<u>Desiccant Method</u>

50%, 70%, 90%

RH ↑ WVT Rate ↑

Increasing ΔP

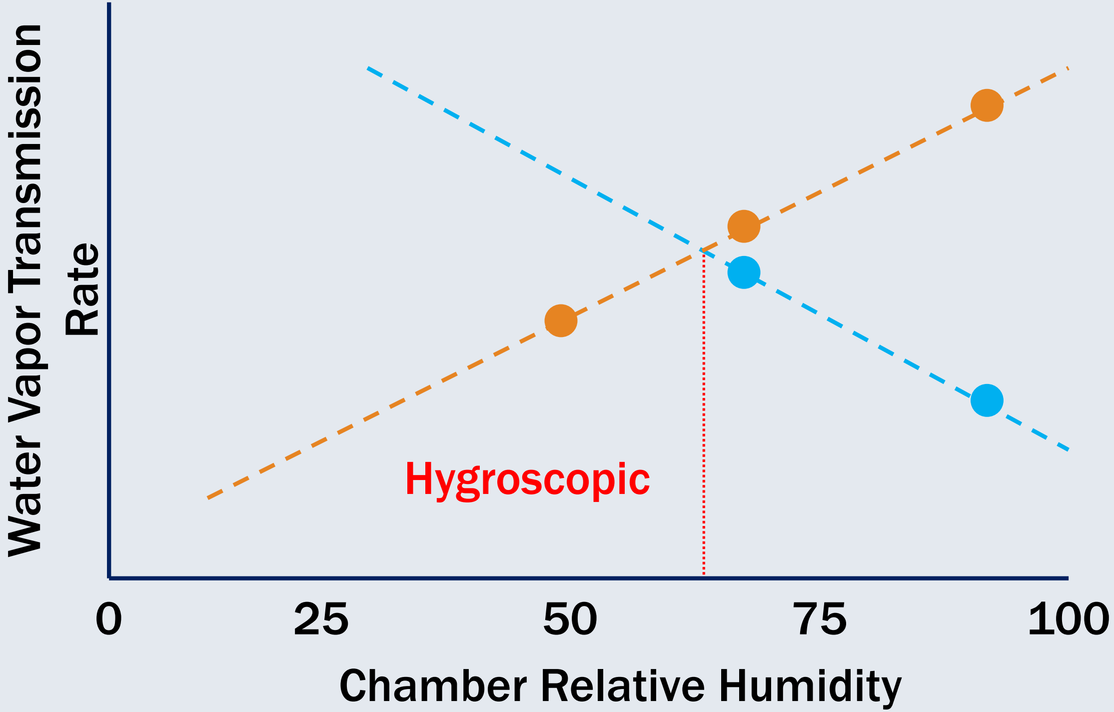
<u>Water Method</u>

70%, 90%

RH ↑ WVT Rate ↓

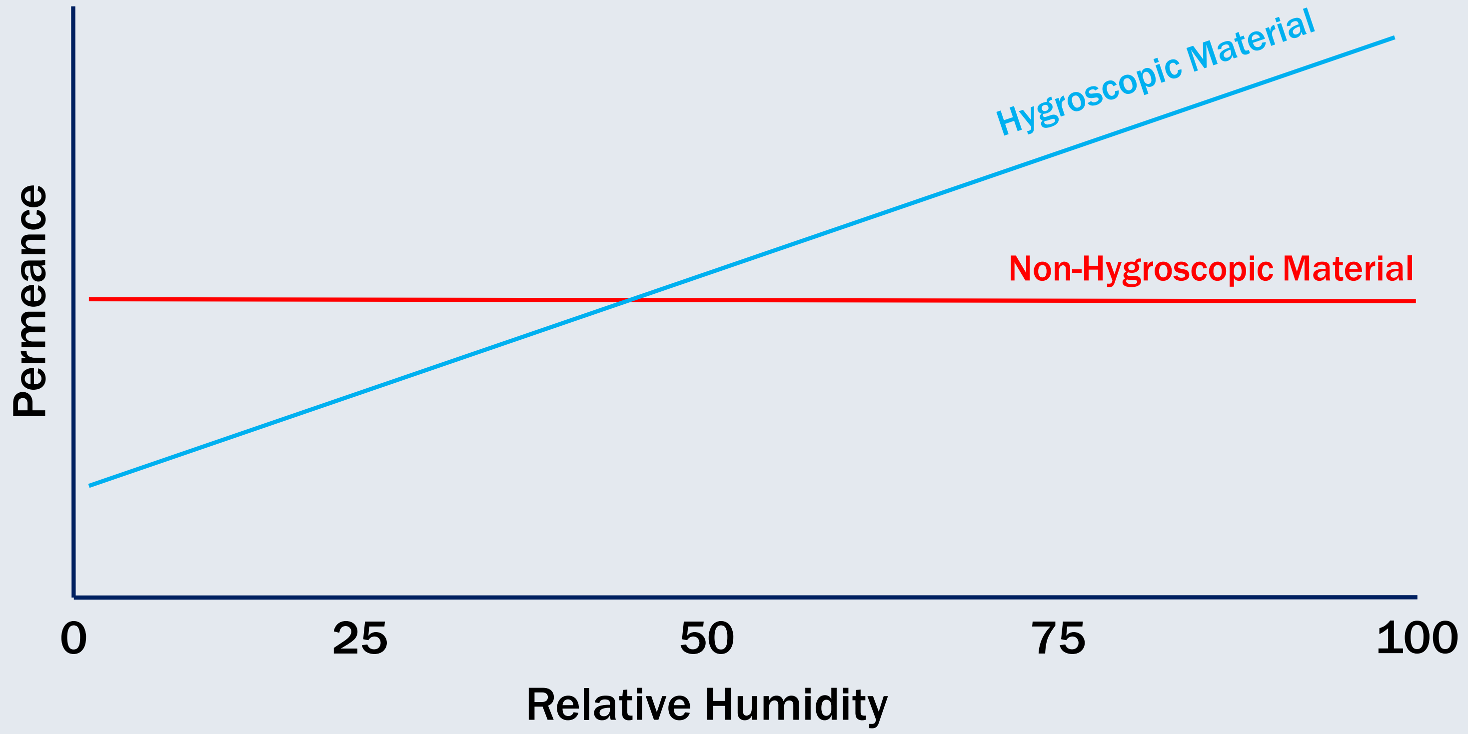
Decreasing ΔP

ASTM E96: Appendix X3
"Procedure to Calculate Dependency of Water Vapor Transmission Rate on Relative Humidity"

