Water, Water Everywhere and Not a Drop to Drink

Practical Building Science to Keep Walls Dry

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Applied Building Technology Group (ABTG) is committed to using sound science and generally accepted engineering practice to develop research supporting the reliable design and installation of foam sheathing. ABTG's educational program work with respect to foam sheathing is supported by the Foam Sheathing Committee (FSC) of the American Chemistry Council.

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Foam sheathing research reports, code compliance documents, educational programs and best practices can be found at www.continuousinsulation.org.

Foam Plastic Applications for Better Building

Introduction

- Newer homes, materials and code requirements have changed the way “invisible” water (water vapor) must be managed to avoid it becoming visible in unwanted ways.
- Water vapor control is one of the trickiest and riskiest areas of building and energy code compliance.
- The old “rules of thumb” are no longer reliable or universal.
- This program will provide actionable prescriptive guidelines for integrated insulation and vapor control strategies.

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Session Learning Outcomes

- Understand 5 key building science concepts
- Know current U.S. & Canadian code requirements
- Learn simplified method of design to control water vapor
- Apply the method to evaluate solutions

Key Building Science Concepts (BSC's)

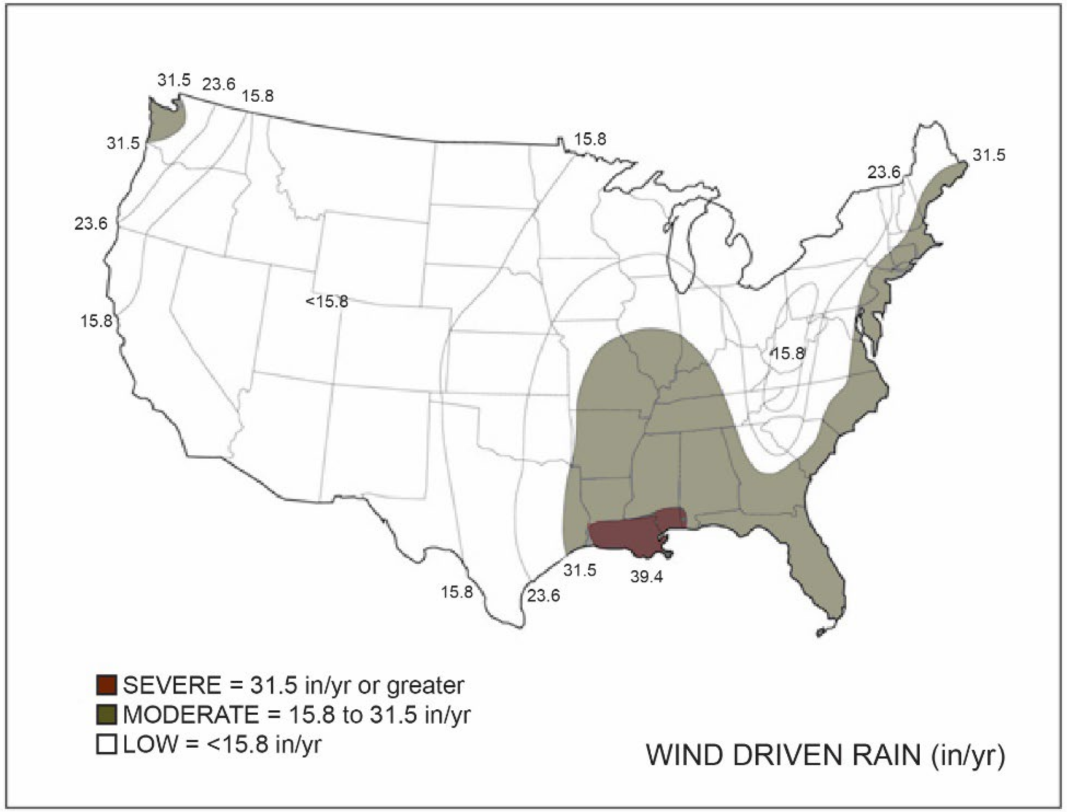
- Successful moisture control requires an integrated approach to 5 key building science concepts:

  1. **Control Rain Water Intrusion** (e.g., continuous water-resistive barrier)
  2. **Control Air Leakage** (e.g., continuous air barrier)
  3. **Control Indoor Relative Humidity** (e.g., building ventilation & de-humidification)
  4. **Control Initial Construction Moisture** (e.g., prevent enclosure of wet materials)
  5. **Control Water Vapor** (e.g., optimized balance of wetting and drying through strategic use of insulation and vapor retarders)

- All are important, all vary in significance, all have inter-dependencies.

BSC #1 – Rain Water Control

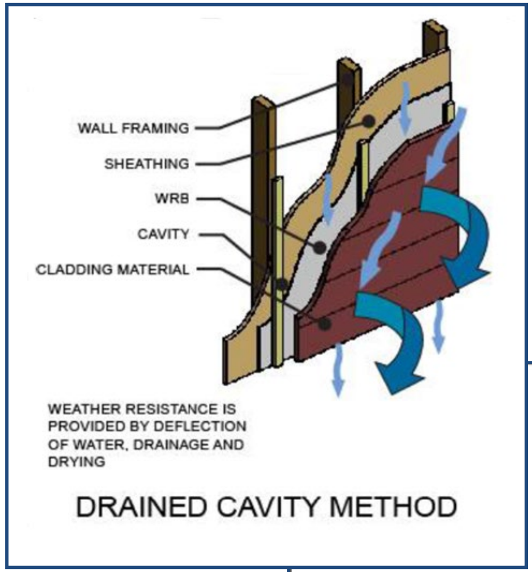
- Rain water control is often the primary factor associated with observed failure or success of moisture control.
- If rain water is not adequately controlled, other building science measures can be rendered ineffective.
- Concept is simple:
  Keep water out!

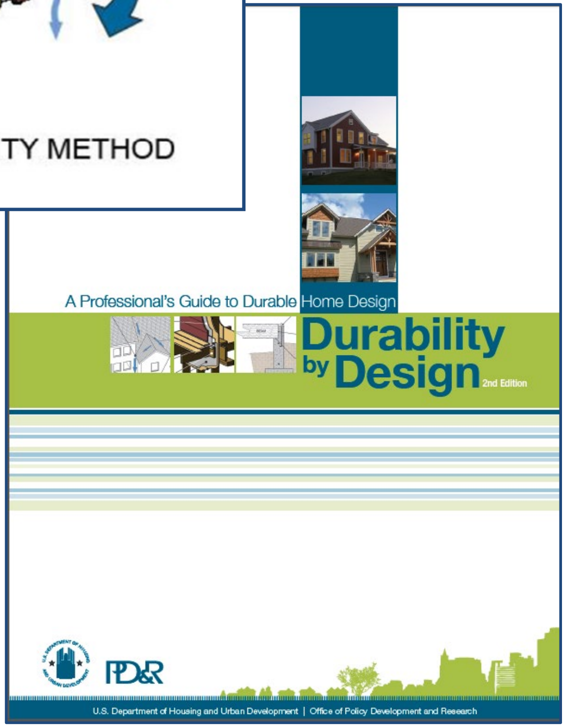


Wind driven rain is the primary hazard
(map based on UofGA research)

BSC #1 – Rain Water Control

- Select cladding type, windows & doors, and installation methods best suited to the local climate wind-driven rain hazard.
  - Durability by Design – 2nd Edition
  - Cladding type/method performance not differentiated in the code.





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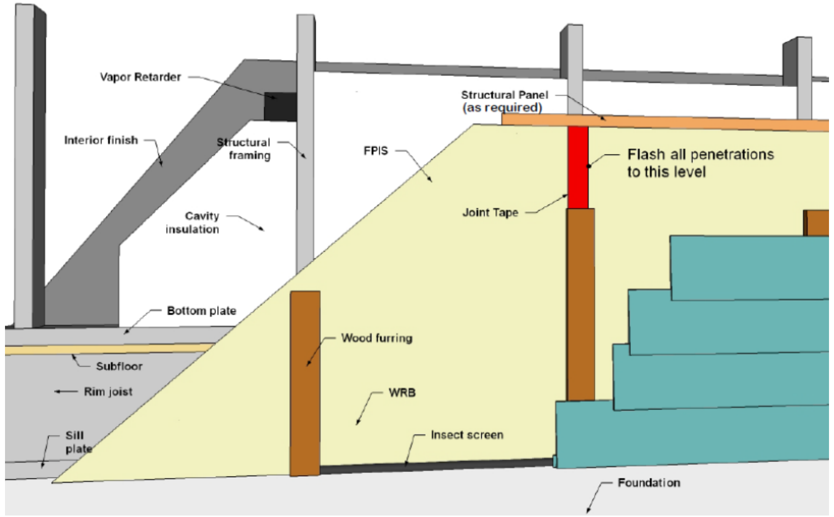
BSC #1 – Rain Water Control

- Use a code compliant water-resistive barrier (WRB) and flashing details at all penetrations for a continuous drainage plane behind the cladding
  - WHY? Claddings leak!
  - Required by code
- Pan flashing strongly recommended under all window sills and door thresholds
  - Why? Many windows/doors leak or will leak.
  - Code doesn't require plan flashing in any climate.



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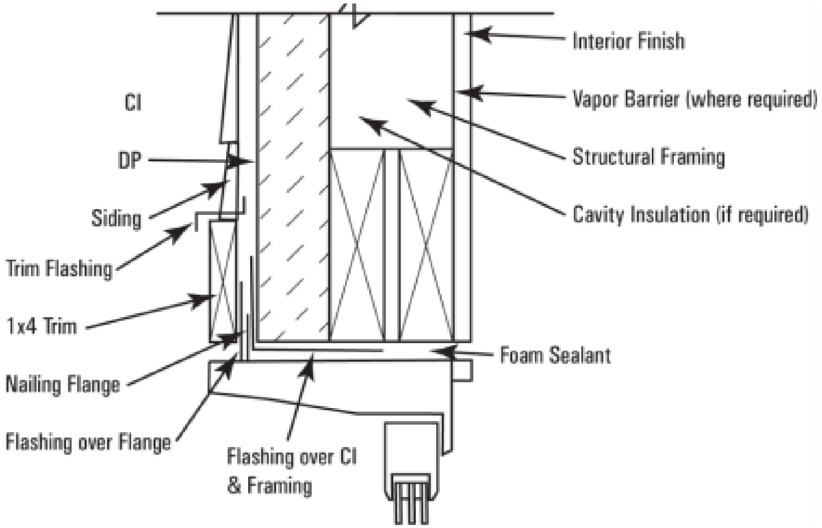
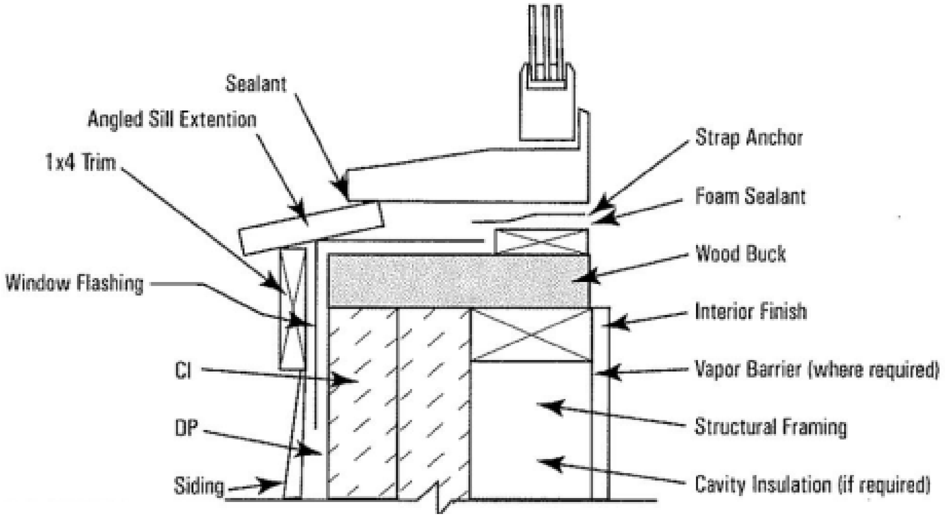
BSC #1 – Rain Water Control

- Integrate Window/Door/Flashing/WRB Manufacturer Installation Instructions
  - Why? This is not done for all possible combinations of approved materials and components that must be integrated
  - For integration examples, refer to continuousinsulation.org/window-installation for window installation recommendations.

- Inspect/Verify WRB and flashing prior to concealment by cladding
  - Why? Installation quality is important.





BSC #2 – Air Leakage Control

Lack of air leakage control can allow substantial amounts of moist/humid air into and through assemblies.

- Air can bypass vapor retarders, rendering them much less effective.
  - Increased risk of moisture problems such as condensation and mold
- Air can bypass insulation, rendering insulation less effective.
  - Increased energy bills

BSC #2 – Air Leakage Control

A continuous air-barrier (AB) is required by the International Energy Conservation Code (IECC). The IECC does not specify where the air barrier must be located

- Can be located on the interior, inside, or to the exterior side of walls

EPA Energy Star* requires AB on both sides of assemblies in cold climates (best practice and highly recommended).

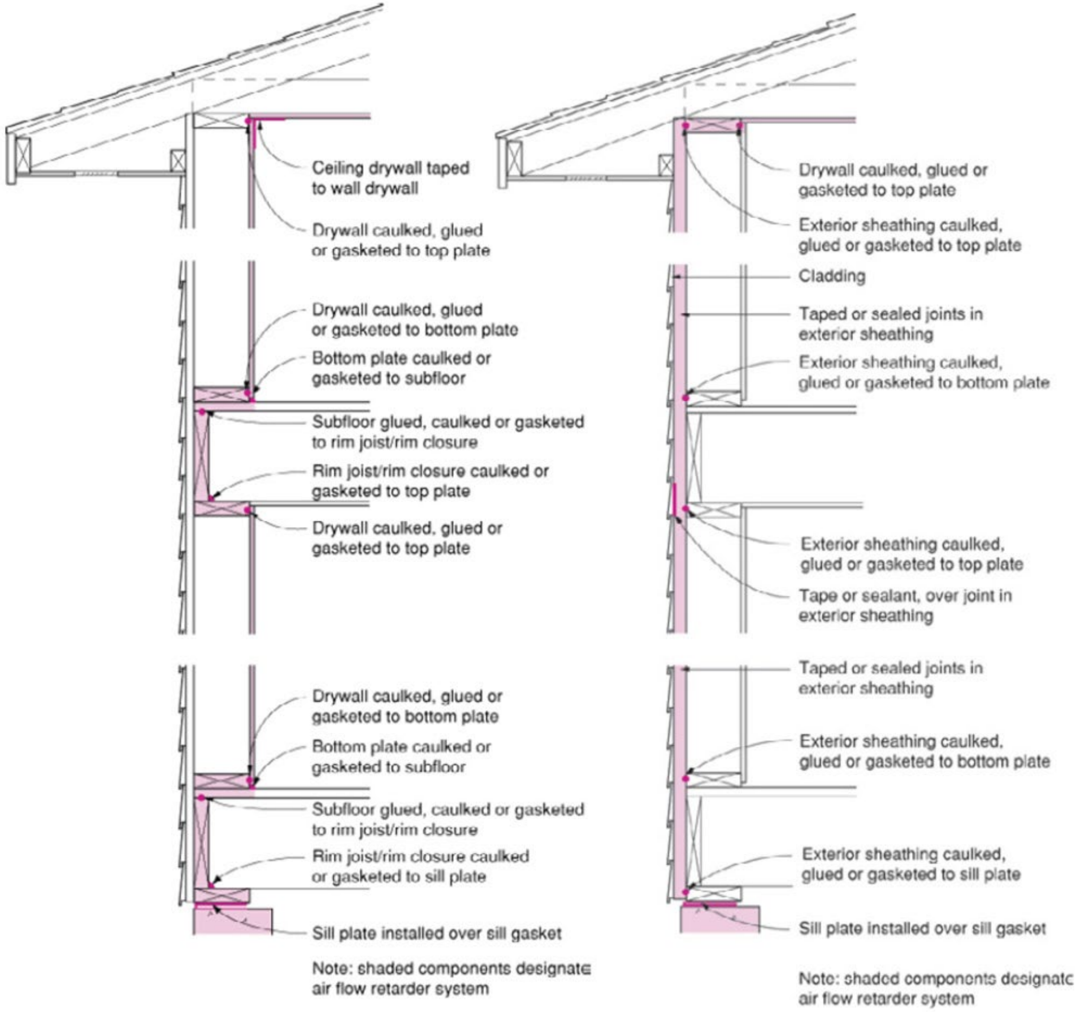
For additional guidance refer to:

- Durability by Design: A Professional's Guide to Durable Home Design
- Air Leakage Guide, US DOE, Building Technologies Program

BSC #2 – Air Leakage Control

Many materials and methods of AB installation are available:

- Exterior sheathing with sealed joints
- Sealed drywall installation
- Mechanically attached wraps with sealed joints
- Adhered membranes
- Spray-applied coatings
- Closed-cell spray foam



BSC #2 – Air Leakage Control

It's not just a material; it's a system!

- As with the WRB and flashing, the AB must be properly sealed at all joints and penetrations and discontinuities.
- Inspection and air-leakage testing are important for quality installations.

With proper design and location in an assembly, some air barrier materials may perform multiple roles (e.g., sheathing, insulation, vapor retarder, and air barrier all in one).

BSC #3 – Control Indoor Relative Humidity

- Excessive indoor relative humidity (RH) can also overwhelm any reasonable code-compliant building envelope design.
  - Acceptable indoor RH levels are not specified the code (or coordinated with vapor retarder and insulation requirements).
  - Include a relative humidity meter in the home for homeowner use and to guide proper operation of the home (avoid excessive indoor RH >> 40%).
- Building ventilation requirements in the code for indoor air quality purposes can help control indoor RH in the winter.
  - Whole building ventilation methods are better than spot ventilation.
  - Must be reasonably balanced to avoid increased air-leakage due to indoor-outdoor pressure imbalances.
- Proper sizing and specification of AC equipment can help control indoor RH in the summer.
  - Dehumidification should be considered and used as needed.

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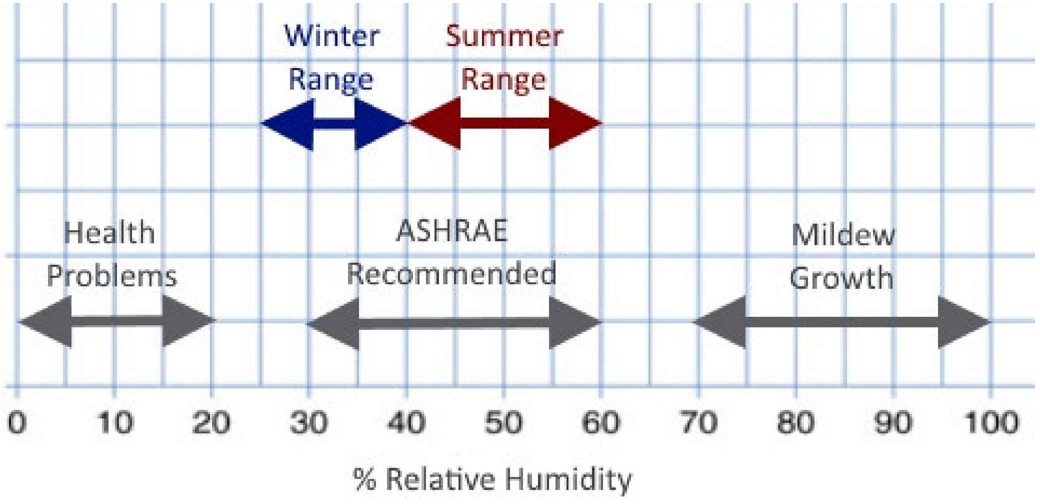
BSC #3 – Control Indoor Relative Humidity



- In general, summertime indoor RH should not exceed 60%.
- In the winter, max recommended RH varies by climate (25% to 40%).
  - Lower indoor RH needed in colder climates for water vapor control.
- Preferred indoor RH levels for building durability and occupant comfort can be in conflict.
  - Must control indoor RH or adjust water vapor control strategy accordingly.
- Special conditions require special solutions (e.g., pool rooms, saunas, hot tubs, etc.).

BSC #4 – Control Initial Construction Moisture

- Wet framing materials and wet-applied insulation materials can overwhelm the tolerance of materials and assemblies to withstand prolonged exposure to moisture and high water vapor drives.
- This issue mainly affects the initial year of building operation.
  - The solution varies based on the time of year a wall is enclosed with wet materials, which will determine the primary direction of vapor flow for drying.
- Can result in mold or moisture-related damage to materials such as moisture-sensitive sheathings and interior finishes, if not dried out in a timely manner.

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BSC #4 – Control Initial Construction Moisture

- Solutions are simple:
  - Don’t use wet materials and when they are wet, don’t close-in the assembly until they are dry.
  - Don’t install cavity insulation, vapor retarder, and interior finishes until the wall is dried-in (e.g., water-resistive barrier and all flashings completed).

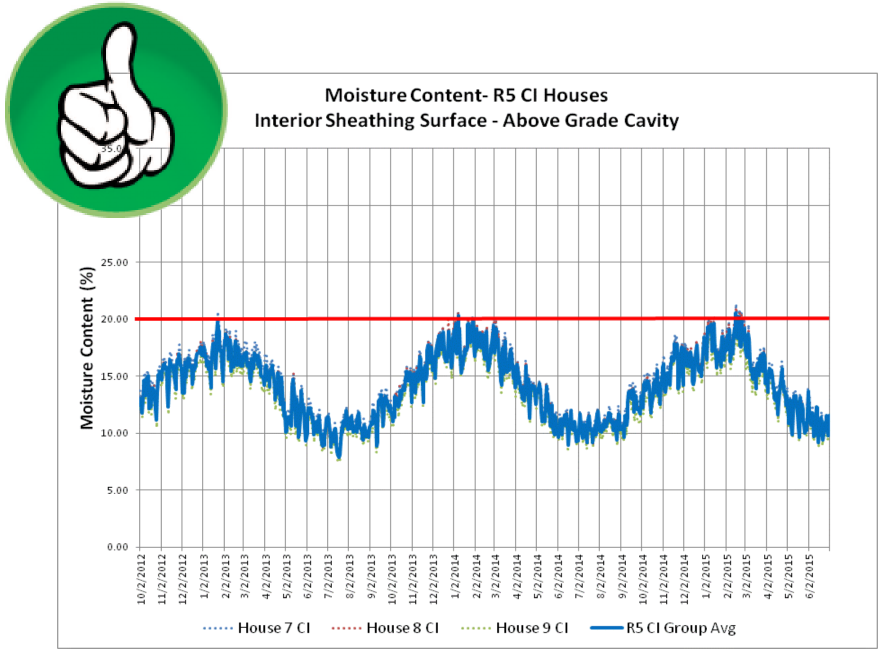
Storm water expelled from FG batt insulation installed prior to completion of the WRB and flashing

BSC #4 – Control Initial Construction Moisture

- TIP: Don’t dry buildings using gas/fuel fired heaters – water vapor is a primary combustion by-product!
    - Hot/humid air creates huge vapor drives and can slow drying rather than help it.
    - Use hot/dry air instead (electric heaters, dry air ventilation, etc.).