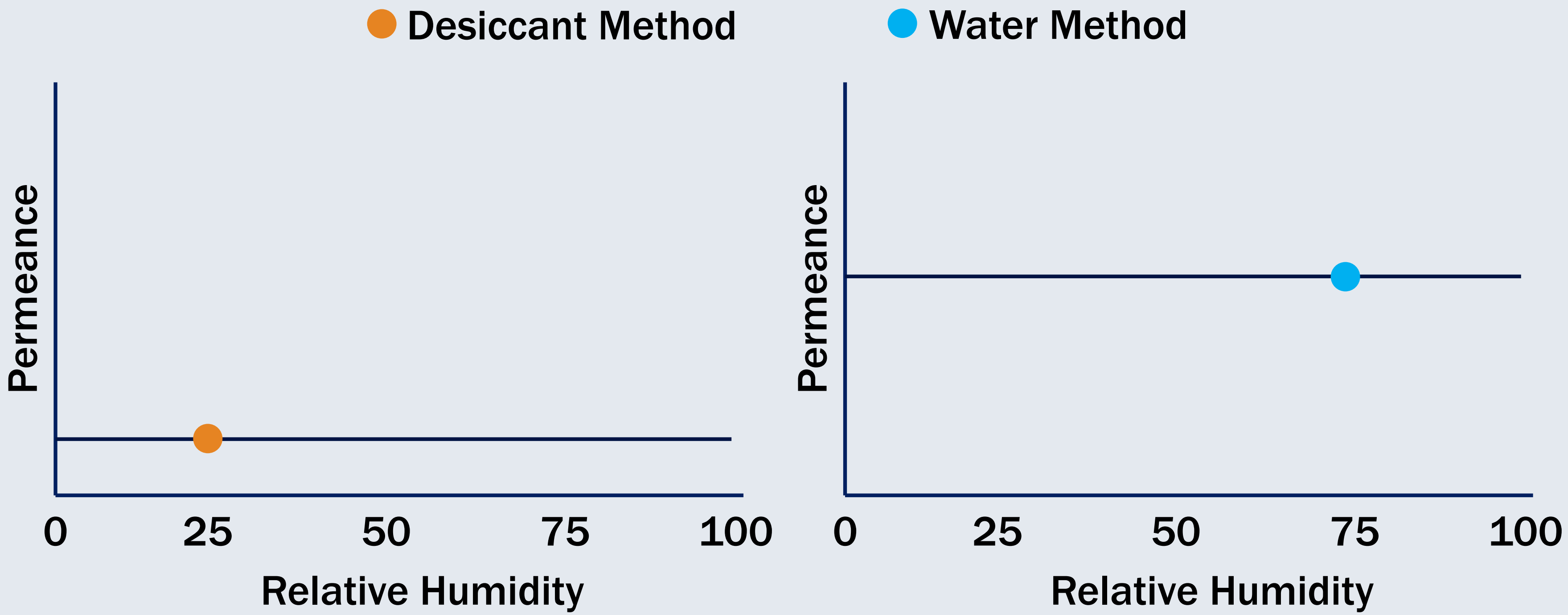


Plots intersect > 50%

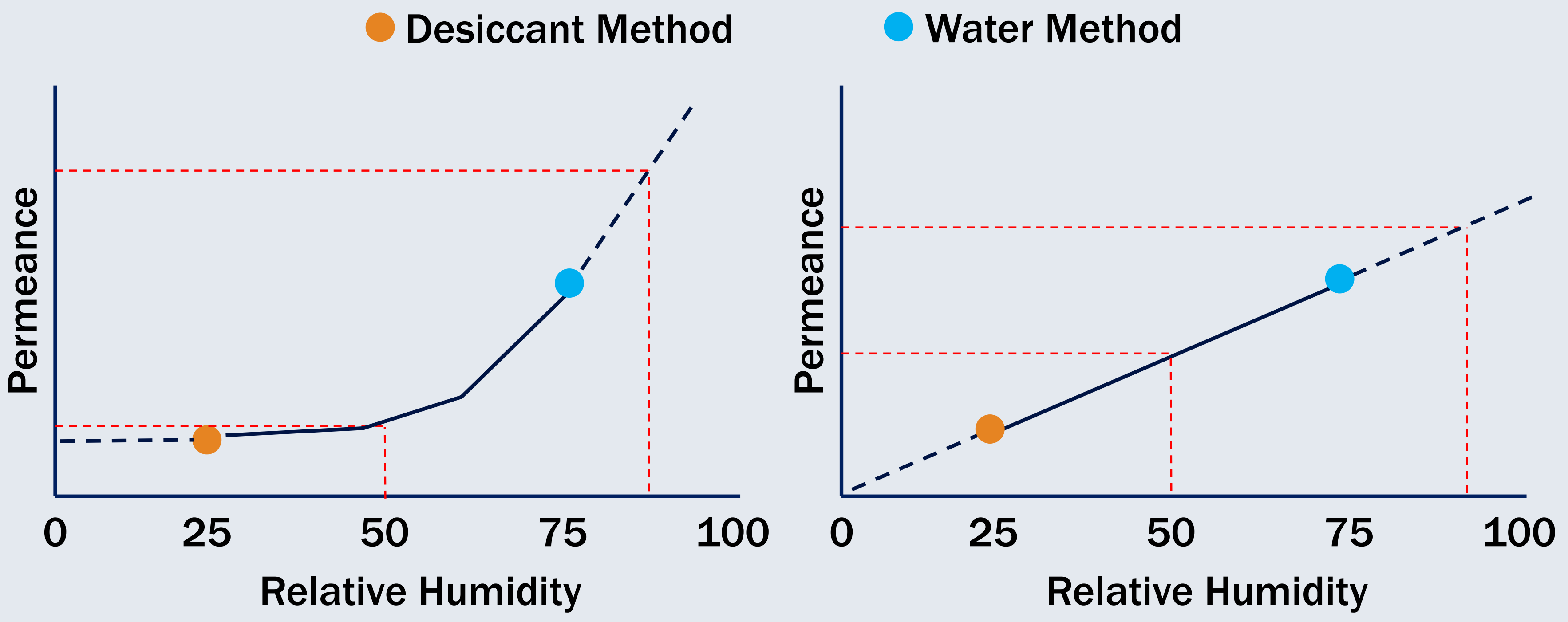
Impact of Hygroscopic Materials



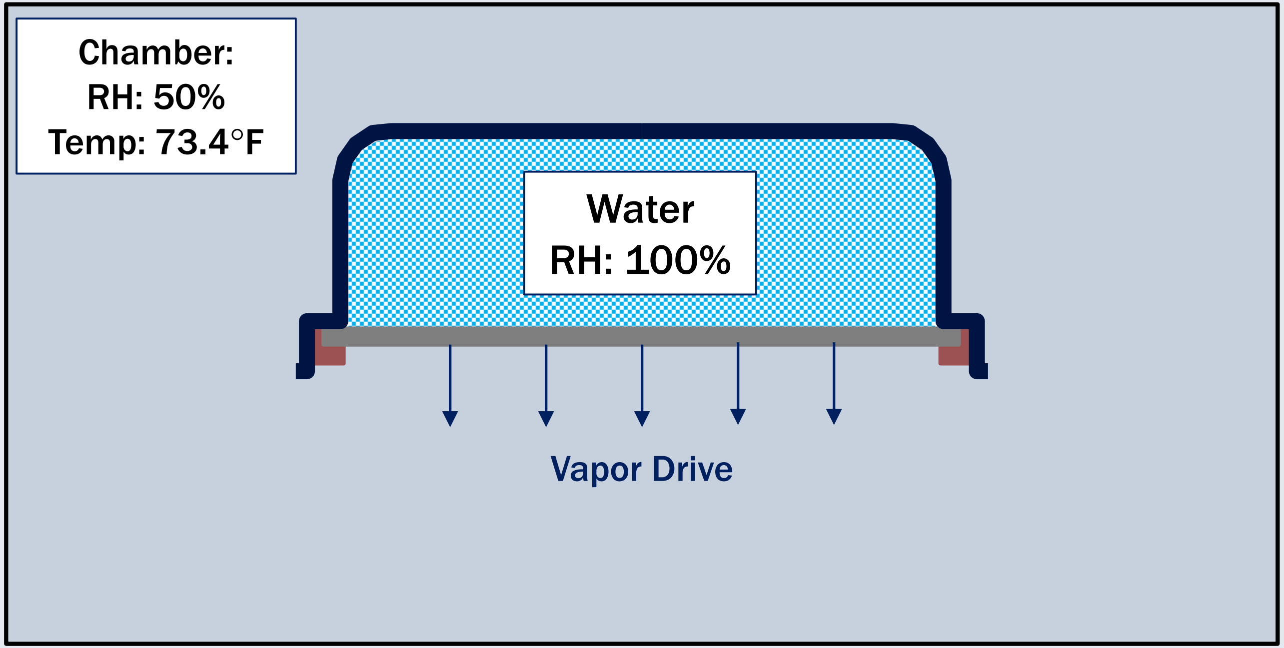
Designing for Hygroscopic Materials



Designing for Hygroscopic Materials



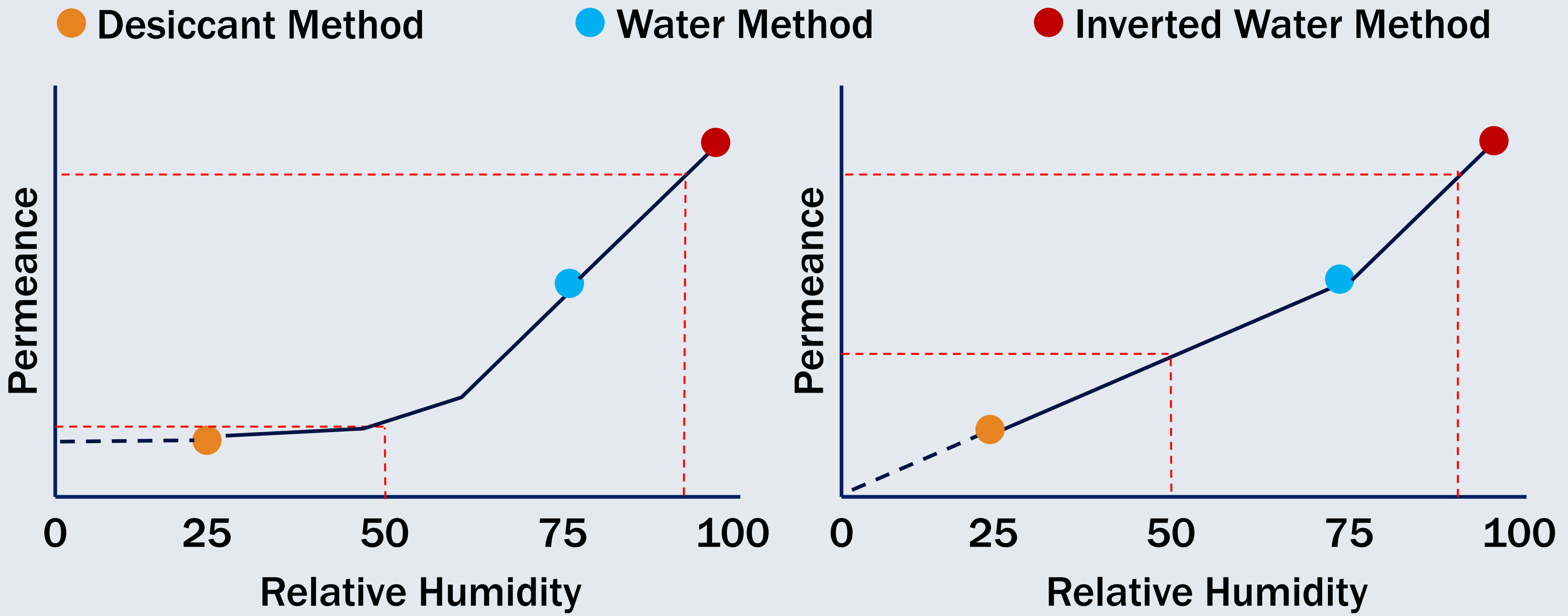
Inverted Water Method



True Exposure to 100% RH

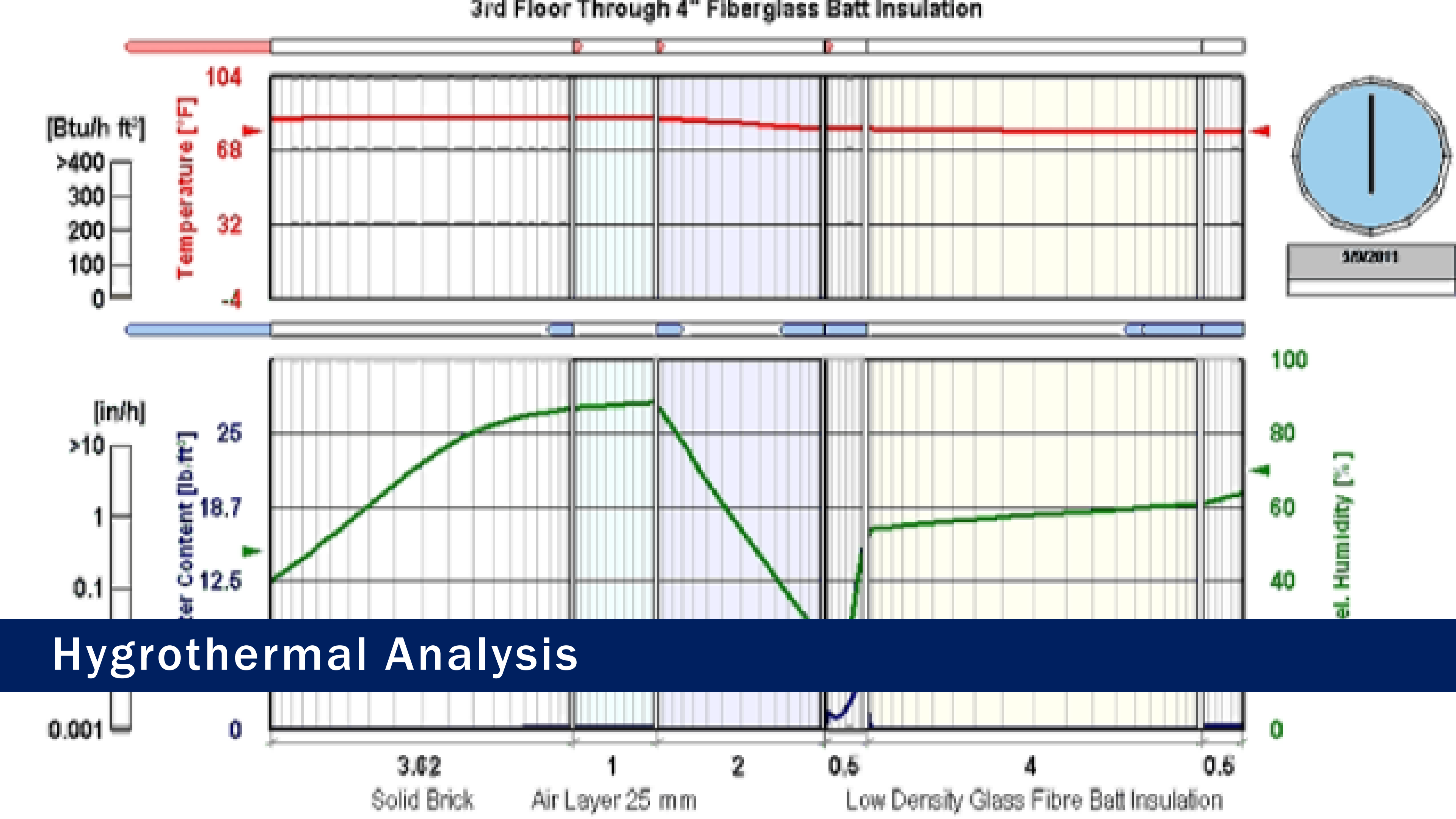
Head pressure may impact WVT Rate

Designing for Hygroscopic Materials



Proposed Changes to ASTM E96

- ASTM E96 Task Group – April 1-3, 2019
  - Frequency of chamber condition monitoring
  - Velocity of air in chamber
  - Utilize “blank” specimens for all tests
  - Discussions relating to desiccant types and drying procedures
  - <u>Deliberation of RH% within dish</u>



Hygrothermal Analysis

Why does this matter now?

- Energy codes have driven buildings to be more air tight
- Tighter building envelope means less air movement to dry out incidental moisture
- Higher risk for moisture to accumulate over time

Long-Term Moisture Accumulation

- Condensation
- Corrosion
- Biological Growth
- Reduced long term material durability
- Concerns with occupant comfort and health

Performing Hygrothermal Analysis

Steady-State

- Evaluates conditions at a point in time
- Considers thermal and vapor resistance

Transient

- Evaluates changes over time and impact of changes on material properties
- Considers thermal resistance, vapor resistance, moisture sources, ventilation, moisture storage, liquid transport, rain/solar loads