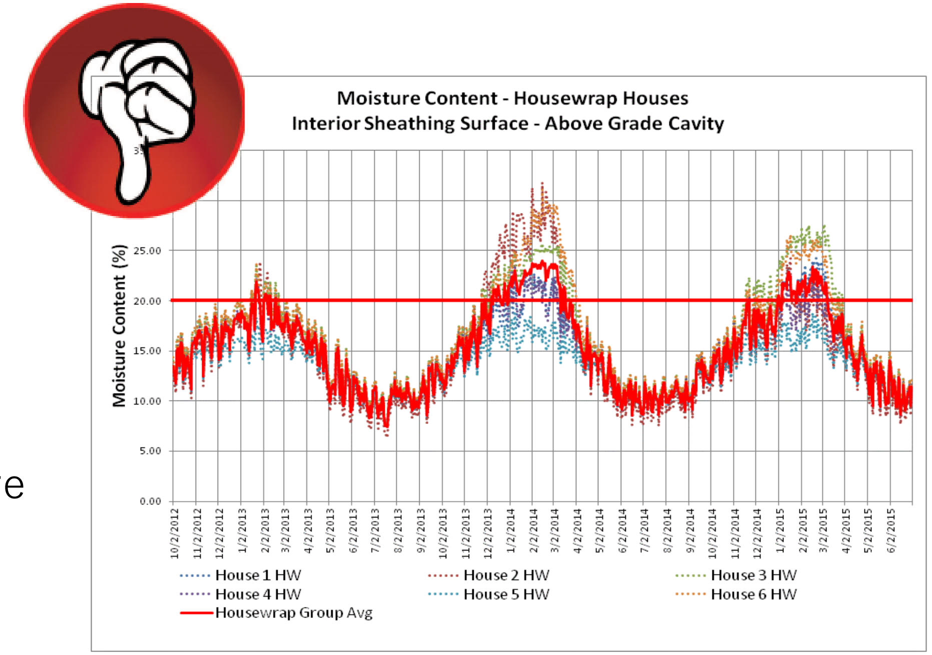
BSC #5 – Control Water Vapor

- Water vapor control involves two simple concepts:
  - Minimize the risk of the assembly getting wet due to water vapor diffusion (adsorption or condensation).
  - Optimize the ability of the assembly to dry in relation to its risk of getting wet.



Two "Code-Compliant" Walls:

- Left – moisture cycling <u>below</u> 20% MC
- Right – moisture cycling <u>above</u> 20% MC

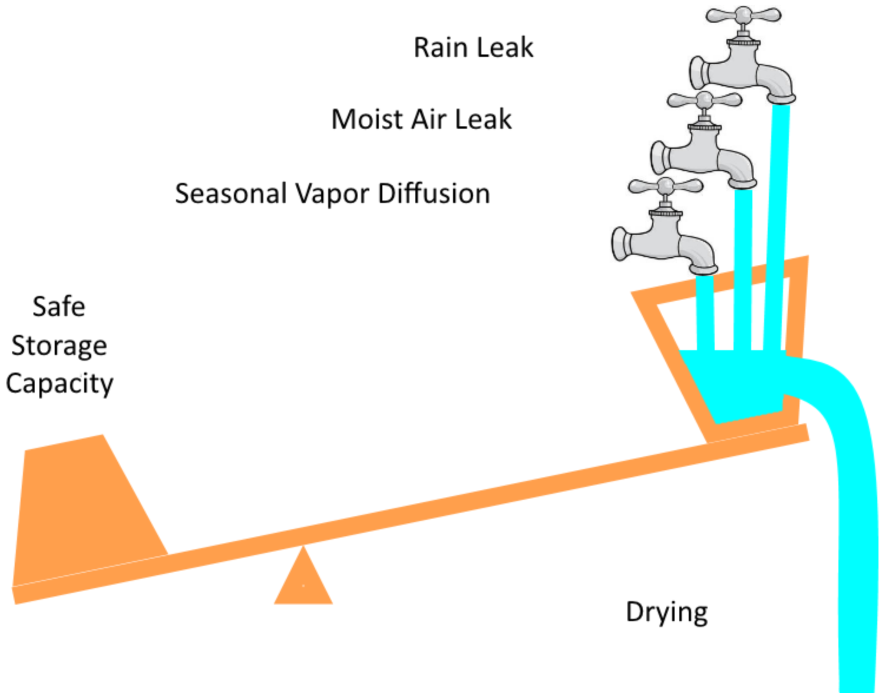


BSC #5 – Control Water Vapor

- While simple in concept, this practice involves consideration of several factors (not all addressed in code):
  - Climate and Indoor RH (boundary conditions)
  - Water vapor permeance (WVP) of exterior materials
    - Sheathing, WRB, etc.
  - WVP of interior materials
    - Interior vapor retarders in cold climates, or interior finishes in warm climates
  - Location and properties of insulation:
    - Cavity insulation R-value and its WVP
    - Exterior insulation R-value (continuous insulation) and its WVP

BSC #5 – Control Water Vapor

- It is truly a balancing act!
  - Risk of rain water wetting
  - Risk of air-leakage wetting
  - Wetting and drying by water vapor diffusion
- R-value and relative WVP of materials and their location within the assembly matters
  - Ability of materials to store and tolerate moisture also matters
- **GOAL:** Drying > wetting (in annual, not monthly/seasonal basis) to control risk of mold or water-sensitive material degradation



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BSC#5 – Control Water Vapor
(Addressing a common misconception)

- Also, there are different consequences for different types of wetting:
  - The first photo (above right) illustrates localized wetting from a leak and affirms the need for good WRB and flashing practices (e.g., pan flashing)
  - The second photo (lower left) deals with wetting over large areas that can occur due to inward water drives (too vapor permeable on the exterior) or inadequate wintertime condensation control (sheathing too cold, poor VR, poor AB, etc.).
- Neither consequence is good.
  - But, there is a way to avoid both of these consequences…

More on wall rot at: http://www.greenbuildingadvisor.com/blogs/dept/musings/all-about-wall-rot

Water Vapor Control: Putting BSC's to Practice

- The remainder of this presentation addresses the following water vapor control topics:
  - Terms to know (see handout))
  - Assessment of US and Canada building code requirements
  - Two unifying design methods for water vapor control
  - Framework for simplified design and example applications
  - Supplemental Design Considerations

Terms to Know

- **Vapor Retarder (VR):** A material in an assembly designated for purpose of serving as means to limit water vapor flow into or through the assembly.
  - Also known as a "vapour barrier" in Canada (material used as a vapor retarder having permeance of 1 perm or less).
  - In the U.S., the term "vapor barrier" is reserved for Class I vapor retarders (very low perm, 0.1 perm or less).

- **This definition does not mean that the vapor permeance and location of other materials in an assembly is not important!**

Terms to Know

- [2015 IBC/IRC] VAPOR RETARDER CLASS. A measure of the ability of a material or assembly to limit the amount of moisture that passes through that material or assembly. Vapor retarder class shall be defined using the desiccant method with Procedure A of ASTM E 96 as follows:
  - *Class I: 0.1 perm or less (e.g., polyethylene, foil facing, etc.)*
  - *Class II: 0.1 < perm <= 1.0 perm (e.g., Kraft paper, VR paints)*
  - *Class III: 1.0 < perm <= 10 perm (e.g., latex paint)*

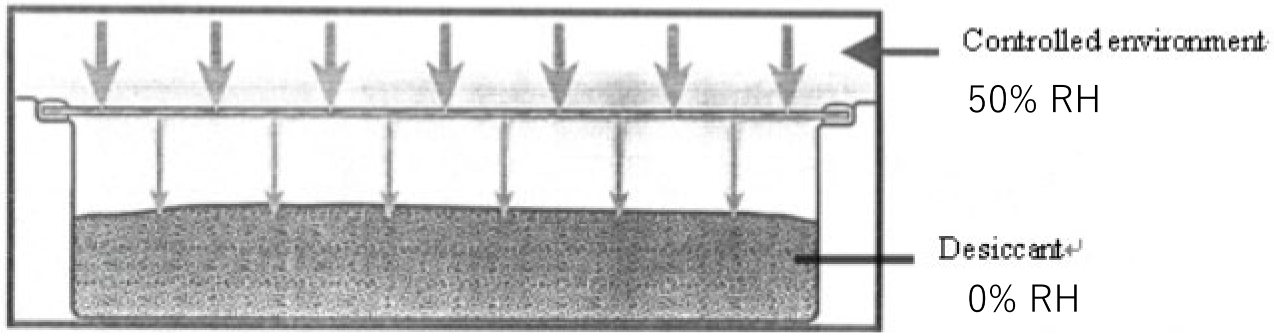
- Vapor retarder classes in the codes are not precise (e.g., a factor of 10 difference within a given class) but they help to generally communicate solutions and material selections.

Terms to Know

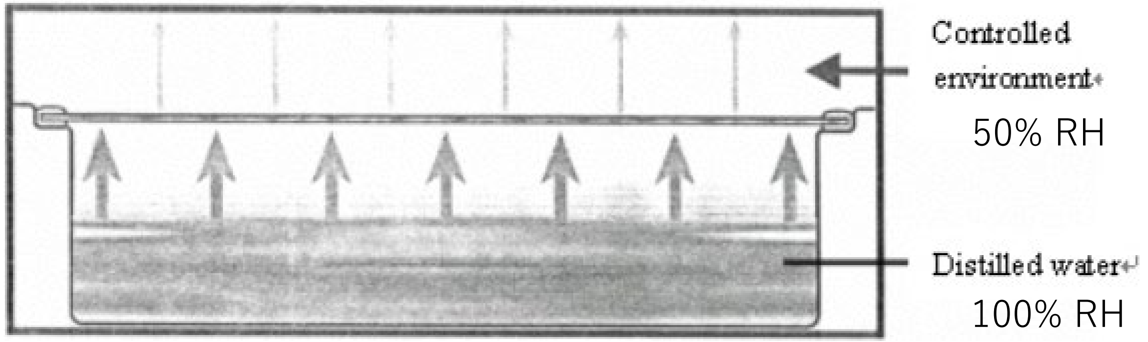
- **Water vapor permeance** (WVP): The property of a building material related to the ability of water vapor to diffuse through it; measured in "**perms**."
    - This property may vary depending on moisture content of the material as related to its surrounding conditions (e.g., relative humidity) – "smart vapor retarders" fall into this category (usually organic materials like Kraft paper, wood structural panels, or proprietary vapor retarder membranes).
- Low perm = relatively high resistance to water vapor flow
- High perm = relatively low resistance to water vapor flow

Terms to Know

- Water vapor permeance
  - WVP is usually measured by ASTM E96 (dry cup) method which relates to 25% average relative humidity at room temperature.
  - ASTM E96 (wet cup) method relates to 75% average relative humidity condition and may be more relevant to some applications (e.g., materials on the exterior)



Dry Cup Method

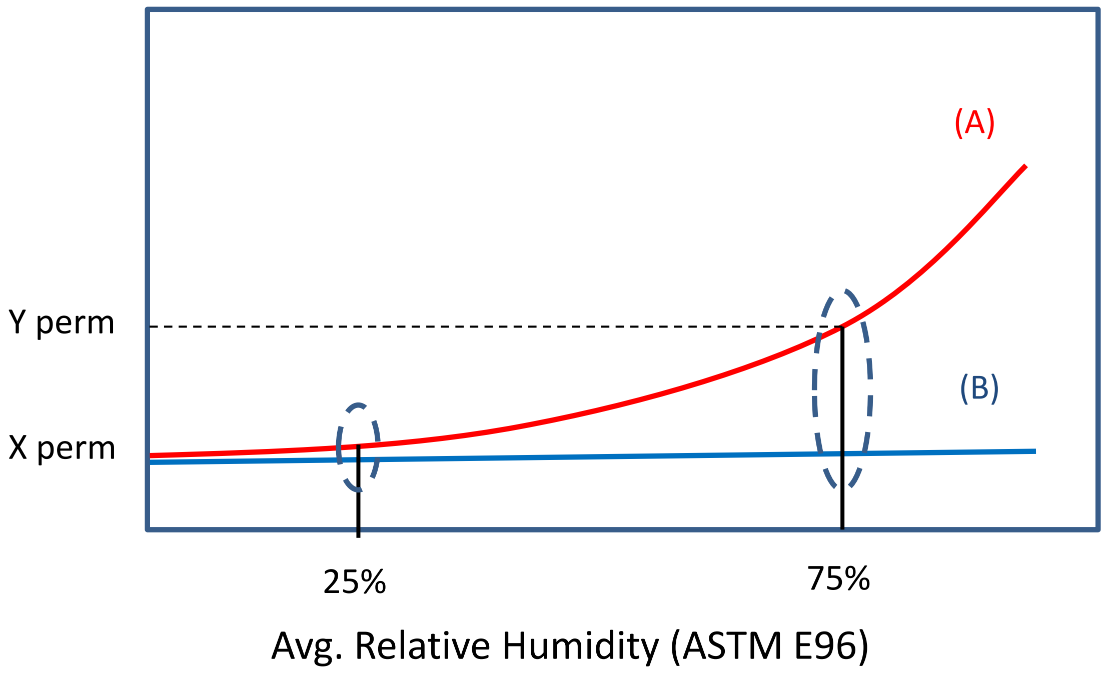


Wet Cup Method

http://www.labthink.com/en-us/literatures/an-outline-of-standard-for-cup-method-water-vapor-permeability-testing.html

Terms to Know

- Water Vapor Permeance
  - Materials that are hygrophyllic (organic) tend to have WVP that changes significantly with the ambient relative humidity (A)
  - Materials that are not hygrophyllic (non-organic) tend to have WVP that changes little with the ambient humidity (B)
- Thus, wet-cup **and** dry-cup WVP per ASTM E96 can better inform material selection and design for water vapor control



Terms to Know

- **[2015 IBC/IRC] VAPOR PERMEABLE.** The property of having a moisture vapor permeance rating of 5 perms (2.9 x 10-10 kg/Pa · s · m2) or greater, where tested in accordance with the desiccant method using Procedure A of ASTM E 96. A vapor permeable material permits the passage of moisture vapor.

- Other classifications: semi-permeable, semi-impermeable, impermeable (varying degrees of vapor retardance)

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Ballpark Examples of Water Vapor Permeance

- All materials, regardless of what they are called, have some measure of resistance to water vapor flow…

Air film = 120+ perm
(Still air, 1” thick – most air is “moving”, so effective permeance is much higher)

Fiberglass/mineral fiber = 116 perms
Batt insulation (without facer), 1” thick

Drywall = 50 perm
(unpainted)

Lap siding = 10 perm
(wood/painted) to 40 perm
(vinyl/vented)

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More examples...

Latex paint film = 3 to 30 perm
(primer + 1-2 coats)

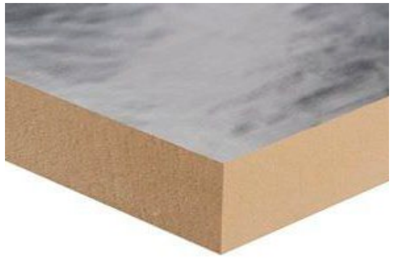
House wraps = 5 to 50 perm
(depending on type)

No.15 asphalt felt paper =
1 perm (dry cup) to
5 perm (wet cup)

1” thick polystyrene insulation =
~1 perm to 5 perm
No facer. Depending on type/density. Decreases with increased thickness or added facers.

OSB or plywood = 0.7 to 1 perm (dry cup)
or 1.5 to 10 perm (wet cup)
OSB is lower perm than plywood

Kraft paper = 0.3 perm (dry cup) or
1.8 perm (wet cup)



Foil faced plyiso insulation < 0.1 perm

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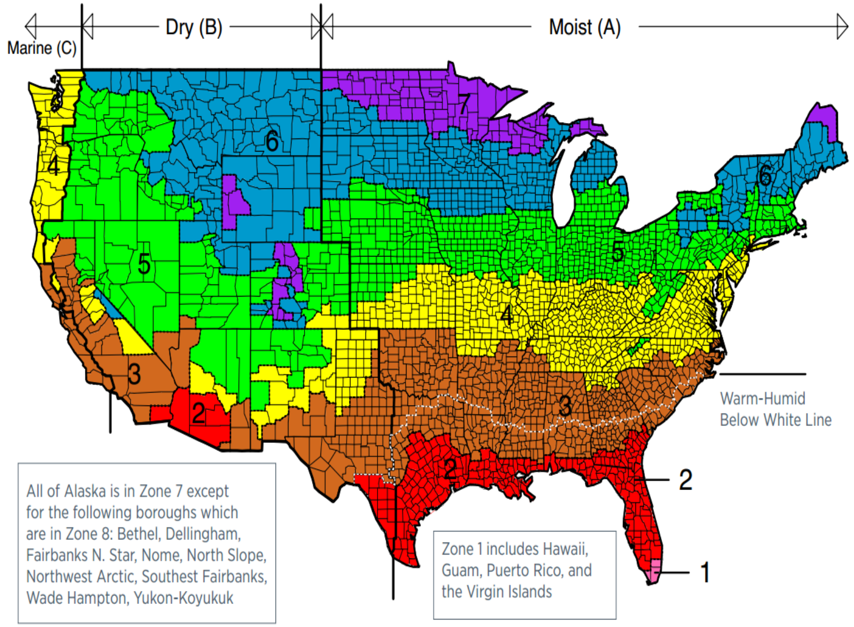
Current U.S. Building Code Requirements

- 2015 IBC and IRC provisions are similar
- 2015 IRC (one and two family dwellings):
  - R702.7 doesn't say not to put a Class I or II VR on the interior side in CZ 1-3!
  - Silent on exterior permeance limits with Class I or II VR
  - Silent on minimum insulation ratio with Class I or II VR

R702.7 Vapor retarders. Class I or II vapor retarders are required on the interior side of frame walls in Climate Zones 5, 6, 7, 8 and Marine 4.

Exceptions:

1. Basement walls.
2. Below-grade portion of any wall.
3. Construction where moisture or its freezing will not damage the materials.



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Current U.S. Building Code Requirements

- Class III vapor retarder is permitted as an alternative to Class I or II VR for two cases:
  - **Vented Cladding**: In this case, exterior permeance is controlled prescriptively by requiring use of vented cladding with limitations on types of sheathing by climate zone (permeance controlled design).
  - **Continuous Insulation**: In this case, insulation ratio is controlled for applications of continuous insulation (temperature controlled design)

TABLE R702.7.1
CLASS III VAPOR RETARDERS

CLIMATE ZONE	CLASS III VAPOR RETARDERS PERMITTED FOR:[a]
Marine 4	Vented cladding over wood structural panels. Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 2.5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 3.75 over 2 × 6 wall.
5	Vented cladding over wood structural panels. Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 7.5 over 2 × 6 wall.
6	Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 7.5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 11.25 over 2 × 6 wall.
7 and 8	Continuous insulation with *R*-value ≥ 10 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 15 over 2 × 6 wall.

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Current U.S. Building Code Requirements

- BUT, now this reveals some gaps in the code!
  - How much continuous insulation is needed if a Class I or II vapor retarder is used?
  - Under what condition should vented cladding or a higher perm exterior sheathing be required for use of a Class II vapor retarder?
  - What about "double vapor barriers"?

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7 and 8	Continuous insulation with *R*-value ≥ 10 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 15 over 2 × 6 wall.

Current Canadian Building Code (NBC 2010)

- Only recognizes use of 1 perm or less vapor retarder on inside (warm-in-winter side) of assembly.
  - Same as Class I or Class II vapor retarder in U.S. codes
  - Polyethylene VR and AB commonly used
  - Does NOT recognize use of a Class III vapor retarder

- Recognizes special design needed for buildings with high internal moisture loads (e.g., high indoor RH).

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Current Canadian Building Code (NBC)

- NBC Part 9 (housing and light-commercial) includes requirements for use of low perm (less than 1 perm) material layers on the exterior side (Section 9.25.5.2)
  - Requires use of exterior insulation meeting minimum insulation ratio (ci R-value / Cavity R-value)
  - First introduced in the 1995 edition of NBC

Heating Degree Days (HDD18C)	Minimum Ratio of Total Thermal Resistance Outboard of Material's Inner Surface to Total Thermal Resistance Inboard of Material's Inner Surface
Up to 4999	0.20
5000 to 5999	0.30
6000 to 6999	0.35
7000 to 7999	0.4
8000 to 8999	0.5
9000 to 9999	0.55
10,000 to 10999	0.6
11000 to 11999	0.65
12000 or higher	0.75

1 HDD(18°C) = 1.8 HHD(65°F)

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The Insulation Ratio Concept

- Same principle as insulation ratios (exterior ci R-value) used for Class III VR in U.S. codes
  - See adjacent table as basis for IRC Table R702.7.1.
- Same principle used for above-deck roof insulation in millions of square feet of low-slope commercial building roofs.