Steady-State Analysis

Impact of Vapor Drive

Temp

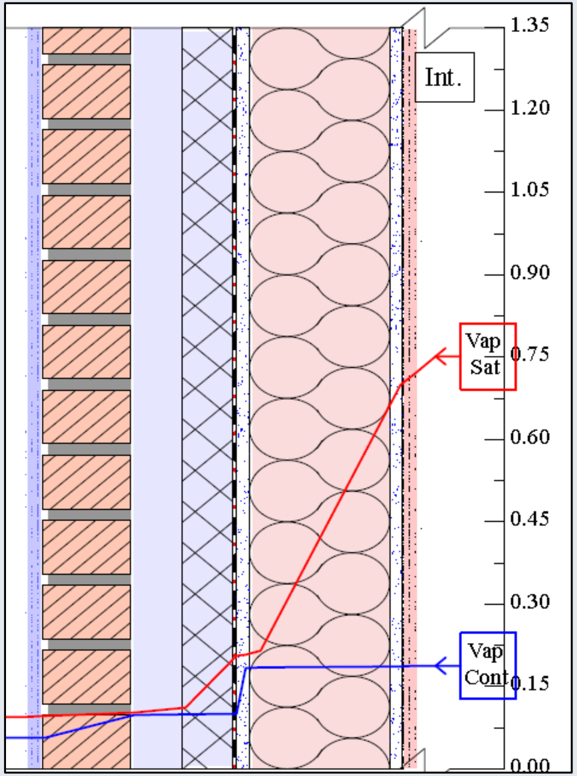
Int: 70°F

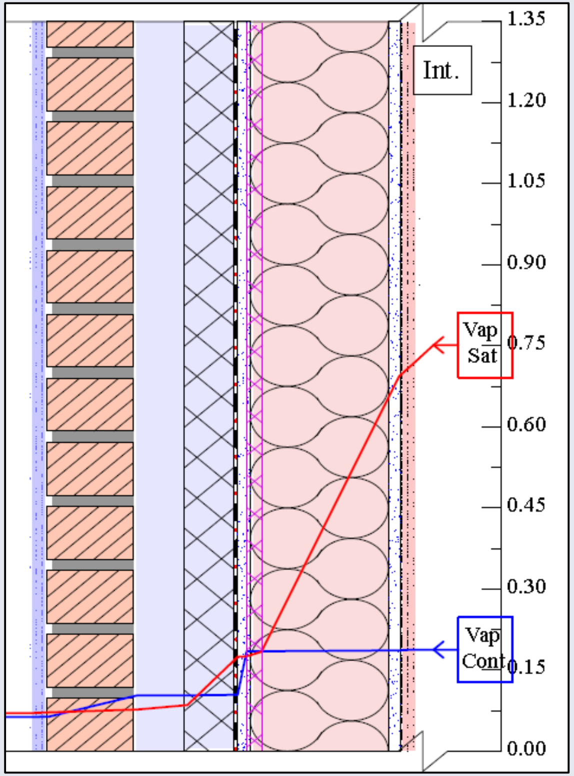
Ext: 18°F

RH

Int: 30%

Ext: 60%





Temp

Int: 70°F

Ext: 12°F

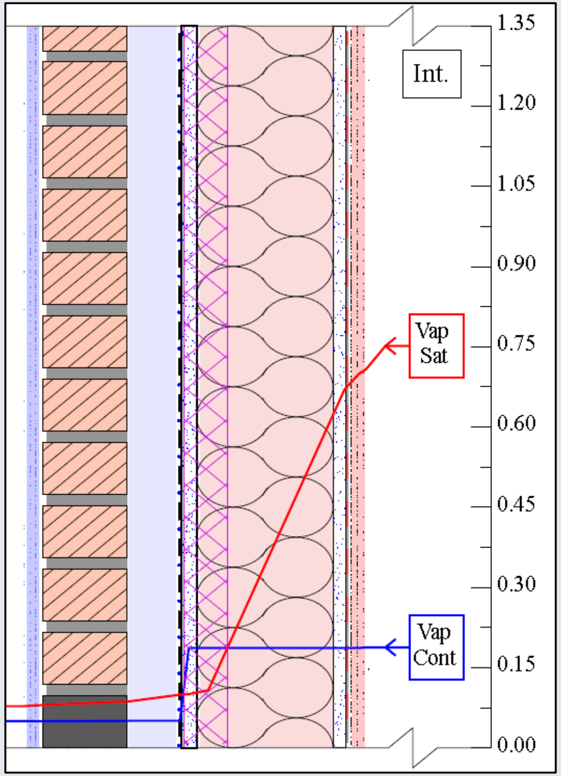
RH

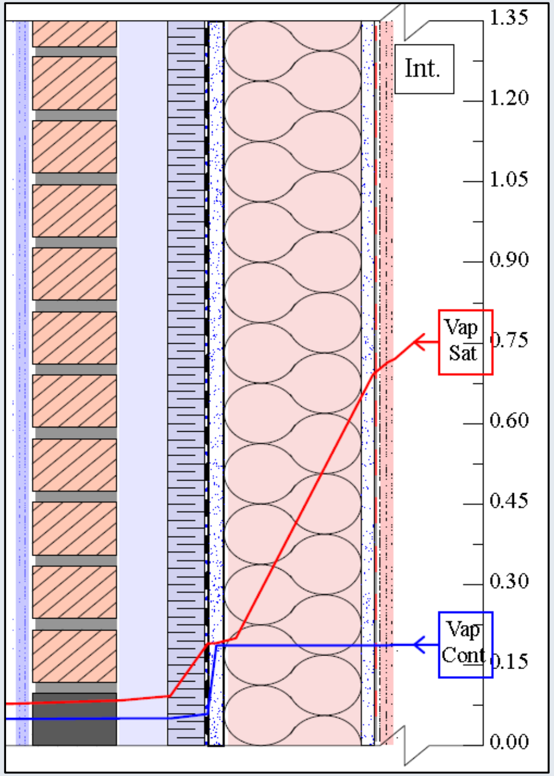
Int: 30%

Ext: 90%

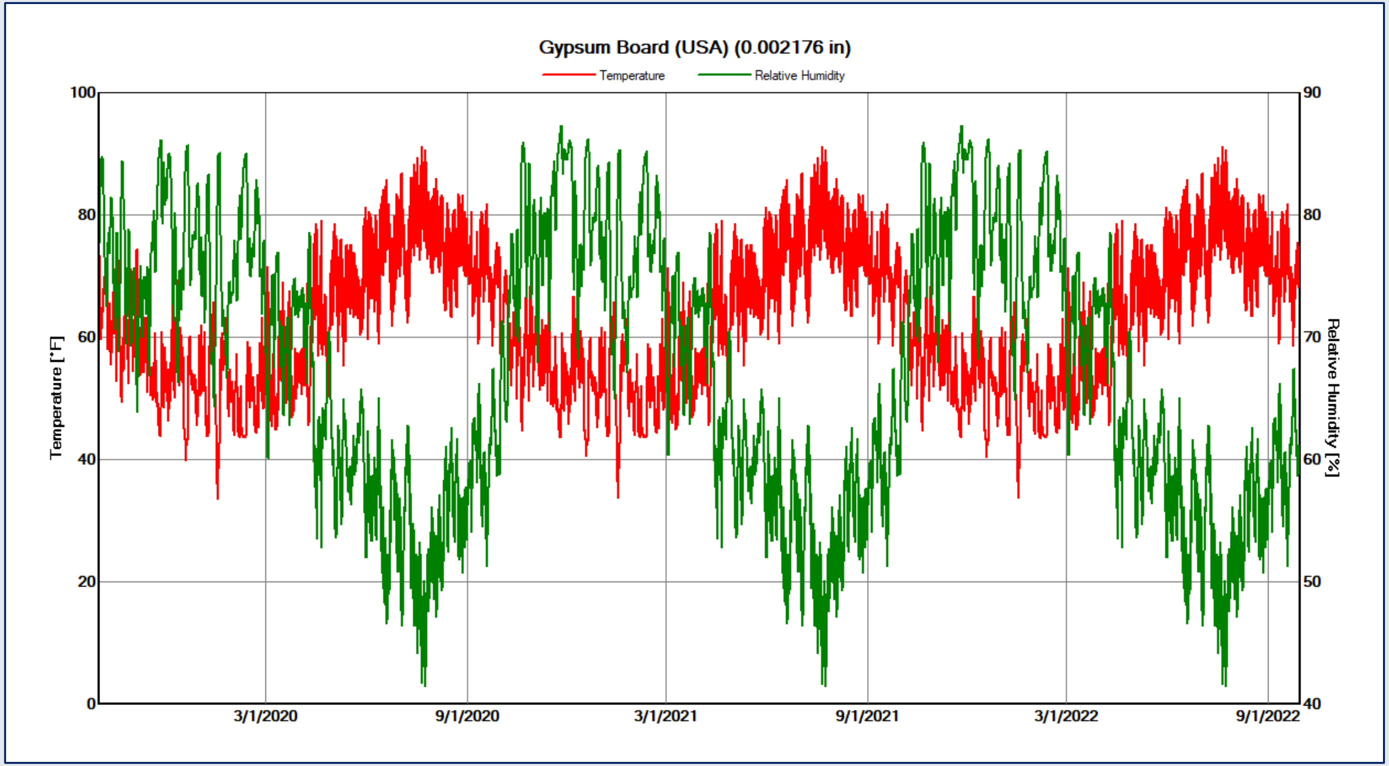
Steady-State Analysis

Impact of Thermal Gradient





Transient Hygrothermal Analysis



WUFI Material Database

- Generic “Vapor Retarder” Membranes
  - 0.1 perm, 1 perm, 5 perm, 10 perm
  - Permeance reported at 0% RH and considered non-hygroscopic membranes
- Limited number of manufacturers have their specific product data represented in WUFI material database

Product Data for Air Barrier Membranes

Classification of Vapor Retarders

Vapor Retarder Class	Permeance
Class I	Equal to 0.1 perms or less
Class II	Greater than 0.1 perms and less than or equal to 1.0 perms
Class III	Greater than 1.0 perms and less than or equal to 10 perms

1405.3.3. Material Vapor Retarder Class, 2015 International Building Code

Industry References

Vapor Class	Permeance
Class I	Impermeable
Class II	Semi-Impermeable
Class III	Semi-Permeable
>10 perms	Permeable

Published Product Data

- Referenced over 50 <u>**readily**</u> available product data sheets for air barrier membranes in the industry
  - Vapor permeance
  - ASTM E96 Test Method

Published Product Data

- 59% Reported <u>**EITHER**</u> Desiccant <u>**OR**</u> Water Method
- 5% did not report a Method

- General Observations:
  - Mil Thickness
  - Vapor Permeance Variation

Published Product Data

Impermeable Membranes

- Reviewed product data for 24 membranes
- 33% Reported **BOTH** Desiccant and Water Method
- When only **ONE** Method was reported
  - 44% reported Desiccant Method
  - 44% reported Water Method
  - 12% did not report a method

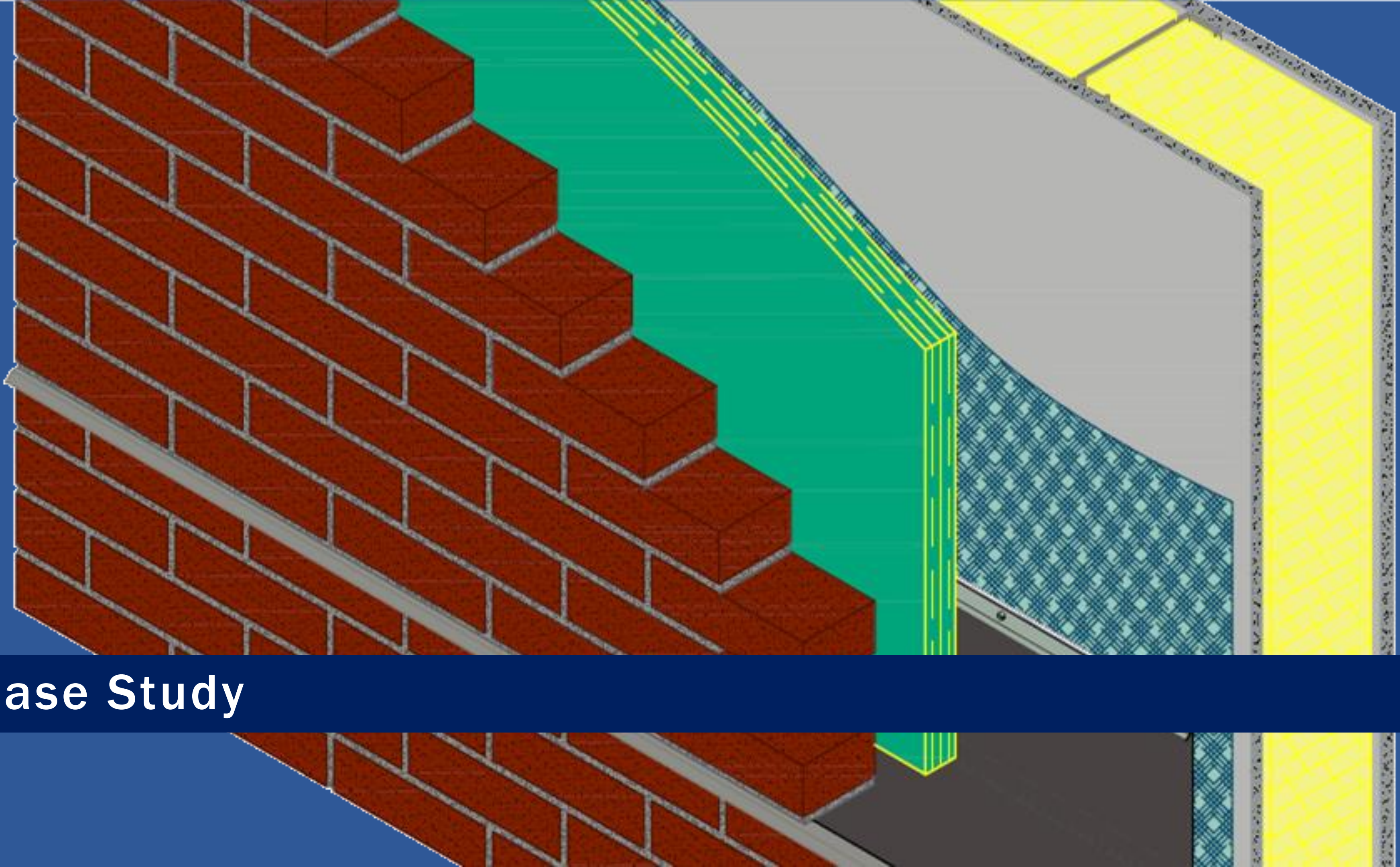
Published Product Data

Permeable Membranes

- Reviewed product data for 31 membranes
- 45% Reported **BOTH** Desiccant and Water Method
- When only **ONE** Method was reported
  - 6% reported Desiccant Method
  - 94% reported Water Method

Challenges for Designers

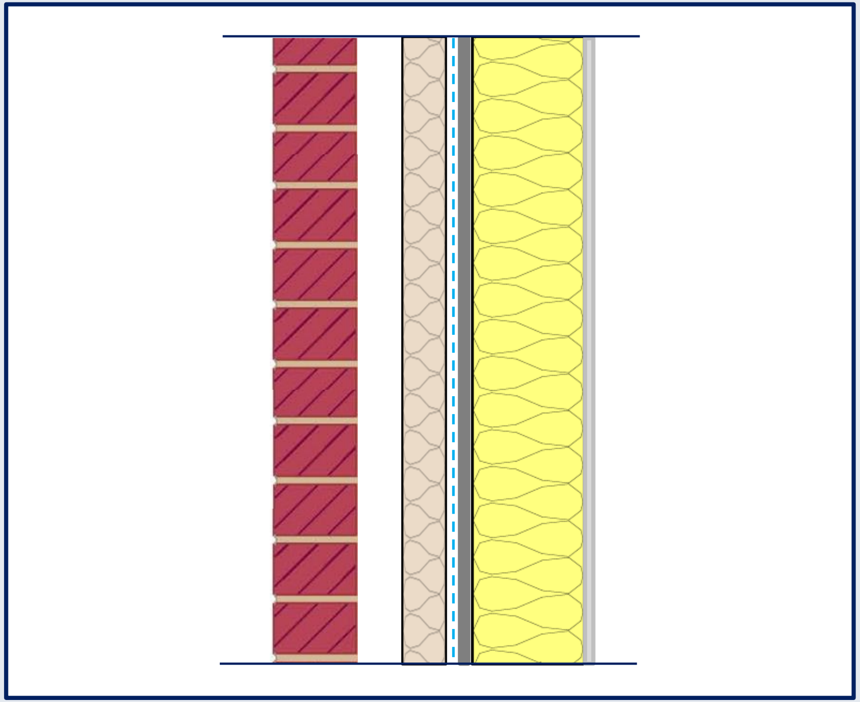
- Representative data to perform hygrothermal evaluation
- Specification of air barrier properties
  - Vapor classification?
  - Permeance value?
- Submittal review of air barrier
  - Does the air barrier meet the design requirements?



Case Study

Case Study Wall Assembly

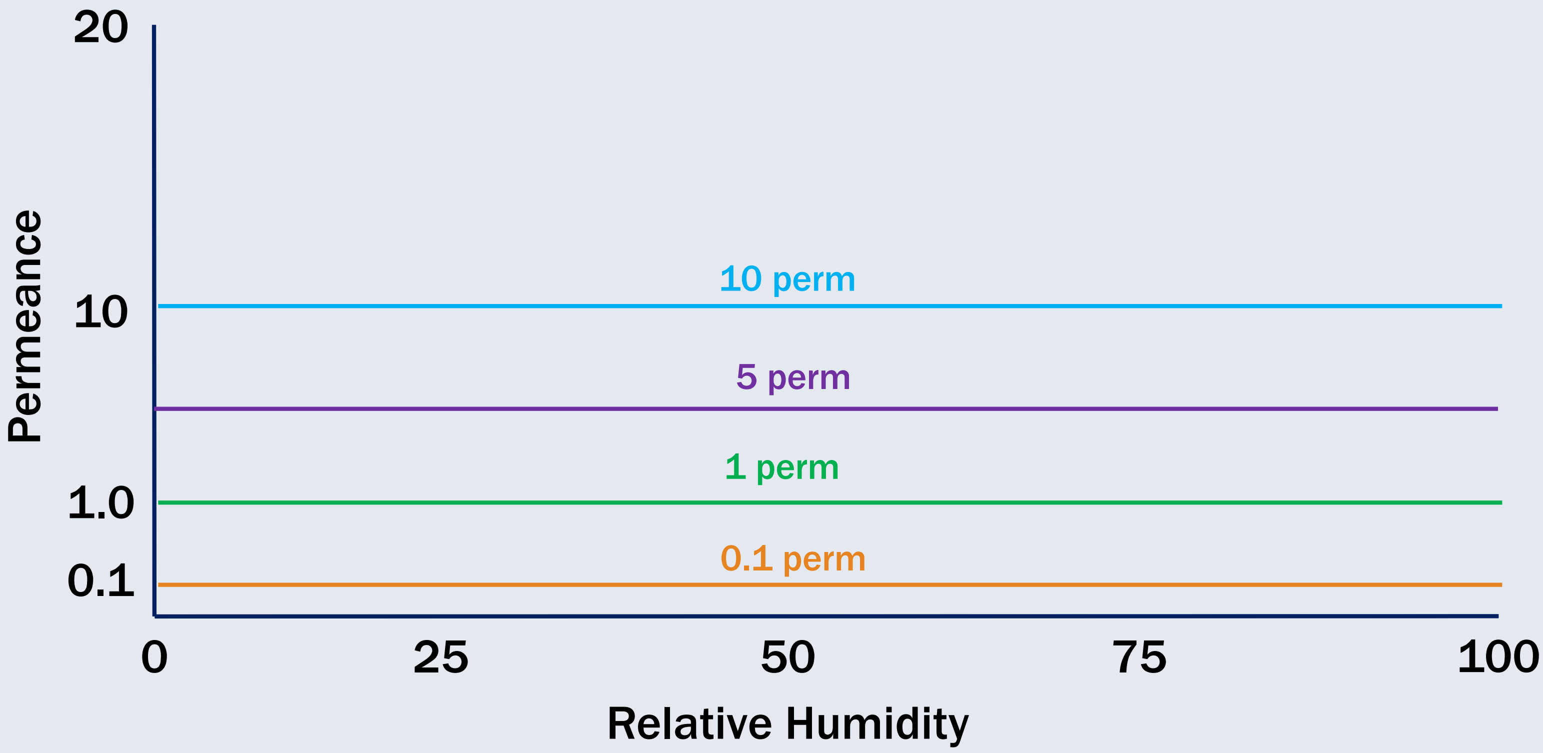
- Brick Veneer
- 2” Mineral Wool
- Air Barrier
- 6” Fiberglass Batt
- Painted Interior Drywall