TABLE 1
Minimum Insulation Ratio (R_e/R_i)
for Use with a Class III Interior Vapor Retarder

CLIMATE ZONE	Maximum Heating Degree Days (HDD65°F)	Minimum R_e/R_i Ratio
Marine 4	5,400	0.2
5	7,200	0.35
6	9,000	0.5
7	12,600	0.7

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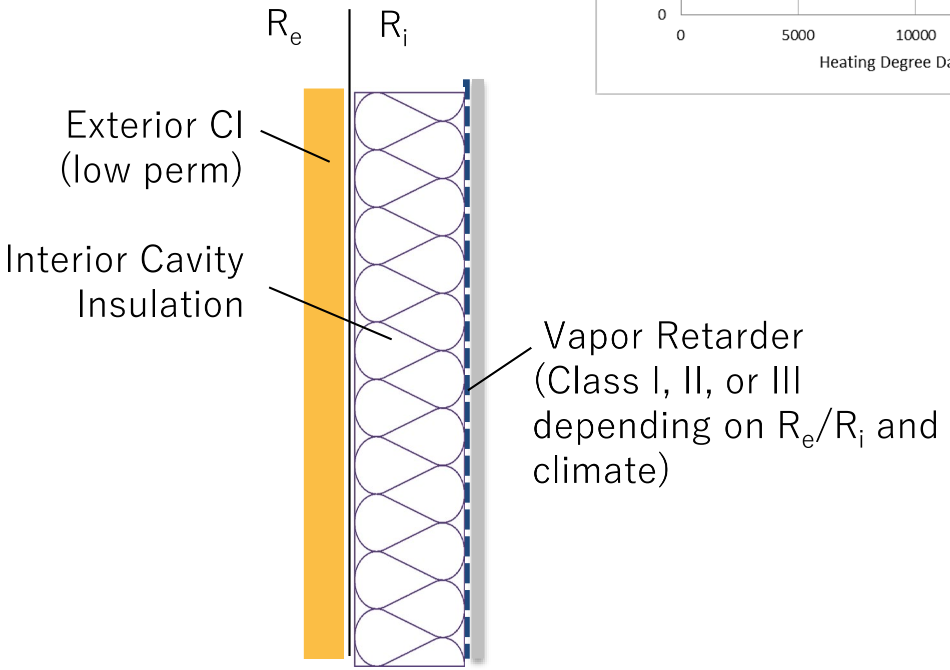
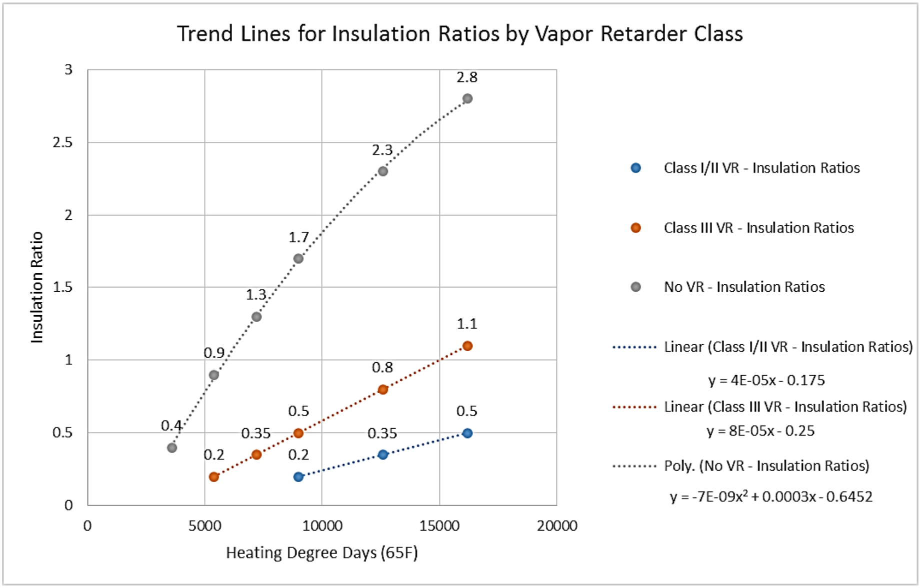
The Insulation Ratio Concept

- Keep the inside of the wall warm in the winter!
- This is the key concept of the “temperature controlled” design approach to manage water vapor.
- Simple to determine:
  - Insulation ratio = R_e/R_i

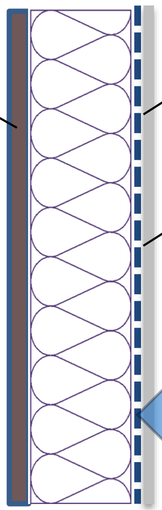




SUMMARY:
US Code + Canadian Code = Complete Approach

- U.S. codes give incomplete guidance.
- Canadian code gives incomplete guidance.
- Both taken together are reasonably complete.
    - **SOLUTION**: Unify North American codes and experience and investigate need for any incremental improvements.

Two Unifying Design Approaches – Same Objective



Condensation plane (winter)

Vapor permeable exterior (non-insulated)

Condensation plane (summer)

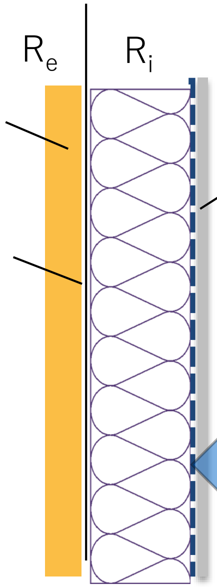
'Strong' vapor retarder

Restricted vapor flow to cold surfaces

Tendency to dry to the exterior during Winter

Water Vapor Source
Indoor RH (winter)
Outdoor RH (summer)

The Water Vapor Control Triangle



Exterior CI (low perm)

Warm surface (restrict dew point occurrences)

'Modest' vapor retarder

Moderated vapor flow in winter

Tendency to dry to the interior during Spring, Summer, & Fall

Control Moisture Vapor Diffusion
Control of vapor flow into and out of an assembly (flow direction changes with seasons)

Control Internal Surface Temperatures
Control surface temperatures to prevent moisture condensation or high surface humidity

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Two Unifying Design Approaches – Different Emphasis

Permeance controlled design

- Applies to walls:
  - Without exterior insulation
  - Or, with vapor-permeable exterior insulation
- Relies on permeance of all interior and exterior layers
  - Interior & exterior must be checked and balanced!
  - Permeance of exterior materials not always known or reliably reported/controlled
  - Not required to be checked by US code (except HUD Code has permeance ratio)

Temperature controlled design

- Applies to walls:
  - With exterior insulation of any permeance
  - Including very low perm
- Only requires control of insulation ratio (R_e/R_i)
  - Insulation ratio varies by climate and in relation to selected interior vapor retarder

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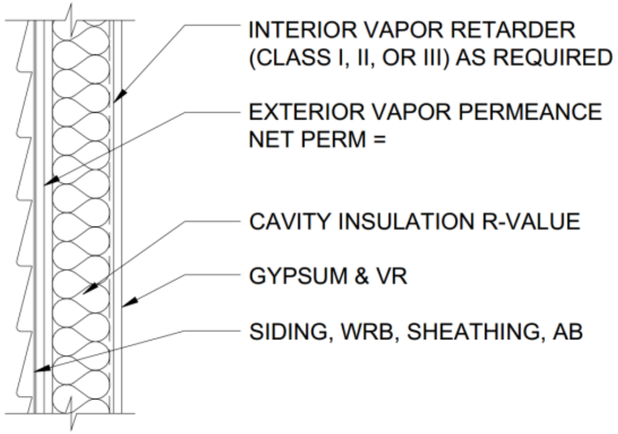
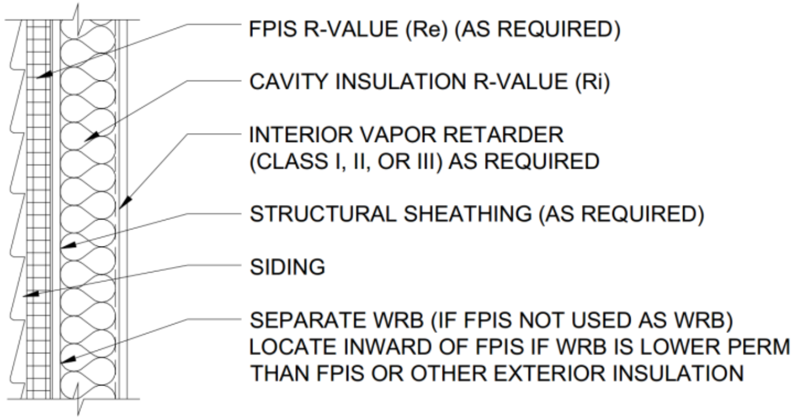
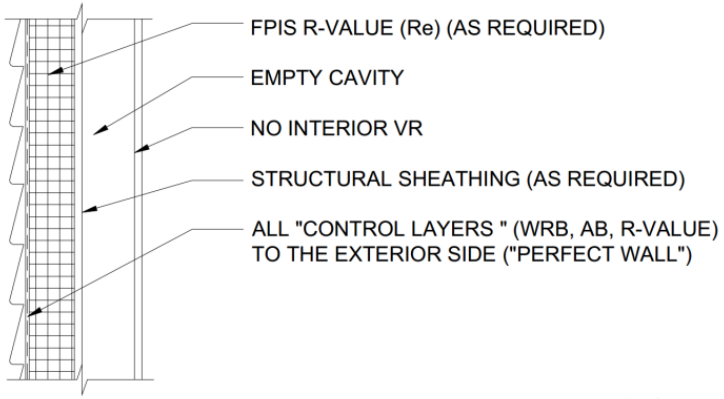
Two Unifying Design Approaches – Many Applications

- Non-material specific and impartial
- Covers a wide range of wall designs:

CAVITY INSULATION ONLY ➔CAVITY + CONTINUOUS HYBRID ➔CONTINUOUS ONLY







Framework for Water Vapor Control

(using prescriptive "cook book" designs)

Design Logic Flow (Applies equally to all methods)	Climate Zone – Figure 1	Method A: Permeance Control with Predominant Drying to Exterior (e.g., Cavity Insulation Walls) SEE FIGURE A1			Method B: Temperature Control with Predominant Drying to Interior (e.g., Continuous Insulation Walls) SEE FIGURE A2			
(1) Interior Vapor Permeance ➔		Interior Vapor Retarder Class			Interior Vapor Retarder Class			
		I (perm≤0.1)	II (0.1<perm≤1)	III (1<perm≤10)	I (perm≤0.1)	II (0.1<perm≤1)	III (1<perm≤10)	None
(2) Exterior Vapor Permeance ➔		Minimum Total Exterior Permeance[c,d]			Minimum Total Exterior Permeance[d]			
	1	NP (IBC 2015)	NP (IBC 2015)	No minimum	NP (IBC 2015)	NP (IBC 2015)	No Minimum	No Minimum
	2	NP (IBC 2015)	NP (IBC 2015)	No minimum	NP (IBC 2015)	NP (IBC 2015)	No Minimum	No Minimum
	3	NP (IBC 2015)	No minimum	No minimum	NP (IBC 2015)	No Minimum (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum	No Minimum
	4	NP (IBC 2015)	0.5 perm	3 perm[e]	NP (IBC 2015)	No Minimum (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum	No Minimum
	5	0.5 perm[f]	3 perm	5 perm[e]	See Note 'f' (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum	No Minimum
	6	1 perm	5 perm	15 perm[e]	See Note 'f' (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum	No Minimum
	7	1 perm	10 perm	NP (IBC/IRC 2015)	See Note 'f' (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum	No Minimum
	8[b]	1.5 perm	NP	NP (IBC/IRC 2015)	See Note 'f' (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum (NOTE: IBC 2015 requires Class III VR if FPIS < 1 perm)	No Minimum	No Minimum