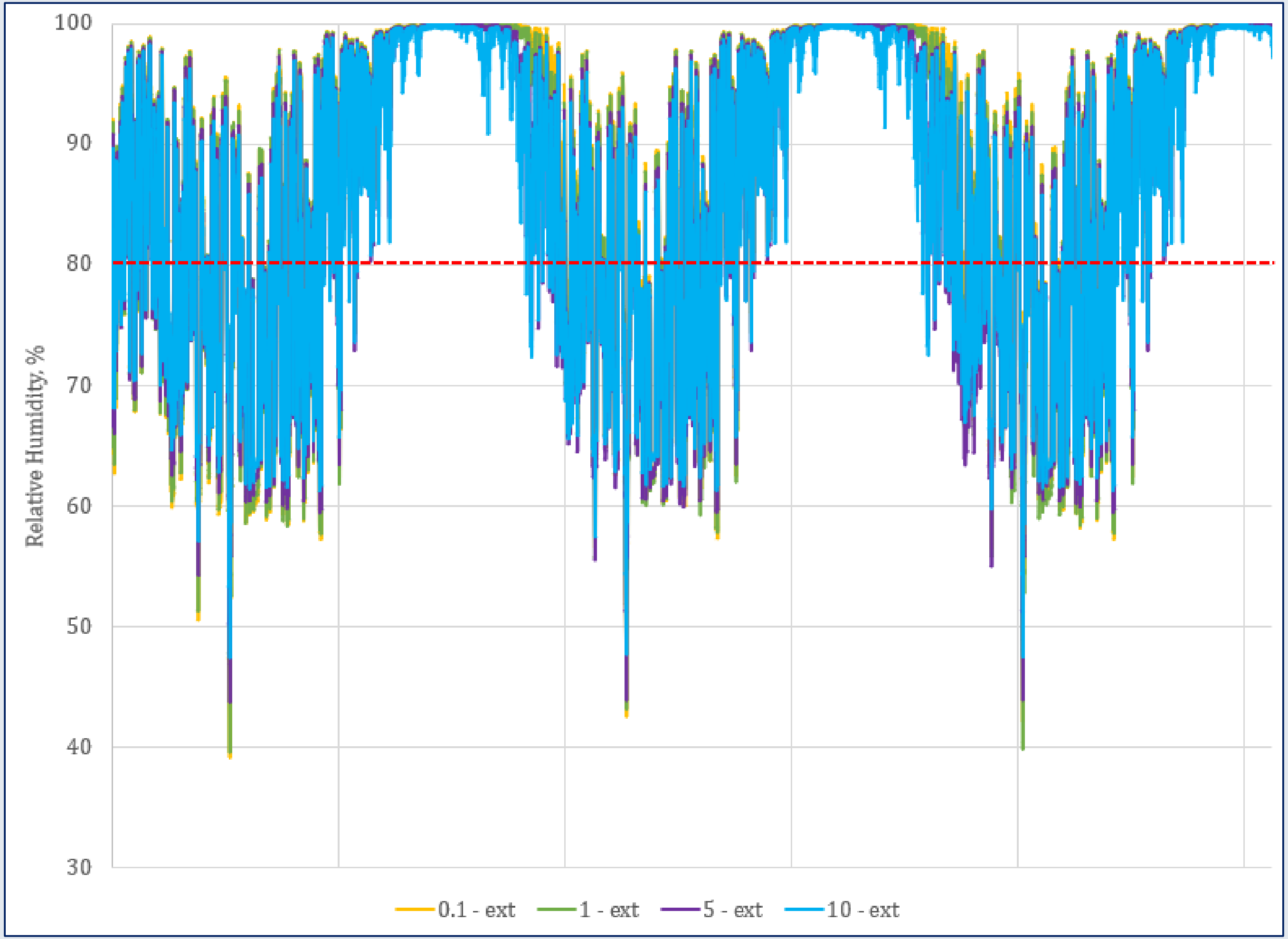


Case Study Assumptions

- Exterior Climate: Norfolk, Virginia, ASHRAE Year 2
  - Temperature: 8.1°F – 95°F; Avg: 59.3
  - Relative Humidity: 17% – 100%; Avg: 73.7%
- Interior Climate: Medium Moisture Load
  - Temperature: 68°F – 71.6°F; Relative Humidity: 40% – 60%
- Initial Moisture Content: EMC 80%
- Elevation: North
- No Additional Moisture Sources; No Air Changes

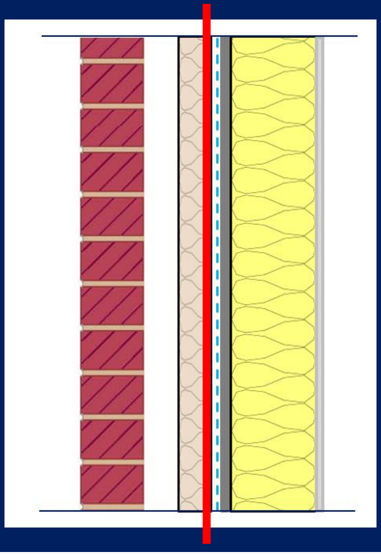
WUFI Material Database

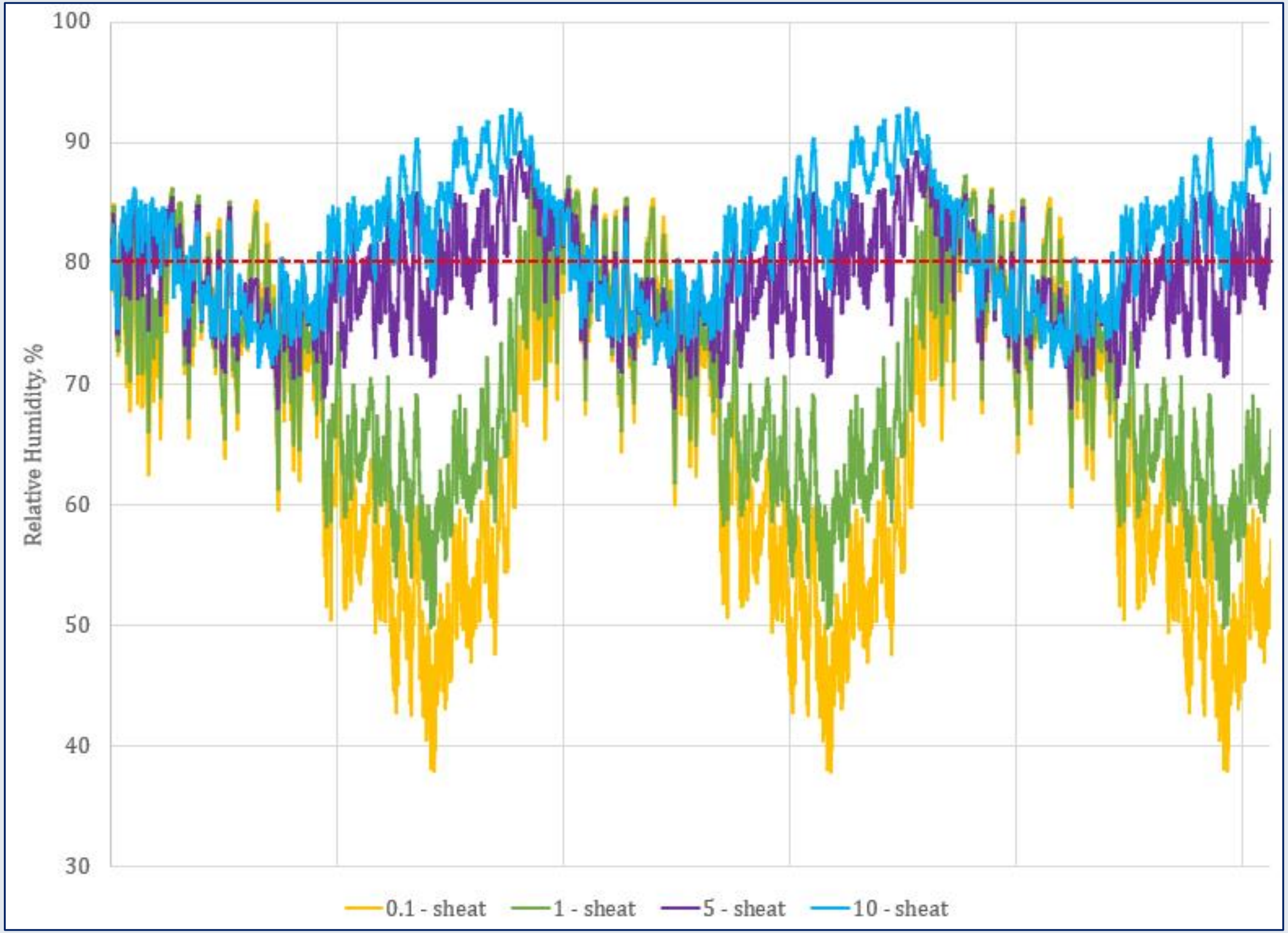




WUFI Material Database

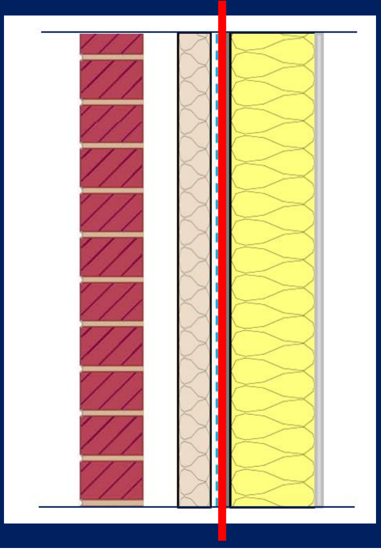
Exterior of Air Barrier Membrane

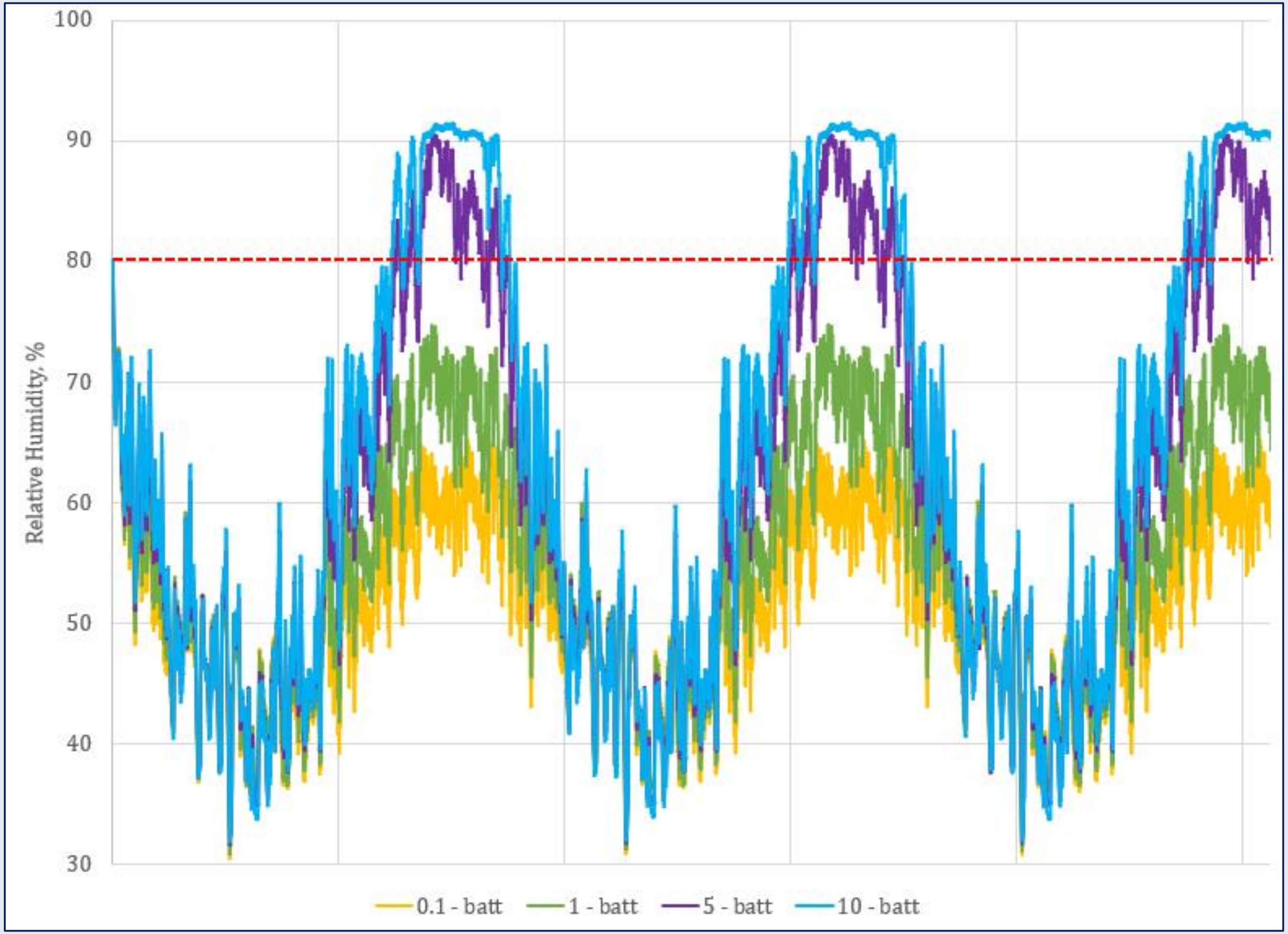




WUFI Material Database

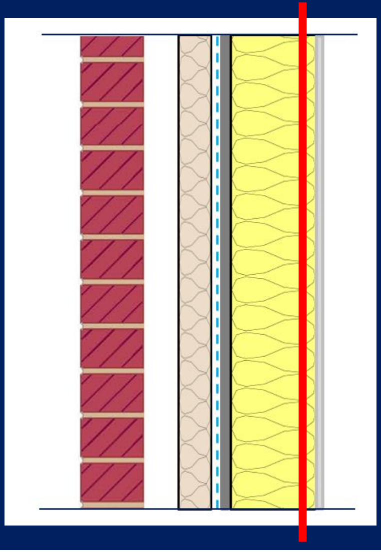
Exterior Sheathing





WUFI Material Database

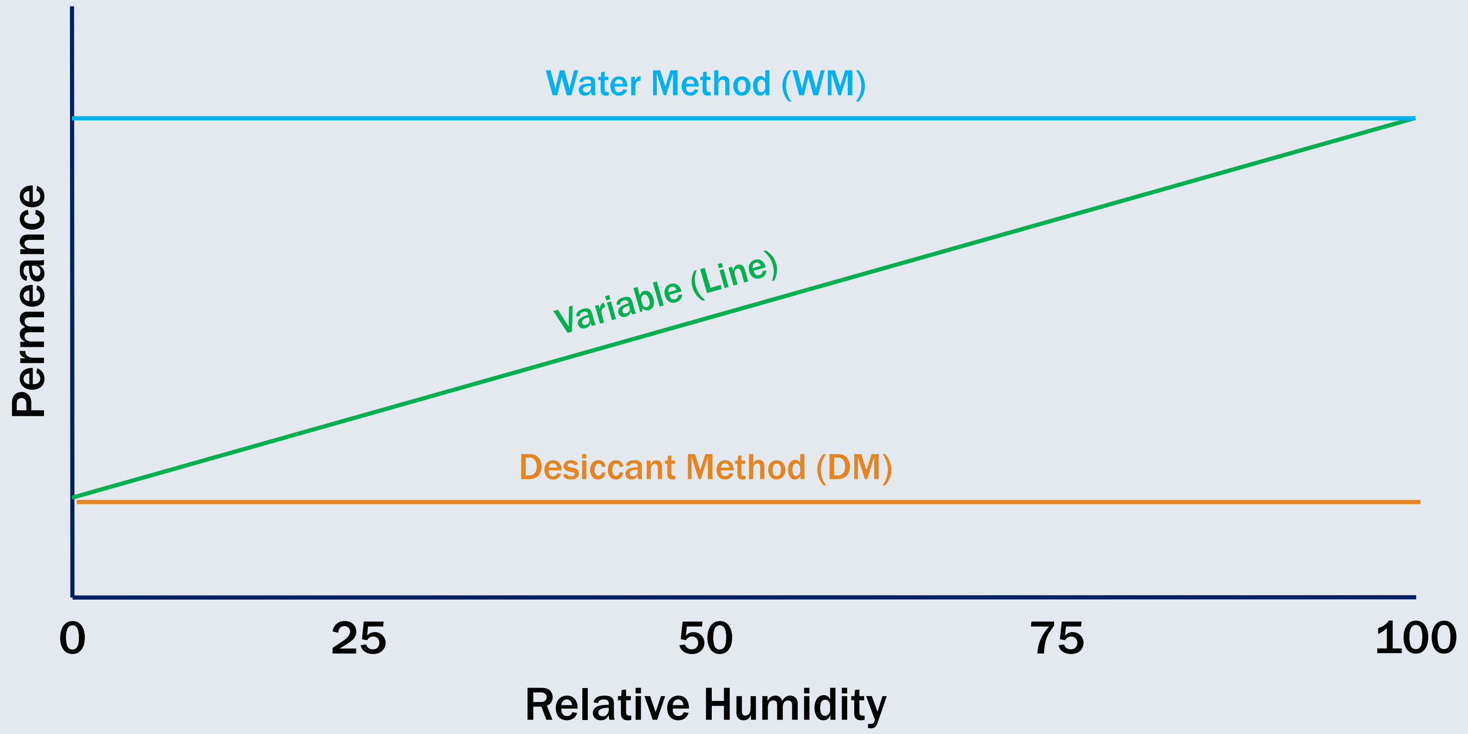
Interior Batt Insulation



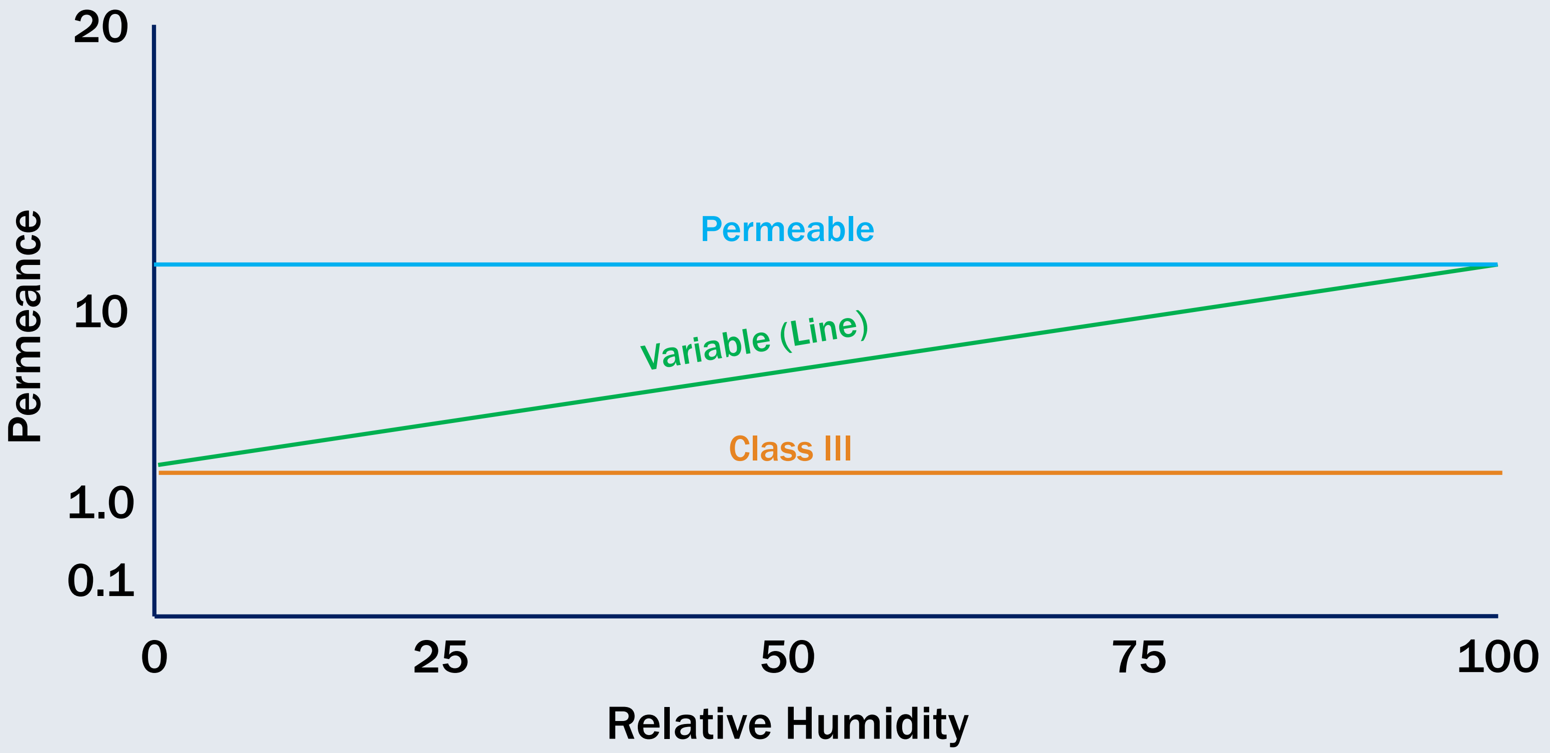
Air Barrier Product Data Examples

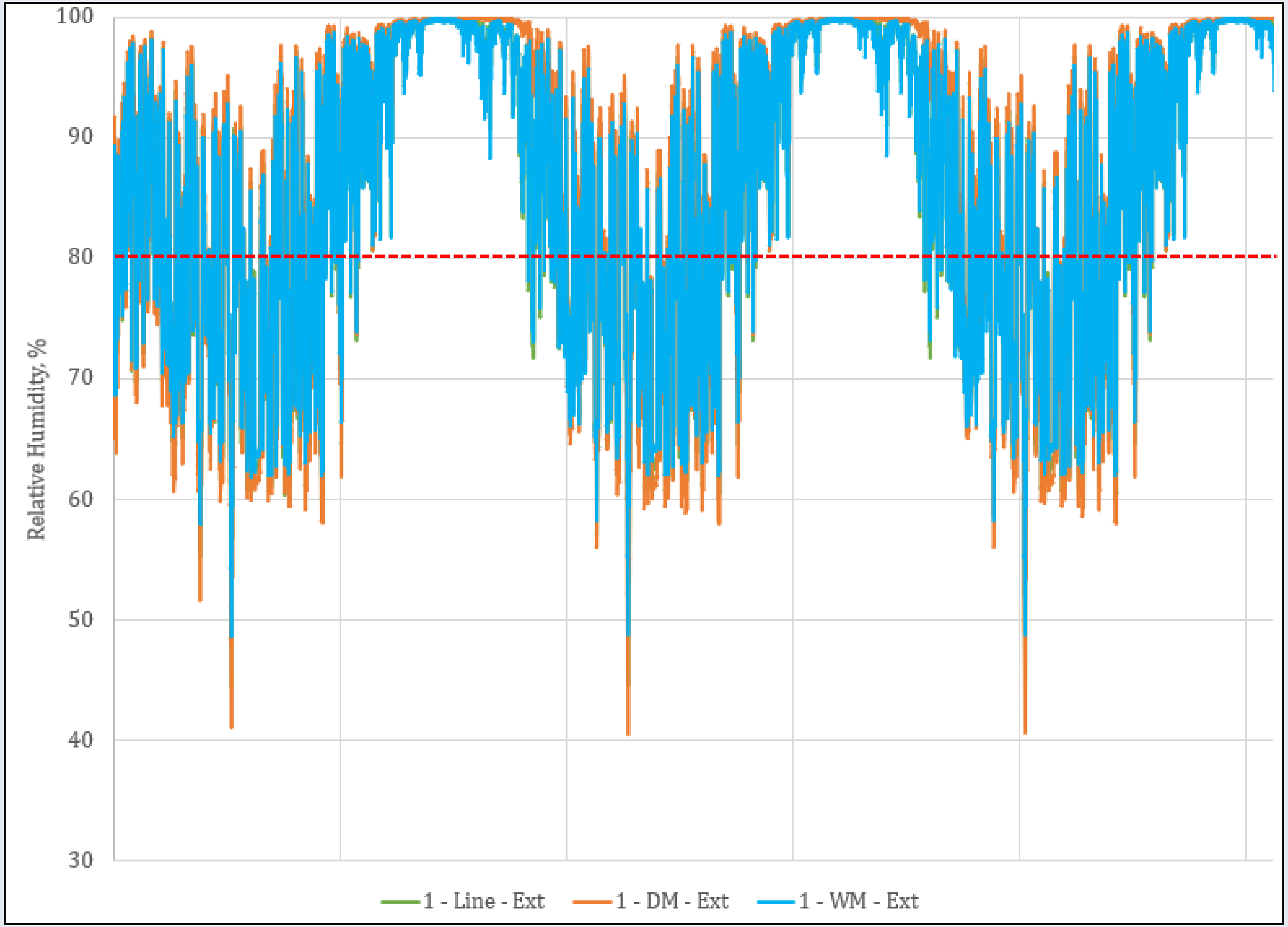
Membrane	Desiccant Method	Water Method
1	Class III	Permeable
2	Class II	Permeable
3	Class I	Class II