Design Logic Flow	Climate Zone – Figure 1	Method A: Maximum Cavity Insulation R-value[g]	Method B: Maximum Cavity Insulation R-value[g] (Ri): I		II		III		None
(3) Cavity Insulation Conditions ➔		R28 (up to 2x8 construction)	2x4 (R-13)	2x6 (R-20)	2x4 (R-13)	2x6 (R-20)	2x4 (R-13)	2x6 (R-20)	Not required (max R-5)

Design Logic Flow	Climate Zone – Figure 1	Method A: Minimum R-value for Continuous Insulation: I	II	III	Method B: Minimum R-value for Continuous Insulation (Re)[h,i]: I 2x4	I 2x6	II 2x4	II 2x6	III 2x4	III 2x6	None
(4) Continuous Insulation Requirements ➔	1	NP (IBC 2015)	NP (IBC 2015)	Re=0ci, No continuous insulation required	NP (IBC 2015)	NP (IBC 2015)	NP (IBC 2015)	NP (IBC 2015)	R-2ci	R-2ci	R-2ci
	2	NP (IBC 2015)	NP (IBC 2015)	Re=0ci, No continuous insulation required	NP (IBC 2015)	NP (IBC 2015)	NP (IBC 2015)	NP (IBC 2015)	R-2ci	R-2ci	R-2ci
	3	NP (IBC 2015)	Re=0ci, No continuous insulation required	Re=0ci, No continuous insulation required	NP (IBC 2015)	NP (IBC 2015)	R-2ci	R-2ci	R-2ci	R-2ci	R-2ci
	4	NP (IBC 2015)	Re=0ci, No continuous insulation required	Re=0ci, No continuous insulation required	NP (IBC 2015)	NP (IBC 2015)	R-2ci	R-2ci	R-2.5ci (Re/Ri=0.2)	R-3.8ci (Re/Ri=0.2)	R-4.5ci (Re/Ri=0.9)
	5	Re=0ci, No continuous insulation required	Re=0ci, No continuous insulation required	Re=0ci, No continuous insulation required	R-2.6ci (Re/Ri=0.2)	R-4.0ci (Re/Ri=0.2)	R-2.6ci (Re/Ri=0.2)	R-4.0ci (Re/Ri=0.2)	R-4.6ci (Re/Ri=0.35)	R-7.0ci (Re/Ri=0.35)	R-6.5ci (Re/Ri=1.3)
	6	Re=0ci, No continuous insulation required	Re=0ci, No continuous insulation required	Re=0ci, No continuous insulation required	R-2.6ci (Re/Ri=0.2)	R-4.0ci (Re/Ri=0.2)	R-2.6ci (Re/Ri=0.2)	R-4.0ci (Re/Ri=0.2)	R-6.5ci (Re/Ri=0.5)	R-10ci (Re/Ri=0.5)	R-8.5ci (Re/Ri=1.7)
	7	Re=0ci, No continuous insulation required	Re=0ci, No continuous insulation required	NP	R-4.6ci (Re/Ri=0.35)	R-7.0ci (Re/Ri=0.35)	R-4.6ci (Re/Ri=0.35)	R-7.0ci (Re/Ri=0.35)	R-10ci (Re/Ri=0.8)	R-16ci (Re/Ri=0.8)	R-12ci (Re/Ri=2.3)
	8[b]	Re=0ci, No continuous insulation required	NP	NP	R-6.5ci (Re/Ri=0.5)	R-10ci (Re/Ri=0.5)	R-6.5ci (Re/Ri=0.5)	R-10ci (Re/Ri=0.5)	R-14ci (Re/Ri=1.1)	R-22ci (Re/Ri=1.1)	R-14ci (Re/Ri=2.8)

(Exception: Continuous insulation of any amount permitted where minimum total exterior permeance values are met)

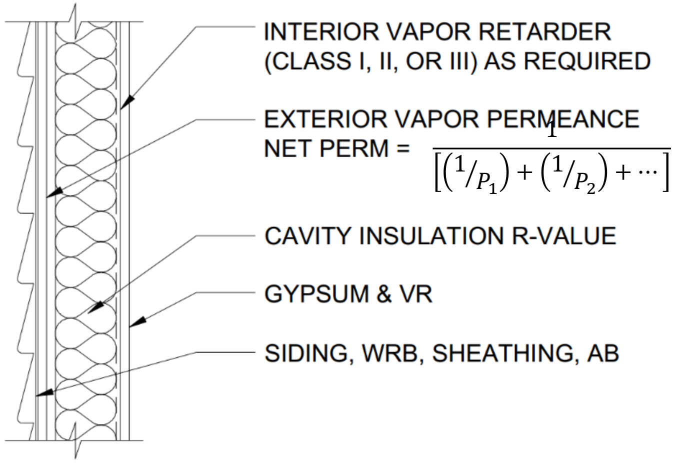
Based on compilation of US and Canadian building codes and practices plus extensive review of research and analysis of actual field data.

Source: Assessment of Water Vapor Control Methods for Modern Light-frame Wall Assemblies, ABTG Research Report 1410-03, 2015

ABTG

Simplified Permeance-Controlled Design

Cavity Insulation Only*



* Can also include any amount of continuous insulation complying with exterior permeance limits

TABLE 1
MINIMUM WATER VAPOR PERMEANCE (WVP)
FOR MATERIAL LAYERS LOCATED ON THE EXTERIOR SIDE OF WALL STUDS [a,b,c]

CLIMATE ZONE	INTERIOR VAPOR RETARDER CLASS		
	Class I	**Class II**	**Class III**
1	Class I not permitted	Class II not permitted[d]	No minimum WVP
2	Class I not permitted	Class II not permitted[d]	No minimum WVP
3	Class I not permitted	No minimum WVP	No minimum WVP
4	0.5 perm (Marine 4 only) otherwise Class I not applicable	0.5 perm	3 perm
5	0.5 perm	3 perm	5 perm
6	1 perm	5 perm	15 perm
7	1 perm	15 perm	Not permitted
8[e]	1.5 perm	Not permitted	Not permitted

For SI: 1 perm = 57.2 ng/s-m^2-Pa

a. The WVP of materials on the exterior side of the wall studs shall be permitted to be determined using Method A (‘dry cup’) or Method B (‘wet-cup’) of ASTM E96 for the purposes of compliance with this table.

b. Where there is more than one layer to the exterior side of wall studs, the net water WVP of the layers comprising the exterior wall covering assembly, excluding vented claddings, shall be determined using the following equation: Net WVP (perms) = 1/[1/perm1 +1/perm2 + 1/perm3 + etc.], where ‘perm#’ is the WVP of each individual layer exterior to the wall studs. Perm ratings for each material layer shall be based on approved test data representative of the actual product, including all component layers of composite products.

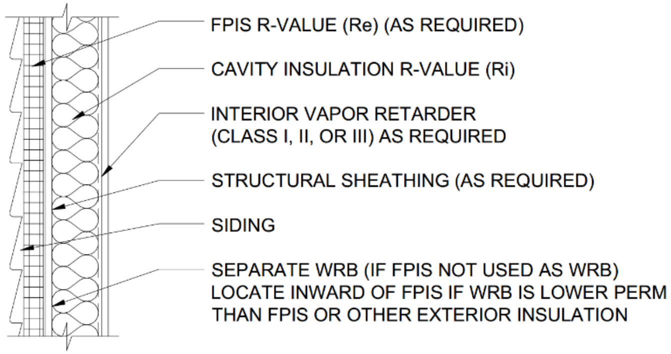
c. Where exterior continuous insulation of any amount is used in accordance with this table in lieu of Table AV103(2), its water vapor permeance shall be considered in accordance with footnote ‘b’.

d. In Climate Zones 1 and 2, a Class II vapor retarder shall be permitted where the WVP of the vapor retarder is greater than 1 perm as measured in accordance with Method B (‘wet-cup’) of ASTM E96.

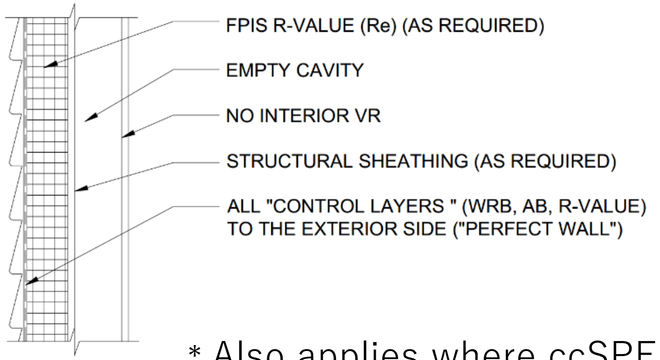
e. The WVP requirement for Climate Zone 8 is based on a maximum 16,200 heating degree days (65ºF basis) [9,000 heating degree days (18ºC basis)]. Where this heating degree day limit is exceeded, a design shall be required to determine the minimum required water vapor permeance for materials on the exterior side of the assembly.

Simplified Temperature-Controlled Design

Cavity* + Continuous + Interior VR



Continuous Only (No VR)



* Also applies where ccSPF is used in cavity

TABLE 2
MINIMUM INSULATION RATIO OR CONTINUOUS INSULATION R-VALUE FOR WOOD-FRAME WALLS WHERE EXTERIOR CONTINUOUS INSULATION (ci) IS USED [a,b,c]

Climate Zone	Maximum Heating Degree Days (65F basis)	Vapor Retarder (VR) Class			
		Class I[d]	Class II	Class III	No VR[d]
1	**N/A**	Class I not permitted	Class II not permitted[e]	R-2ci minimum	R-2ci minimum
2	**N/A**	Class I not permitted	Class II not permitted[e]	R-2ci minimum	R-2ci minimum
3	**3,600**	Class I not permitted	R-2ci minimum	R-2ci minimum	0.4
4	**5,400**	Class I not permitted	R-2ci minimum	0.2	0.9
5	**7,200**	0.2	0.2	0.35	1.3
6	**9,000**	0.2	0.2	0.5	1.7
7	**12,600**	0.35	0.35	0.8	2.3
8[f]	**16,200**	0.5	0.5	1.1	2.8

For SI: 1 heating degree day (65°F basis) = 0.56 heating degree days (18°C basis)

a. Insulation ratio is the exterior continuous insulation R-value divided by the cavity insulation R-value.
b. Interpolation of insulation ratios using a site-specific heating degree day value shall be permitted.
c. In addition to the vapor retarder, spray foam with a maximum permeance of 1.5 perms at the installed thickness, applied to the interior side of wood structural panels, fiberboard, insulating sheathing or gypsum is deemed to meet the insulation ratio requirement where the spray foam R-value plus continuous insulation R-value, if any, meets or exceeds the R-value determined for continuous insulation using the tabulated insulation ratio.
d. Where there is no cavity insulation, the R-value of any material layers, air-space, and air-film to the interior side of the exterior continuous insulation shall be used to determine the insulation ratio in accordance with footnote 'a'.
e. In Climate Zones 1 and 2, a Class II vapor retarder shall be permitted where the WVP of the vapor retarder is greater than 1 perm as measured in accordance with Method B ('wet-cup') of ASTM E96.
f. The exterior continuous insulation requirement for Climate Zone 8 is based on a maximum 16,200 heating degree days (65ºF basis) [9,000 heating degree days (18ºC basis)]. Where this heating degree day limit is exceeded, a design shall be required to determine the insulation ratio.