Modeling Cases



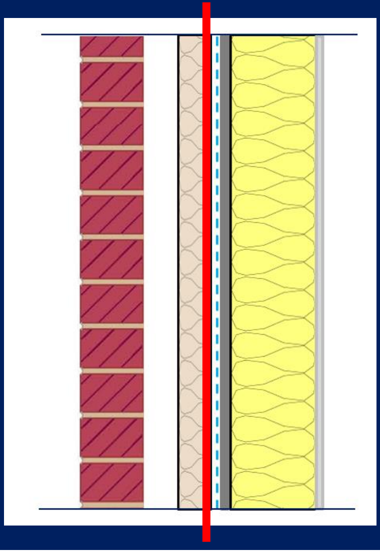
Membrane 1

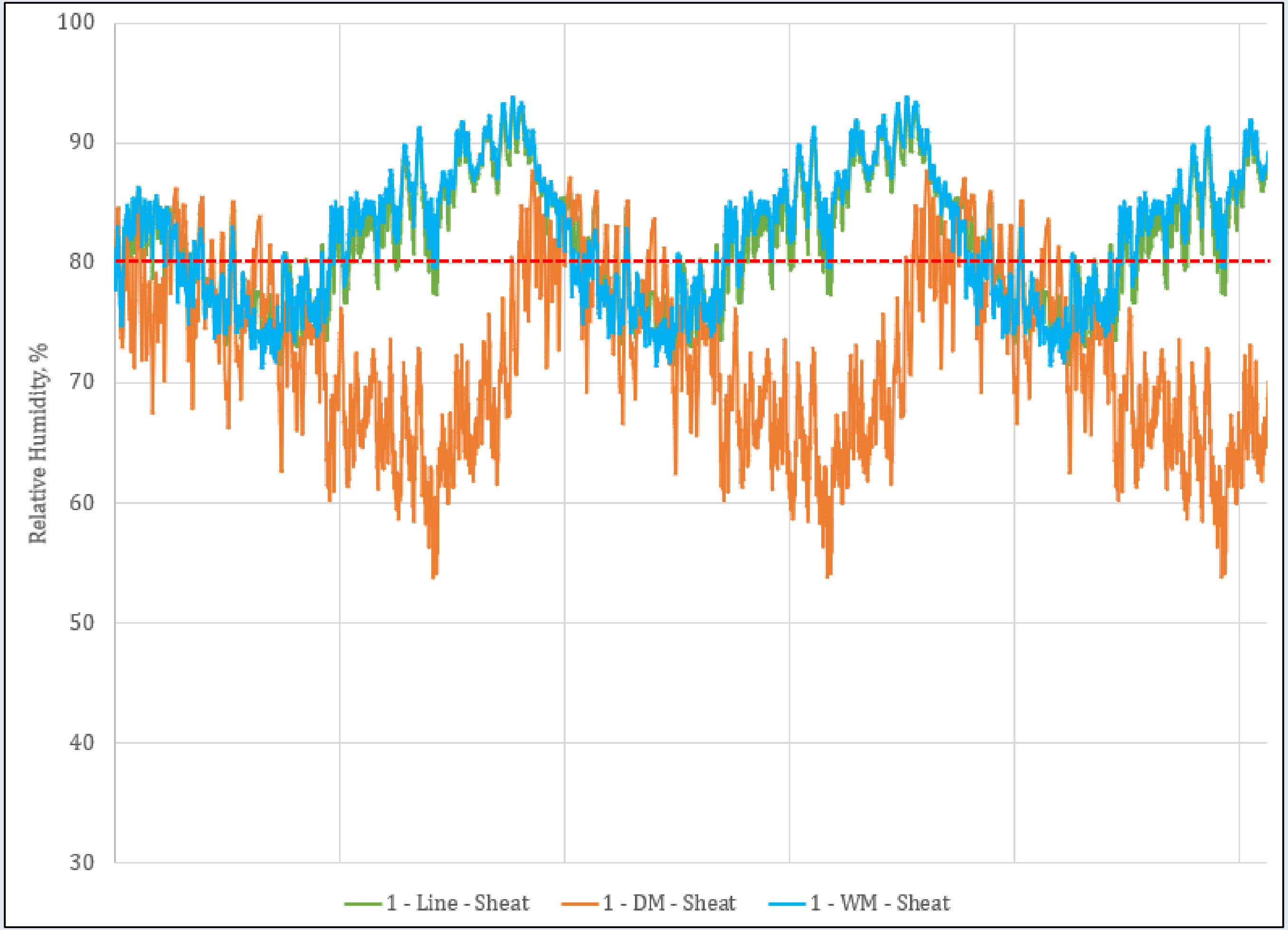

20
10
1.0
0.1
Permeance
Permeable
Variable (Line)
Class III
0
25
50
75
100
Relative Humidity



Membrane 1
Class III → Permeable

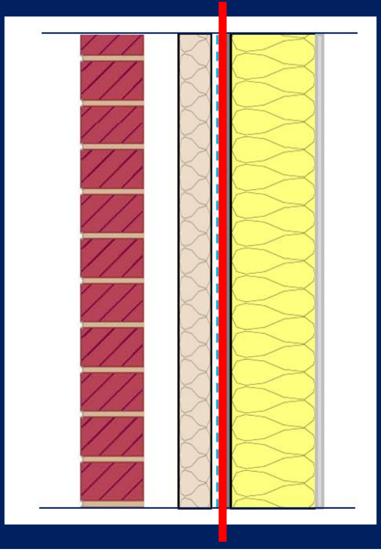
Exterior of Air Barrier Membrane

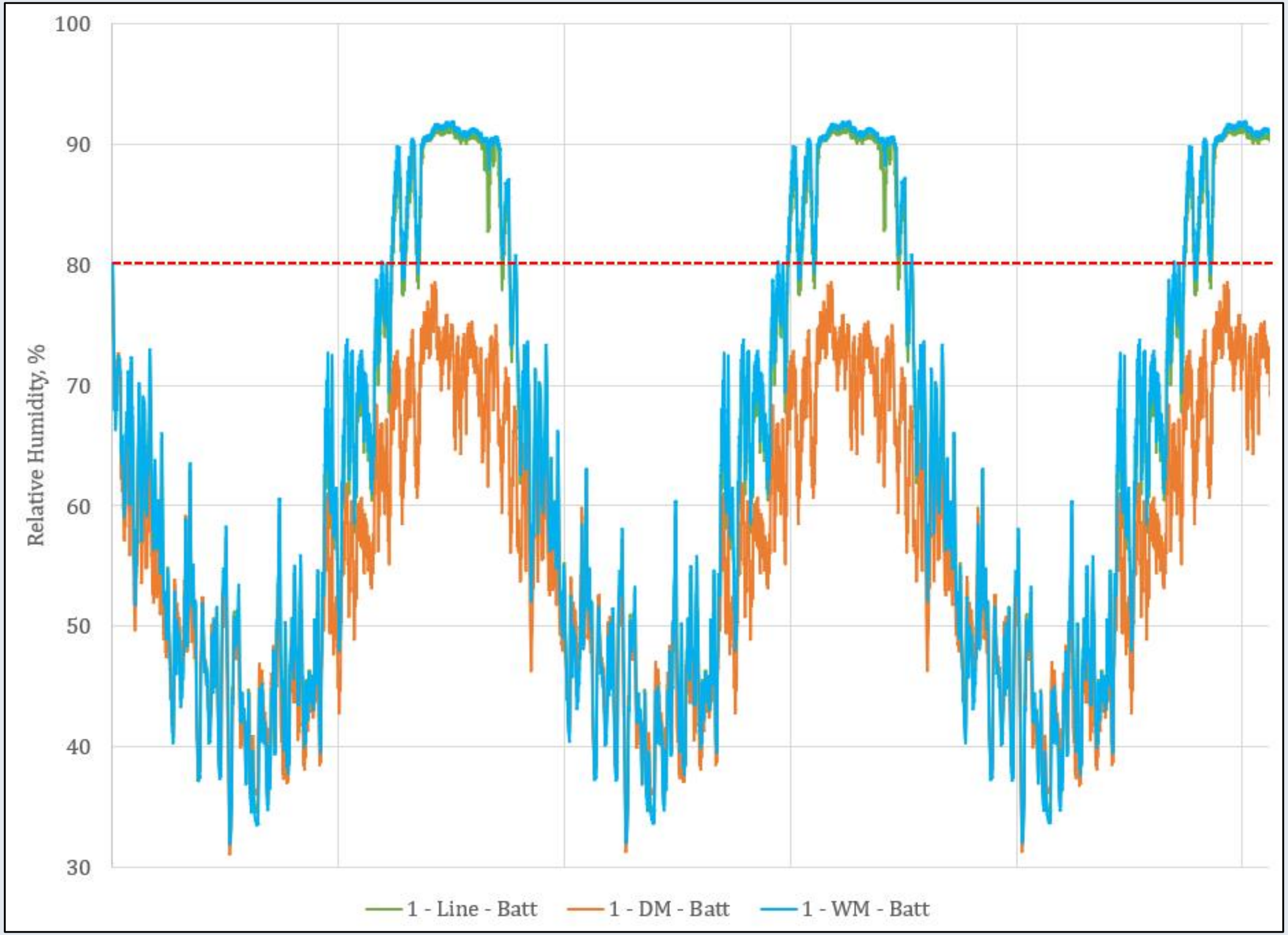




Membrane 1
Class III → Permeable

Exterior Sheathing

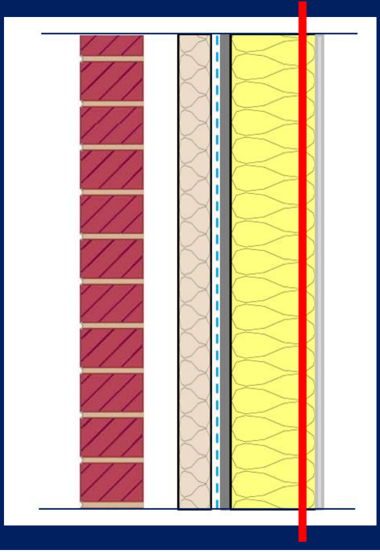




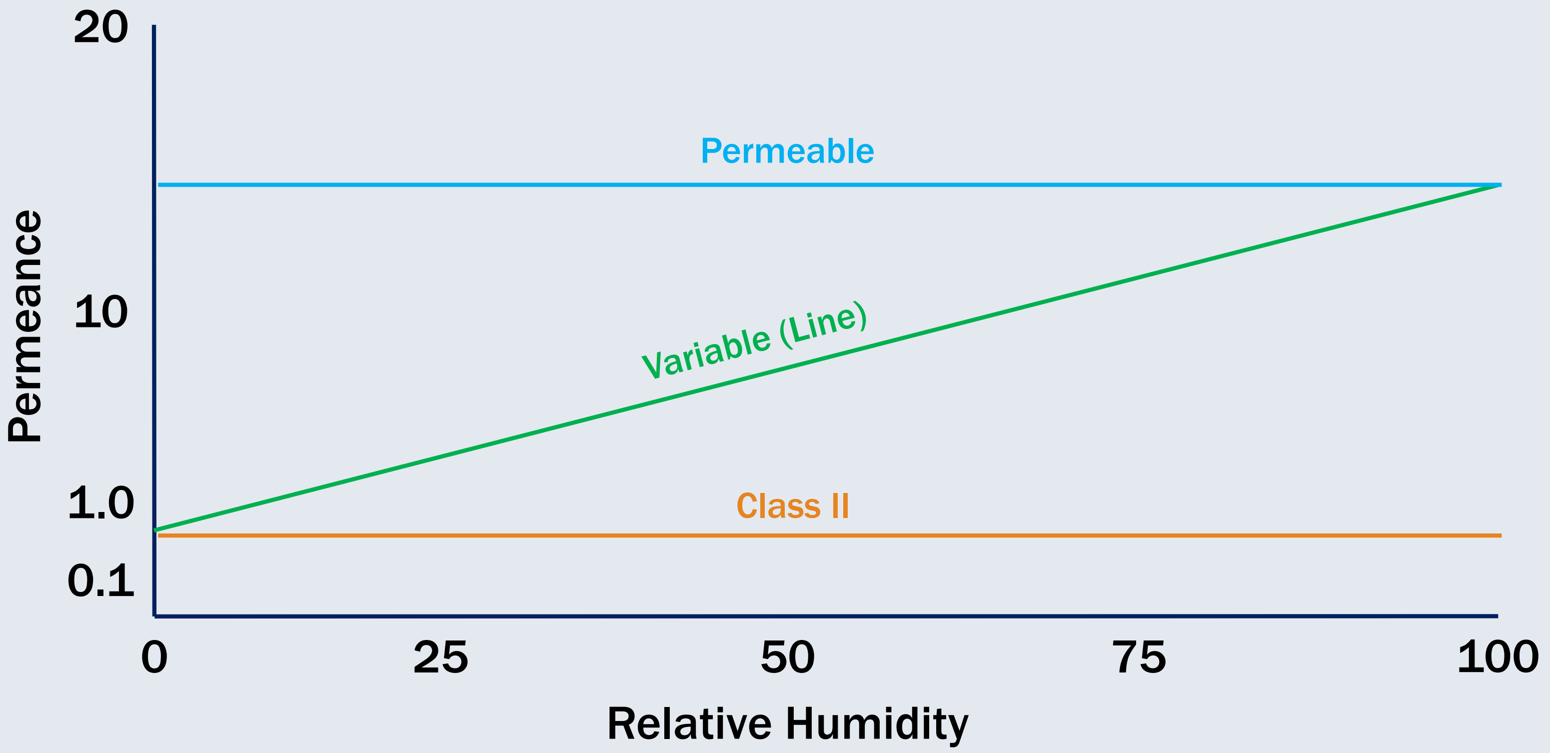
Membrane 1

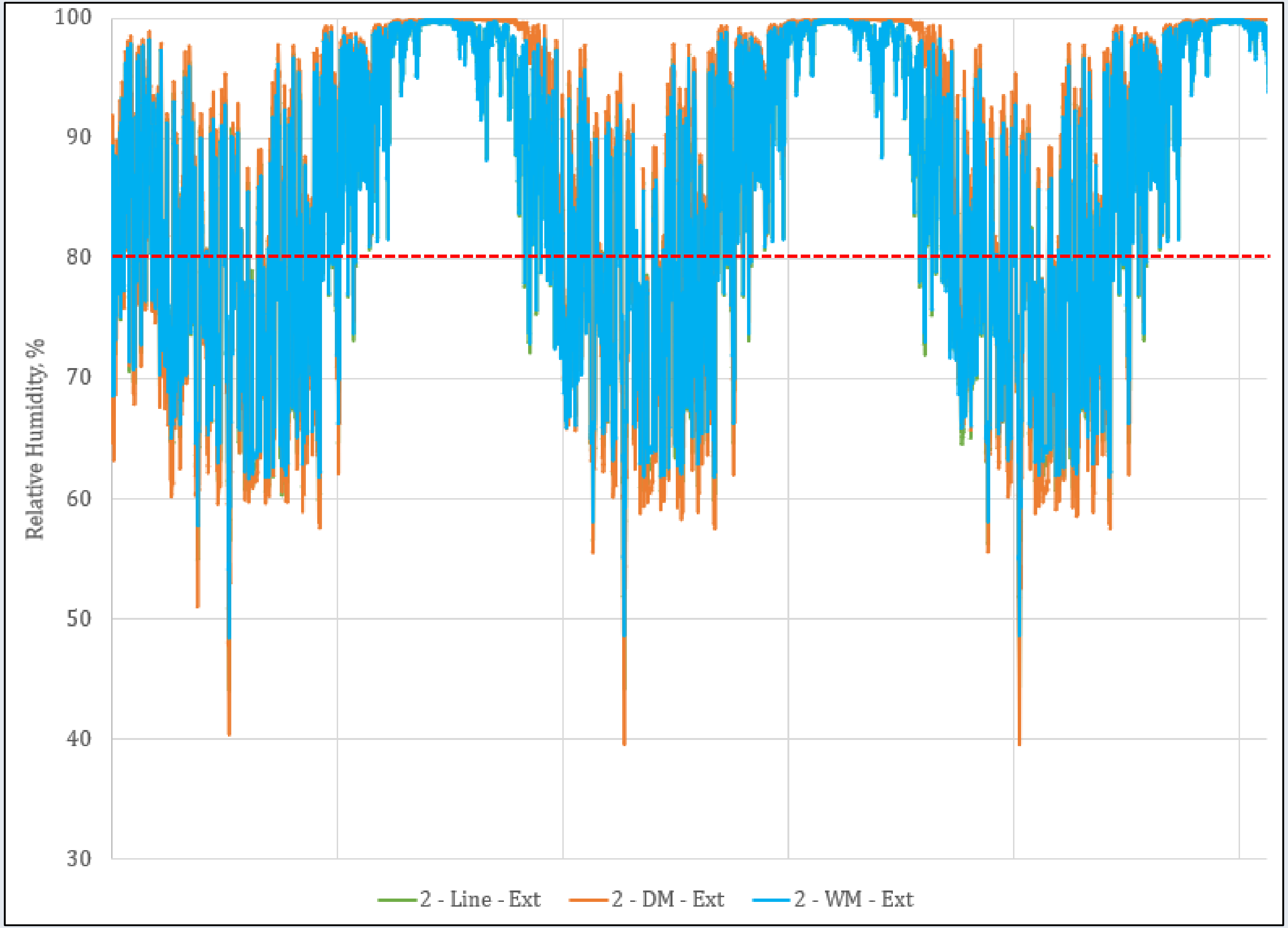
Class III → Permeable

Interior Batt Insulation



Membrane 2

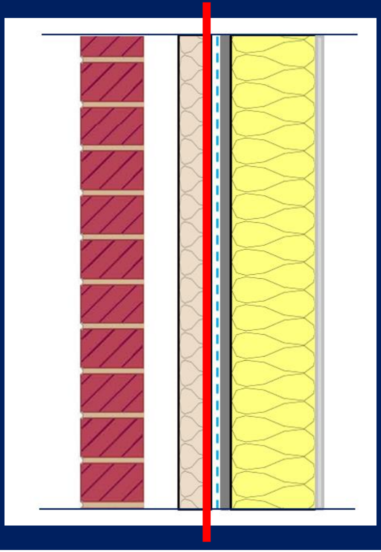

20
10
1.0
0.1
Permeance
Permeable
Variable (Line)
Class II
0
25
50
75
100
Relative Humidity

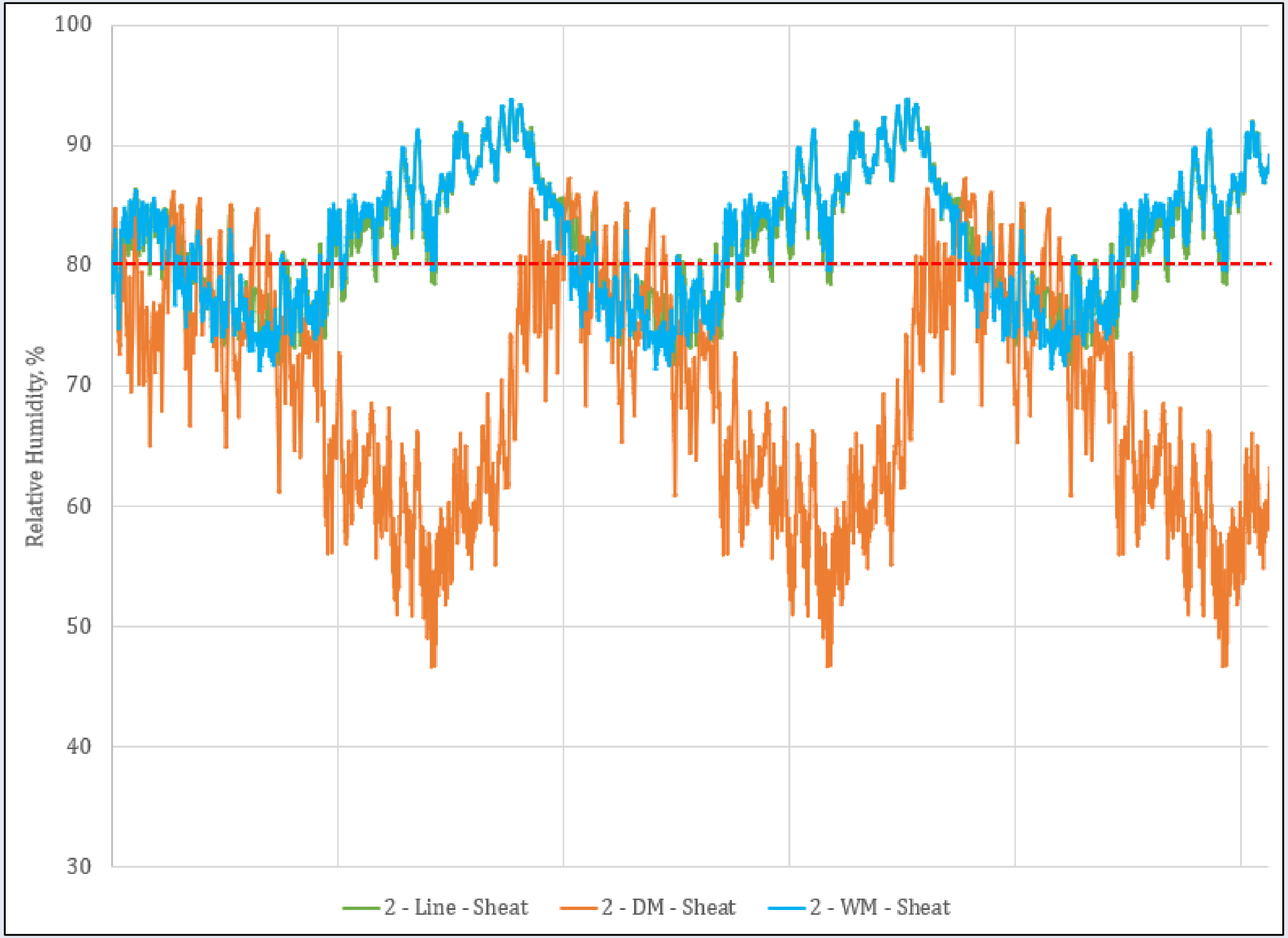


Membrane 2

Class II → Permeable

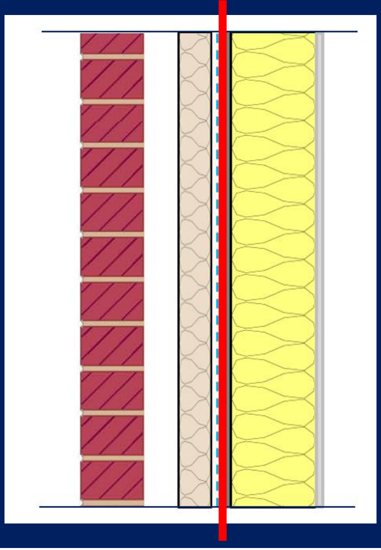
Exterior of Air Barrier Membrane

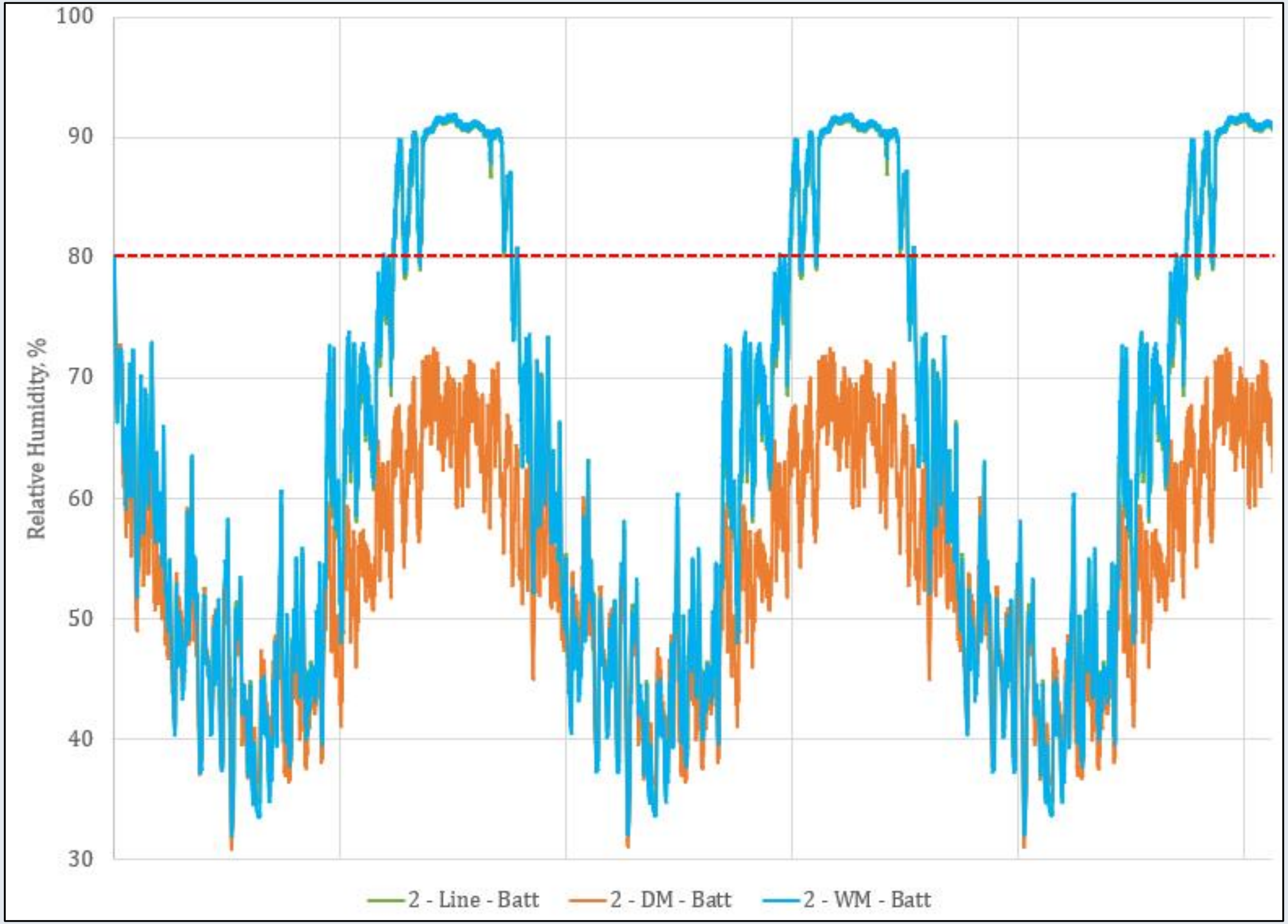




Membrane 2
Class II → Permeable

Exterior Sheathing

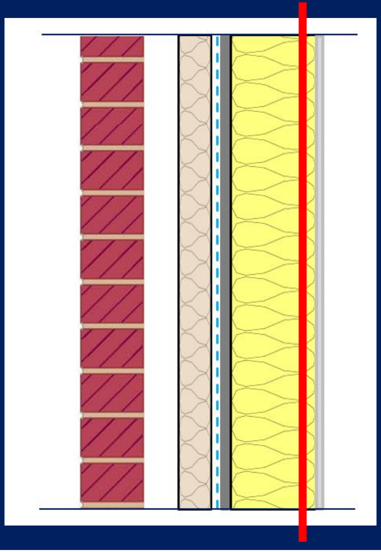




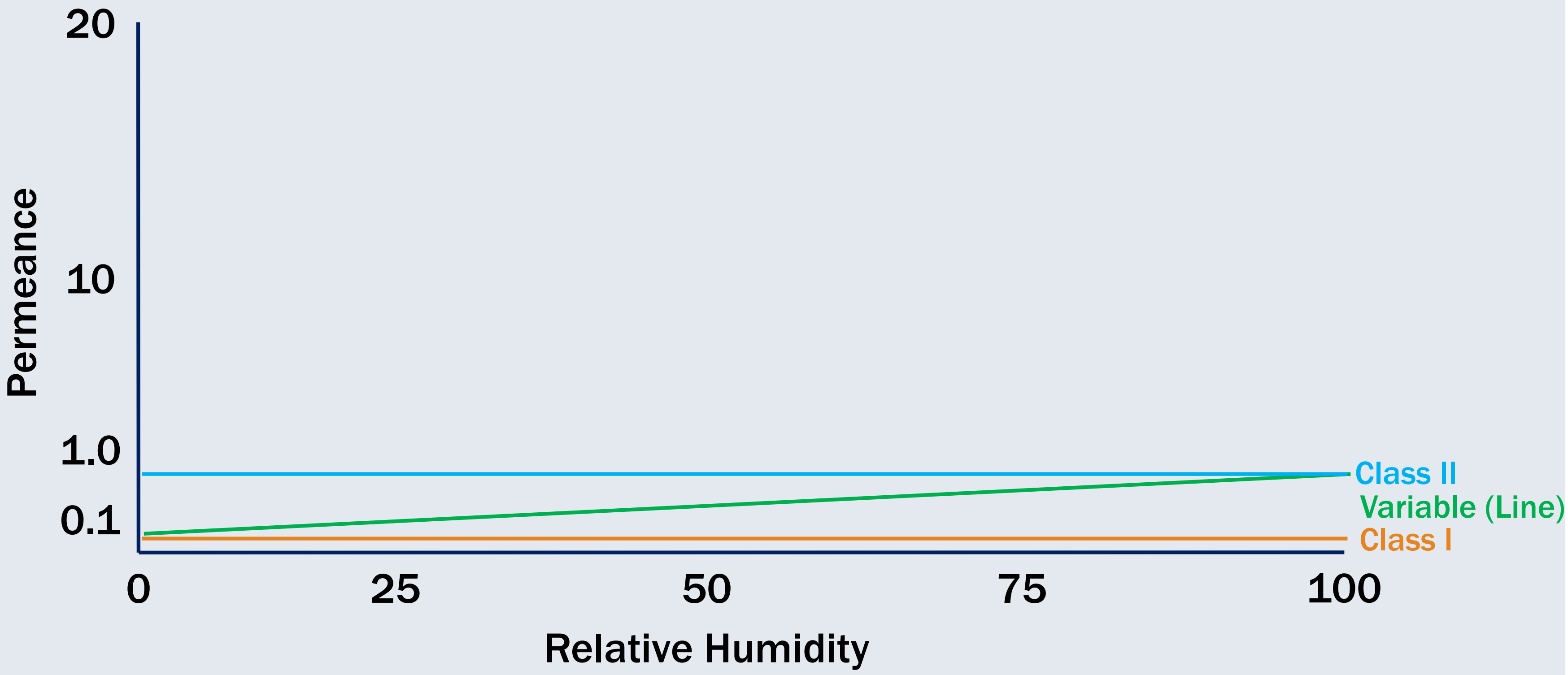
Membrane 2

Class II → Permeable

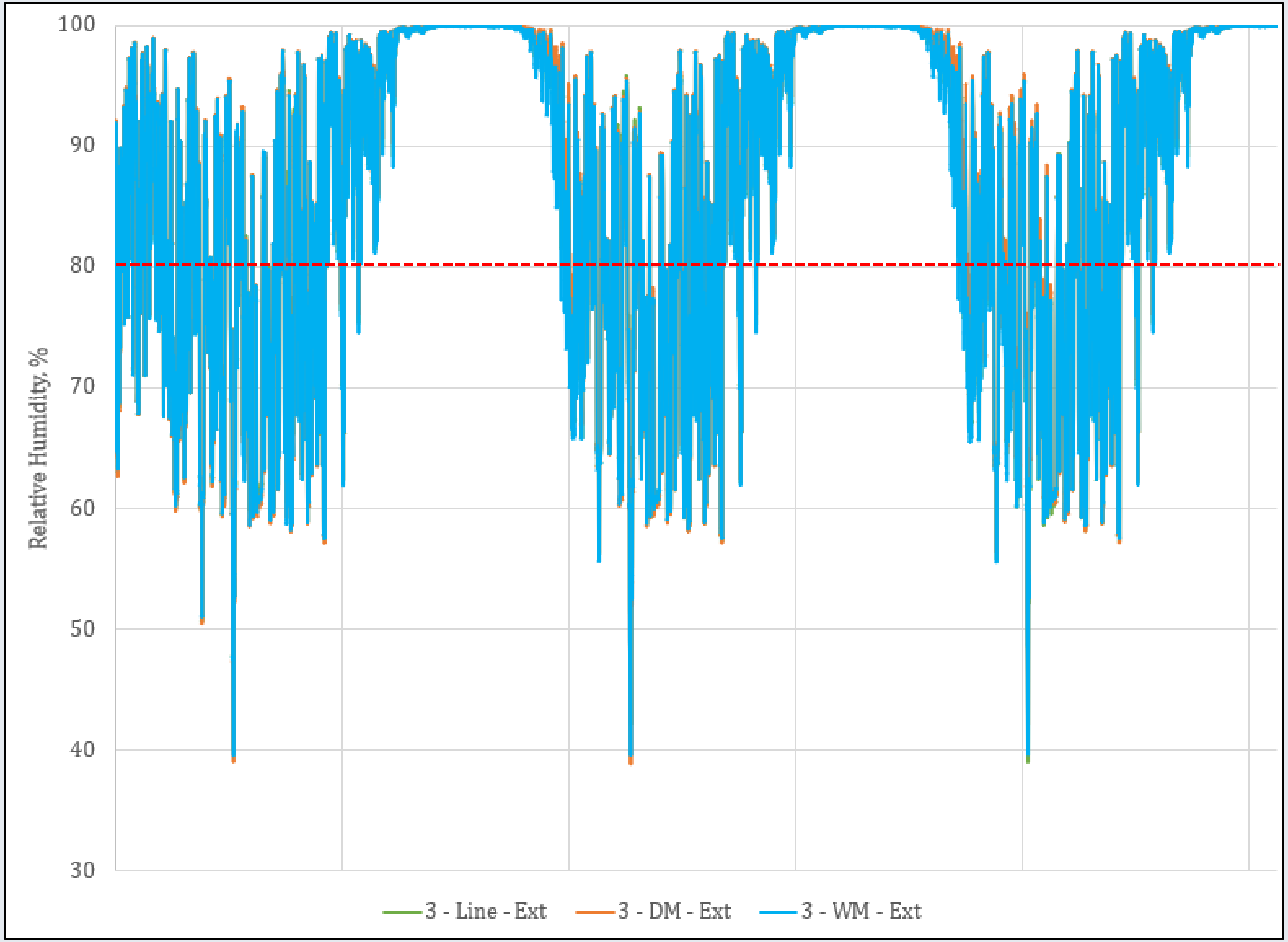
Interior Batt Insulation



Membrane 3



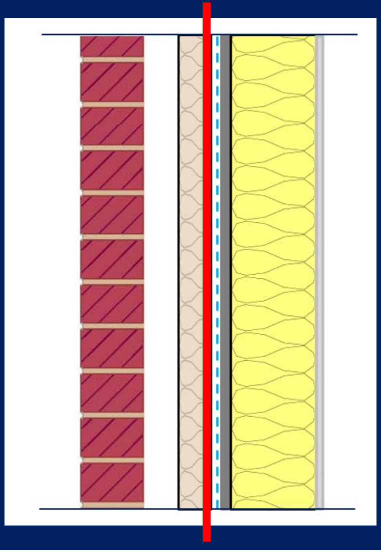
20
10
1.0
0.1
Permeance
Class II
Variable (Line)
Class I
0
25
50
75
100
Relative Humidity

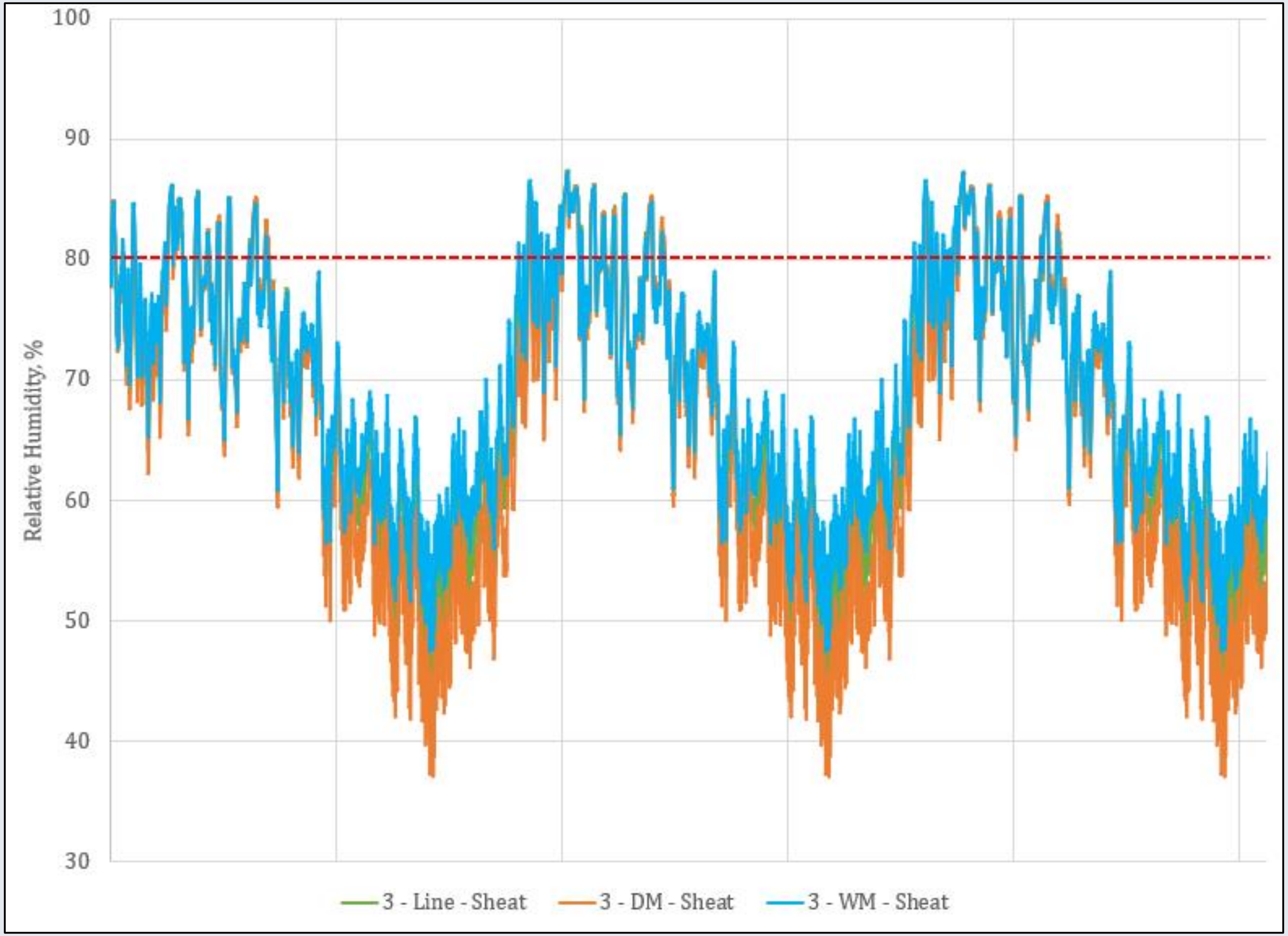