Many ways to use design method to format prescriptive solutions...

Can be very simple...

Permeance Controlled Solutions (CZ 6 only):

Minimum Net Water Vapor Permeance (WVP) of Material Layers on the Exterior Side of Vapor-Permeable Cavity Insulation in Climate Zone 6

Interior Vapor Retarder Class	Walls with Cavity Insulation Only[1,2]	Walls with Exterior Continuous Insulation Meeting Table A3
I	1 perm	See Note '4'
II	5 perm	No minimum perm
III	15 perm[3]	No minimum perm

Temperature Controlled Solutions (CZ 6 only):

Minimum Exterior Continuous Insulation R-value for Moisture Control in Climate Zone 6[1]

Class I or II Interior Vapor Retarder (polyethylene sheet, Kraft paper)		Class III Interior Vapor Retarder (latex or enamel paint)	
Wall Type		Wall Type	
2x4 walls	2x6 walls	2x4 walls	2x6 walls
R-3ci	R-5ci	R-7.5ci	R-12ci

Or allow more options/precision...

Minimum Exterior Continuous Insulation R-value for Moisture Control in Climate Zone 6[1]

Heating Degree Days (Climate Zone 6)		Class I or II Interior Vapor Retarder (1 perm or less)					Class III Interior Vapor Retarder (1<perm≤10)				
		Min. R_e/R_i Ratio	Maximum Cavity Insulation R-value				Min. R_e/R_i Ratio	Maximum Cavity Insulation R-value			
			2x4 walls		2x6 walls			2x4 walls		2x6 walls	
HDD65°F	HDD18°C		R-13	R-15	R-19	R-23		R-13	R-15	R-19	R-23
7,000	3,889	0.2	R-2.6ci	R-3ci	R-3.8ci	R-4.6ci	0.33	R-4.3ci	R-5ci	R-6.3ci	R-7.6ci
7,500	4,167	0.2	R-2.6ci	R-3ci	R-3.8ci	R-4.6ci	0.38	R-4.9ci	R-5.7ci	R-7.2ci	R-8.7ci
8,000	4,444	0.2	R-2.6ci	R-3ci	R-3.8ci	R-4.6ci	0.42	R-5.5ci	R-6.3ci	R-8ci	R-9.7ci
8,500	4,722	0.2	R-2.6ci	R-3ci	R-3.8ci	R-4.6ci	0.46	R-6ci	R-6.9ci	R-8.7ci	R-11ci
9,000	5,000	0.2	R-2.6ci	R-3ci	R-3.8ci	R-4.6ci	0.5	R-6.5ci	R-7.5ci	R-9.5ci	R-12ci

ABTG

Example 1

- Using insulation ratios to check energy code solutions and alternative wall insulation strategies for adequate moisture durability.

  - **Given**: Assume the energy code requires R20+5ci (2x6 wall with R20 cavity insulation and R5 continuous insulation). This is a "temperature-controlled wall" wall in accordance with Table 2.
  - **Find**: What is the maximum (coldest) permissible climate zone for this wall when using a Class I, II or Class III interior vapor retarder?

Example 1

- **Solution**: First, determine the insulation ratio, $R_e/R_i = 5/20 = 0.25$.
- Per Table 2, the maximum/coldest climate zone is 6 with a Class I or II interior vapor retarder and Climate Zone 4 with a Class III interior vapor retarder.
- Using Footnote ‘b’ to interpolate with HDD, this wall could be used into the lower third of the next colder climate zone (0.25 falls between 0.2 and 0.35).

TABLE 2
MINIMUM INSULATION RATIO OR CONTINUOUS INSULATION R-VALUE FOR WOOD-FRAME WALLS WHERE EXTERIOR CONTINUOUS INSULATION (ci) IS USED [a,b,c]

Climate Zone	Maximum Heating Degree Days (65F basis)	Vapor Retarder (VR) Class			
		Class I[d]	Class II	Class III	No VR[d]
1	N/A	Class I not permitted	Class II not permitted[e]	R-2ci minimum	R-2ci minimum
2	N/A	Class I not permitted	Class II not permitted[e]	R-2ci minimum	R-2ci minimum
3	3,600	Class I not permitted	R-2ci minimum	R-2ci minimum	0.4
4	5,400	Class I not permitted	R-2ci minimum	0.2	0.9
5	7,200	0.2	0.2	0.35	1.3
6	9,000	0.2	0.2	0.5	1.7
7	12,600	0.35	0.35	0.8	2.3
8[f]	16,200	0.5	0.5	1.1	2.8

For SI: 1 heating degree day (65°F basis) = 0.56 heating degree days (18°C basis)

a. Insulation ratio is the exterior continuous insulation R-value divided by the cavity insulation R-value.
b. Interpolation of insulation ratios using a site-specific heating degree day value shall be permitted.
c. In addition to the vapor retarder, spray foam with a maximum permeance of 1.5 perms at the installed thickness, applied to the interior side of wood structural panels, fiberboard, insulating sheathing or gypsum is deemed to meet the insulation ratio requirement where the spray foam R-value plus continuous insulation R-value, if any, meets or exceeds the R-value determined for continuous insulation using the tabulated insulation ratio.
d. Where there is no cavity insulation, the R-value of any material layers, air-space, and air-film to the interior side of the exterior continuous insulation shall be used to determine the insulation ratio in accordance with footnote ‘a’.
e. In Climate Zones 1 and 2, a Class II vapor retarder shall be permitted where the WVP of the vapor retarder is greater than 1 perm as measured in accordance with Method B (‘wet-cup’) of ASTM E96.
f. The exterior continuous insulation requirement for Climate Zone 8 is based on a maximum 16,200 heating degree days (65°F basis) [9,000 heating degree days (18°C basis)]. Where this heating degree day limit is exceeded, a design shall be required to determine the insulation ratio.

Example 2

- Verify compliance of a conventional 2x6 (cavity insulation only) wall assembly in Climate Zone 5 with exterior permeance requirements for water vapor control.

  - **Given**: Assume the energy code requires minimum R-20 cavity insulation and the product used is vapor permeable (e.g., fiberglass, cellulose, etc.). This is a "permeance-controlled" wall assembly in accordance with Table 1. Also assume that 7/16" OSB sheathing is used (typical wet cup vapor permeance ~ 3.8 perm – verify with manufacturer) together with a 10 perm building wrap and a vented cladding (e.g., anchored brick veneer).
  - **Find**: What Class of interior vapor retarder is permitted for use with this assembly in Climate Zone 5?

Example 2

- **Solution**: First, determine the net vapor permeance of the exterior material layers (excluding the vented cladding) in accordance with Note 'c' of Table 1. Thus, net permeance = 1 / [(1/3.8) + (1/10)] = 1 / 0.36 = **2.75 perm**.
- This is just under the minimum 3 perm required by Table 1 for use with a Class II (e.g., Kraft paper) vapor retarder. Thus, a Class I vapor retarder is required.

TABLE 1
MINIMUM WATER VAPOR PERMEANCE (WVP)
FOR MATERIAL LAYERS LOCATED ON THE EXTERIOR SIDE OF WALL STUDS [a,b,c]

CLIMATE ZONE	INTERIOR VAPOR RETARDER CLASS		
	Class I	**Class II**	**Class III**
1	Class I not permitted	Class II not permitted[d]	No minimum WVP
2	Class I not permitted	Class II not permitted[d]	No minimum WVP
3	Class I not permitted	No minimum WVP	No minimum WVP
4	0.5 perm (Marine 4 only) otherwise Class I not applicable	0.5 perm	3 perm
5	0.5 perm	3 perm	5 perm
6	1 perm	5 perm	15 perm
7	1 perm	15 perm	Not permitted
8[e]	1.5 perm	Not permitted	Not permitted

For SI: 1 perm = 57.2 ng/s-m^2-Pa

a. The WVP of materials on the exterior side of the wall studs shall be permitted to be determined using Method A ('dry cup') or Method B ('wet-cup') of ASTM E96 for the purposes of compliance with this table.
b. Where there is more than one layer to the exterior side of wall studs, the net water WVP of the layers comprising the exterior wall covering assembly, excluding vented claddings, shall be determined using the following equation: Net WVP (perms) = 1/[1/perm1 +1/perm2 + 1/perm3 + etc.], where 'perm#' is the WVP of each individual layer exterior to the wall studs. Perm ratings for each material layer shall be based on approved test data representative of the actual product, including all component layers of composite products.
c. Where exterior continuous insulation of any amount is used in accordance with this table in lieu of Table AV103(2), its water vapor permeance shall be considered in accordance with footnote 'b'.
d. In Climate Zones 1 and 2, a Class II vapor retarder shall be permitted where the WVP of the vapor retarder is greater than 1 perm as measured in accordance with Method B ('wet-cup') of ASTM E96.
e. The WVP requirement for Climate Zone 8 is based on a maximum 16,200 heating degree days (65ºF basis) [9,000 heating degree days (18ºC basis)]. Where this heating degree day limit is exceeded, a design shall be required to determine the minimum required water vapor permeance for materials on the exterior side of the assembly.

Example 2

- However, there are alternative solutions:
  - For example, one could use a sheathing product with a minimum permeance of 4.3 perm (e.g., ½" plywood sheathing, fiberboard, etc) which would result in a net vapor permeance of 3.0 perms or greater, allowing use of a Class II vapor retarder.
  - Alternatively, the OSB sheathing can be used (assuming it has a wet cup vapor permeance of 3.8 perm or greater) with a building wrap or other water resistive barrier having a permeance of at least 15 perms.
    - Thus, the net permeance = $1 / [(1/3.8) + (1/15)] = 1 / 0.33 = 3.03$ perm which would also allow use of a Class II interior vapor retarder instead of a Class I.
    - Using a non-vented cladding material of low water vapor permeance will require similar adjustments (or conversion to a vented cladding using furring) to achieve a similarly suitable design.

Supplemental Design Considerations

CAN YOU HAVE TOO MUCH PERMEANCE?
Yes! (in some conditions)

Recommendation:

The Net WVP of exterior layers between the cladding and sheathing (e.g., the WRB or continuous insulation) <u>should not exceed ~10 perm</u>

- This prevents **solar-driven inward moisture movement**, where direct-applied (unvented) reservoir cladding (adhered veneer, stucco, etc.) is used on air-conditioned buildings.
- This is primarily a concern in warmer and more humid climates but can extend up into Climate Zone 5.
- Can also be addressed by increasing back-ventilation of reservoir cladding.