Membrane 3

Class I → Class II

Exterior of Air Barrier Membrane

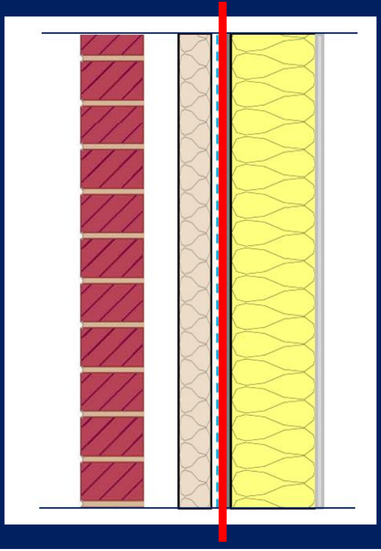


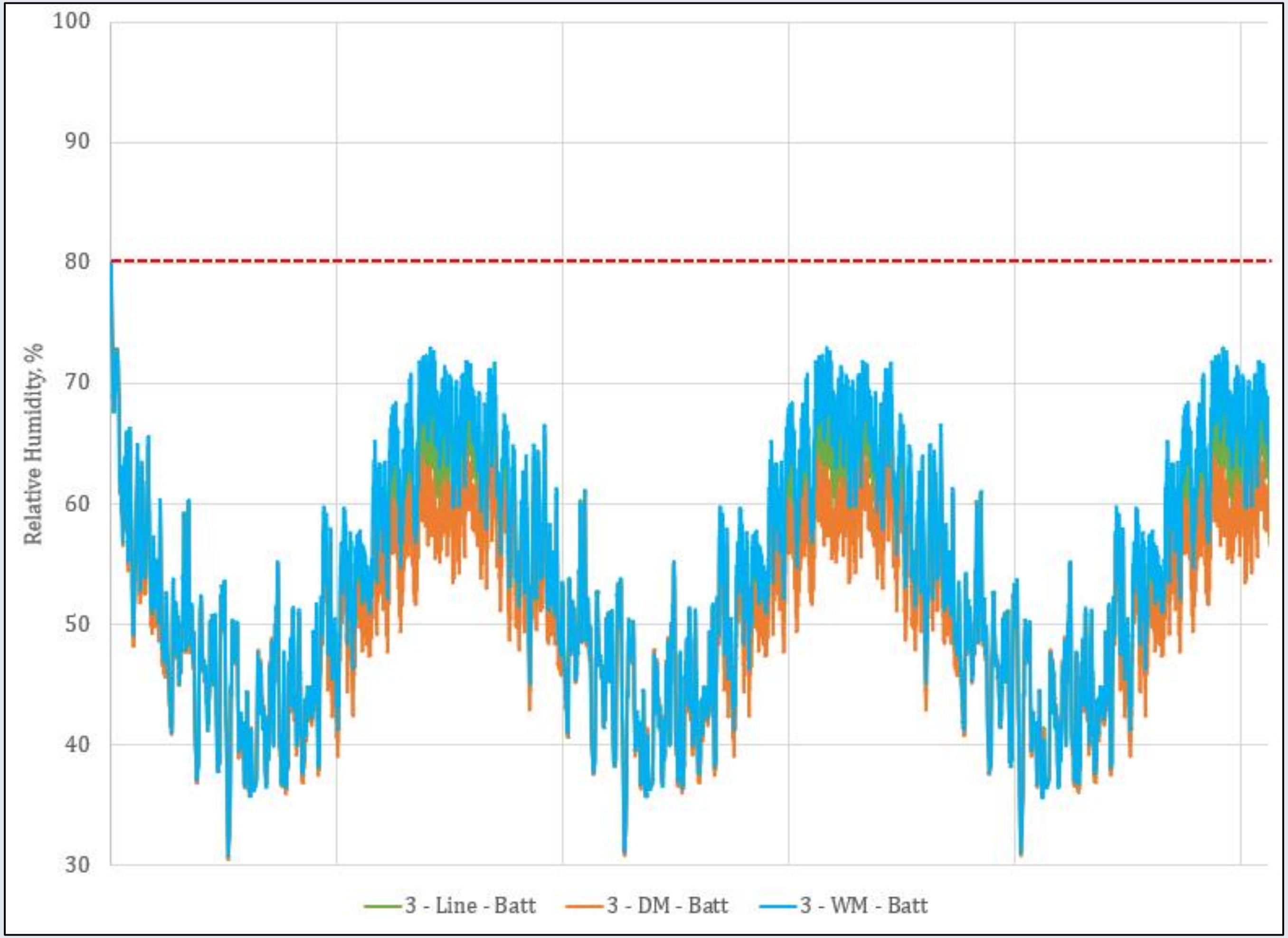


Membrane 3

Class I → Class II

Exterior Sheathing

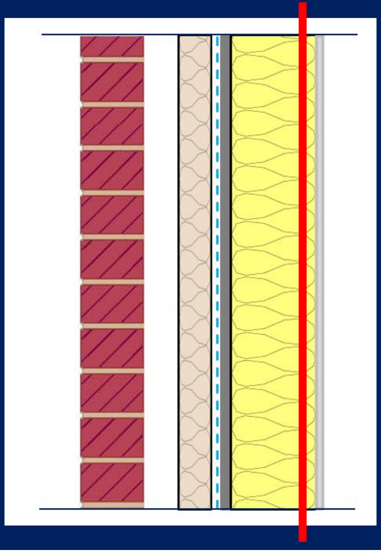




Membrane 3

Class I → Class II

Interior Batt Insulation



Conclusions

- Limited information gained from E96 Basic Test Methods
- Hygroscopic membranes can fluctuate in vapor permeance
- Carefully select and review vapor permeance properties of membranes for specific application

Questions?

Jodi Knorowski, P.E.
jknorowski@wdpa.com

ABAA EDUCATION

WDP & Associates