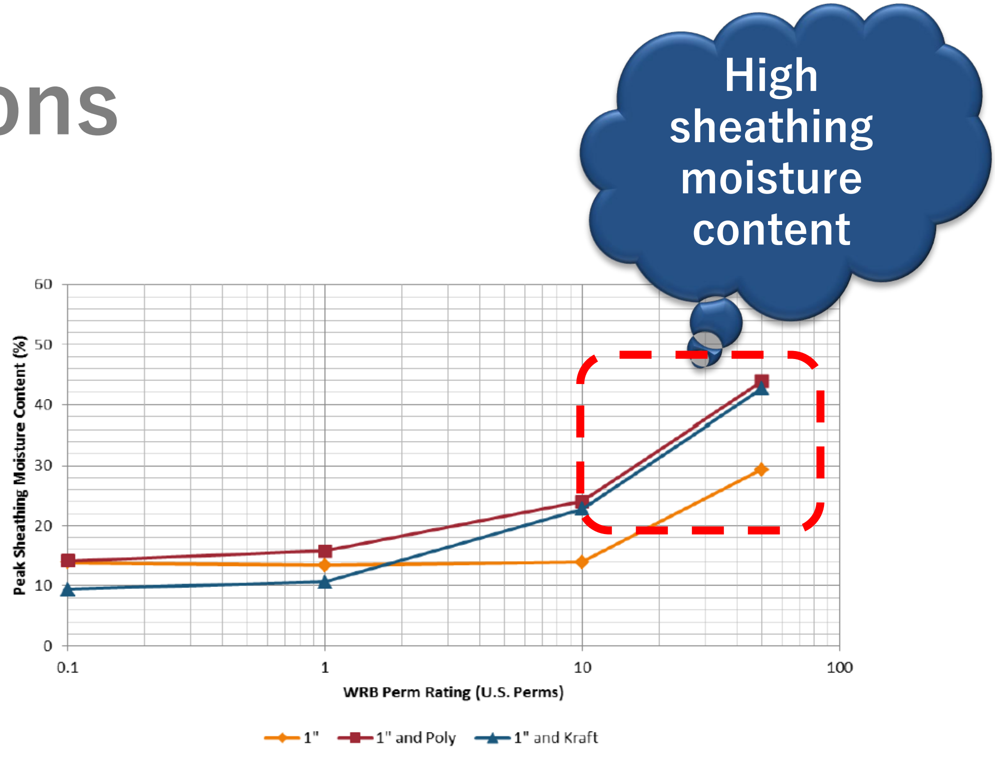


Figure 16. Peak exterior side sheathing MC for 1 in., 1 in.+ Poly, and 1in.+ Kraft at various WRB permeances.

Peak moisture content (wetting) of exterior sheathing increases as the permeance of the exterior insulation and/or WRB approaches and exceeds ~ 10 perm

Source: Lepage & Lstiburek (2013). Moisture Durability with Vapor-Permeable Insulating Sheathing. US DOE, Building Technologies Office, Building America Program

Supplemental Design Considerations

CAN YOU HAVE TOO LITTLE PERMEANCE?
Yes! (in some conditions)

For all wall assembly types in climates with severe wind-driven rain hazard (see next slide), avoid use of “**double vapor barriers***” (e.g., Class I vapor retarder on interior and << 1 perm net water vapor permeance material layers on exterior).

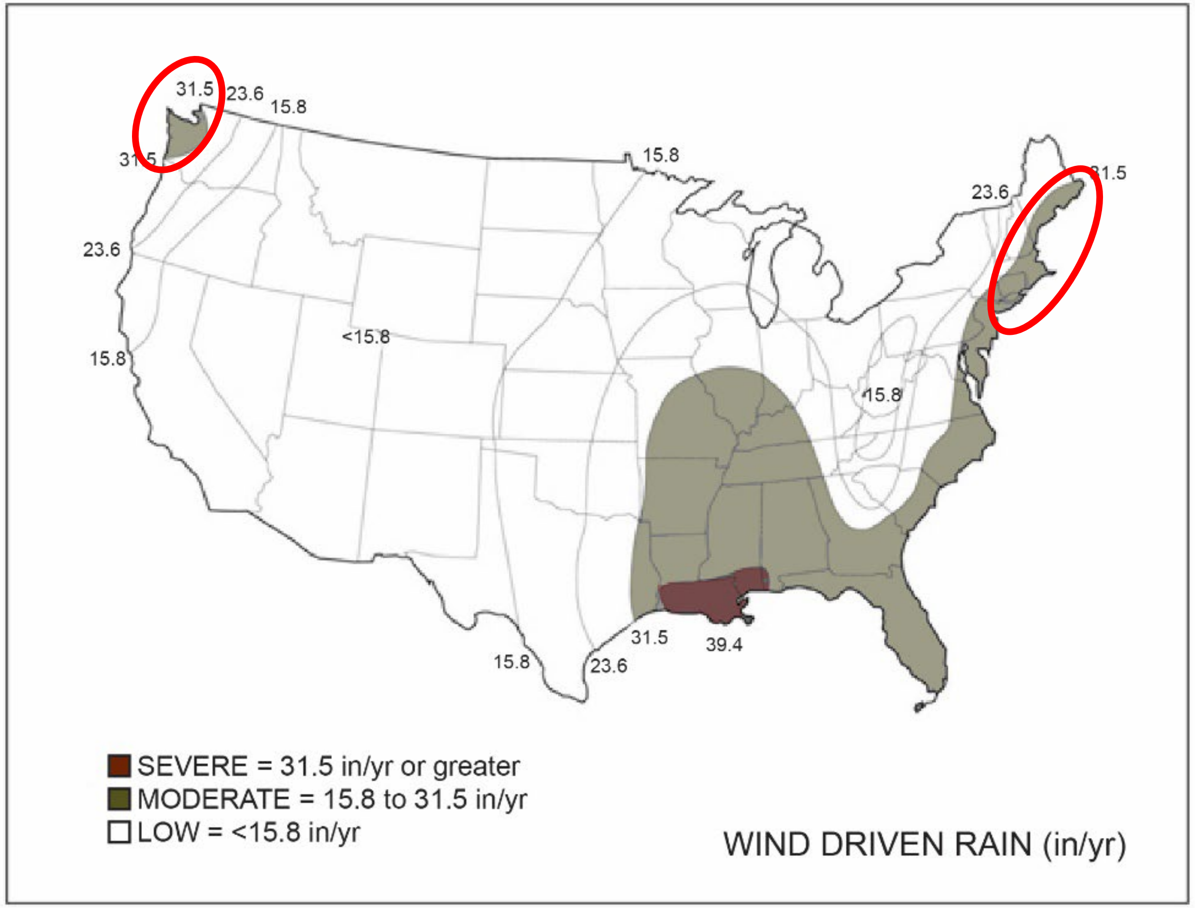
- Use a Class II VR (preferably a “smart” VR like Kraft paper) or Class III VR to **promote drying to interior** or high perm materials on the exterior to **promote drying to the exterior**.
- Use of **pan flashings** below window sills and door thresholds highly recommended to prevent wetting from rain intrusion in the first place. All flashings and WRB installation should be **inspected/verified** before concealment.

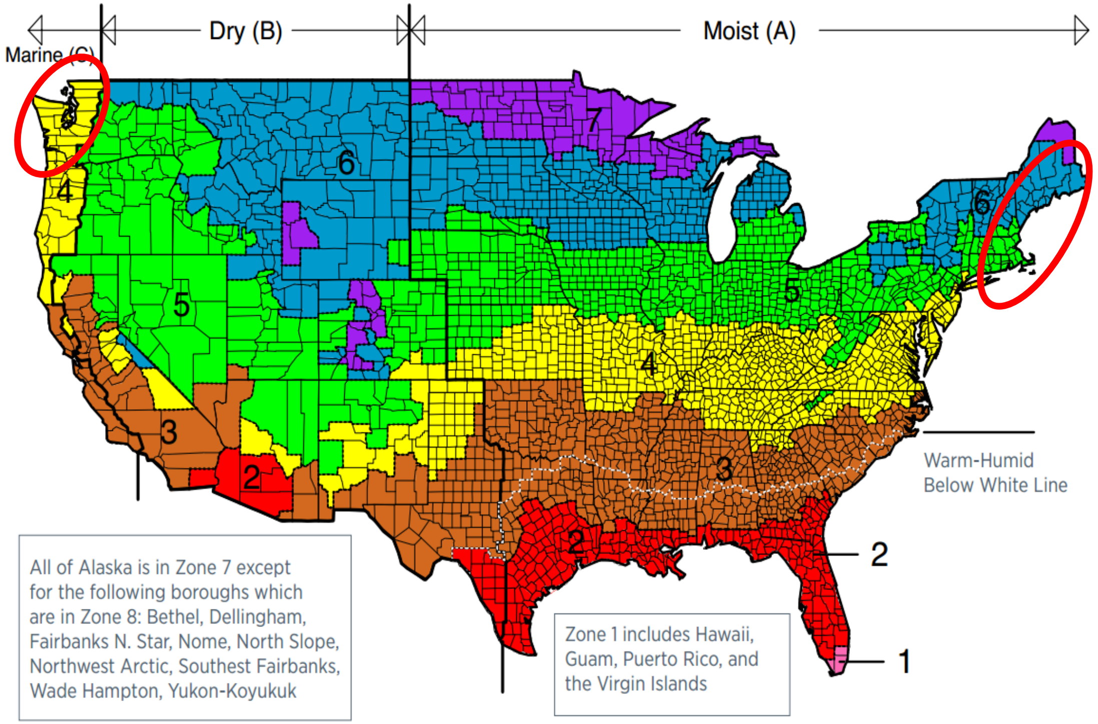
* The concern is not with “**double vapor retarders**.” Many walls are “double vapor retarders” because both sides of typical wall assemblies provide resistance to water vapor diffusion (some more than others).

Supplemental Design Considerations

- **IMPORTANT NOTES FOR PREVIOUS SLIDE:**
  - **Drying potential (breathability)** is not a "cure all" for leaky walls and components. Taken to an extreme, it can lead to "too much permeability" or inattention to the primary concern with preventing leaks or properly specifying insulation location and vapor retarders.
  - Class I vapor retarders are not permitted in climate zones 1-4 already (except Marine 4), so this recommendation **applies mainly to the Northwest and Northeast seaboards** of the US (**see next slide**).
  - Use of a Class I or II "smart" (responsive) vapor retarder is now recognized in the 2024 codes to promote inward drying and restrict outward (winter) vapor movement.
- For additional info on **double vapor barriers**, refer to: "Doubling Down: How Come Double Vapor Barriers Work?" (Dr. Lstiburek, *ASHRAE Journal*, Jan. 2016).

Wind-driven Rain & Climate Zone Maps





Alternative Designs by Analysis

- Insulation ratios and permeance requirements discussed earlier are "simplified" solutions to give reasonable and reliable answers for many common conditions.
- Where alternate or more precise solutions are desired or necessary, various means of hygrothermal analysis are available to help.
  - These design tools generally require some degree of expertise to properly use and interpret results
  - A professional should be consulted.
  - Results may be precise, but are never more accurate than the inputs and assumptions (GIGO).

ABTG

Conclusion

- Summary:
  - 5 Key Building Science Concepts for moisture-resistant & energy efficient construction
  - Terms important to the “trade”
  - Current US and Canadian building code provisions
  - Two Unified Design Approaches
  - Example Applications (prescriptive and design)
  - Supplemental Design Considerations

QUESTIONS?

Jay Crandell

www.aresconsulting.biz

Please submit any questions through the Continuous Insulation website at continuousinsulation.org/contact.