Continuous Insulation (ci) & Water Vapor Control

Educational Overview

Revised March 18, 2020

ABTG

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.

ABTG is a professional engineering firm, an approved source as defined in Chapter 2 and independent as defined in Chapter 17 of the IBC.

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

Learning Objectives

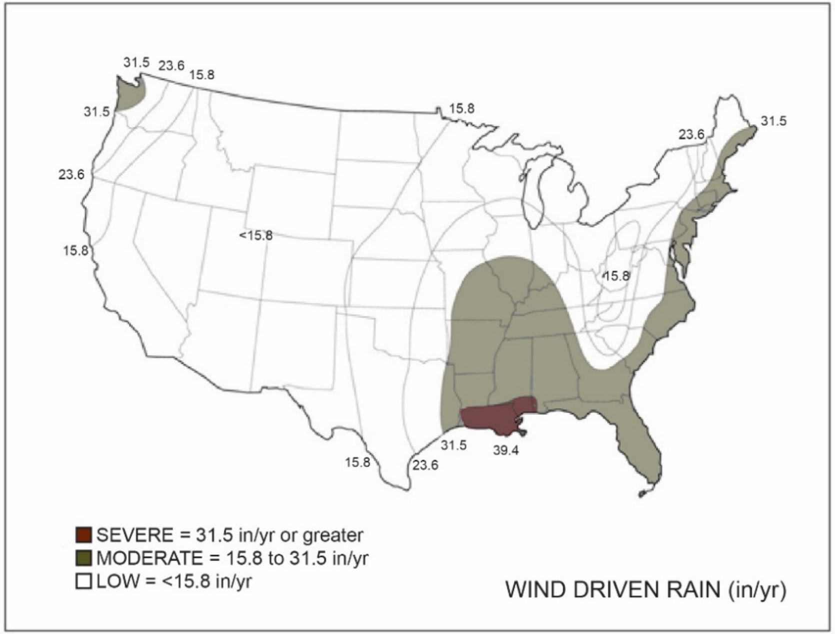
- Review key building science concepts
- Recall current U.S. & Canadian code requirements
- Explain accepted methods of design to control water vapor
- Apply prescriptive design solutions:
  - Framework of prescriptive solutions for all climate zones
  - Example solutions for walls with Continuous Insulation
  - Example solutions for walls without Continuous Insulation

Key Building Science Concepts

- 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 importance, all have inter-dependencies.

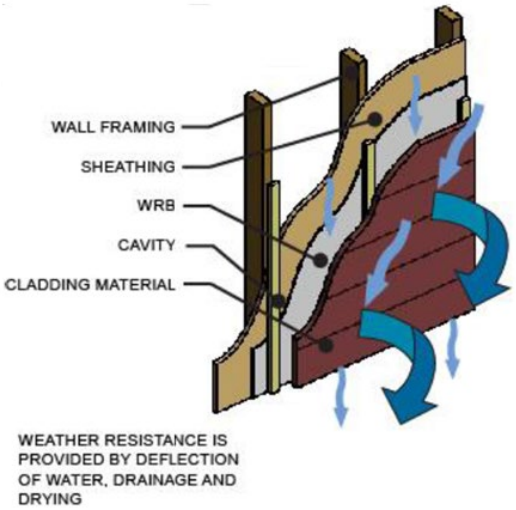
Building Science Concept #1 – Rain Water Control

- Rain water control is often the primary factor associated with observed failure or success of moisture control
- Concept is simple: Keep water out!
- Wind driven rain is the primary environmental hazard (see map)



Building Science Concept #1 – Rain Water Control

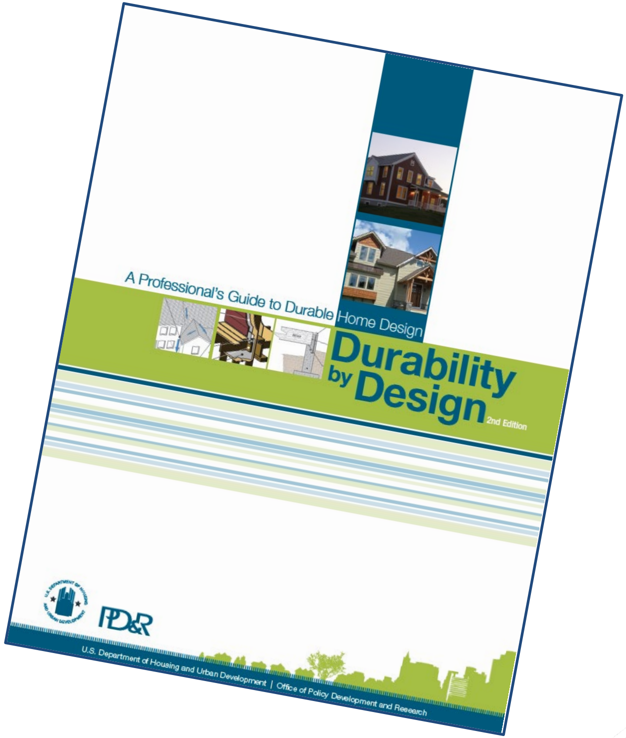
- How to control or mitigate rain water hazard?
- Two main ways:
  - Select materials and methods appropriate to local environment
  - Ensure a continuous drainage plane behind the cladding



DRAINED CAVITY METHOD

Building Science Concept #1 – Rain Water Control

1. Select cladding type, windows & doors, and installation methods best suited to the local climate wind-driven rain hazard
    - Durability by Design Guide – A Professional's Guide to Durable Home Design, U.S. HUD, Office of Policy Development & Research



A Professional's Guide to Durable Home Design

Durability by Design

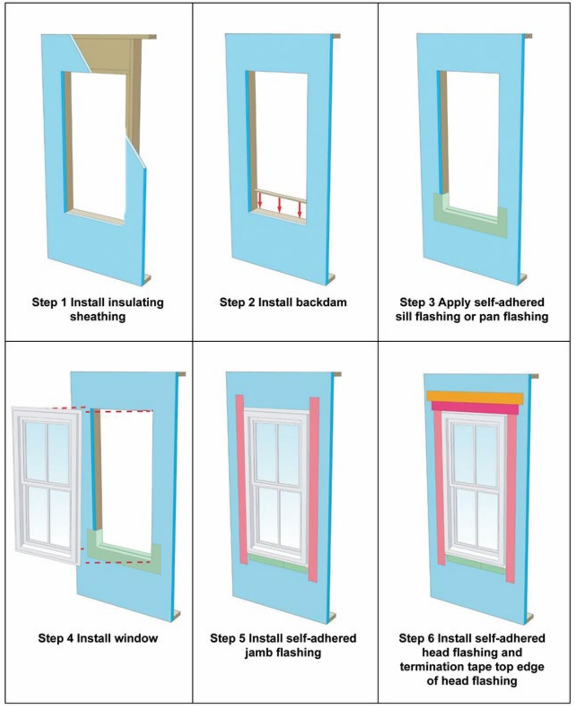
2nd Edition

PD&R

U.S. Department of Housing and Urban Development | Office of Policy Development and Research

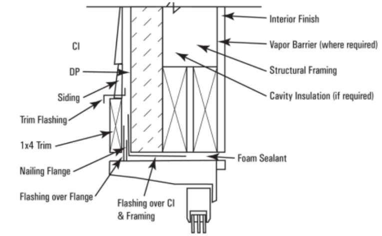
Building Science Concept #1 – Rain Water Control

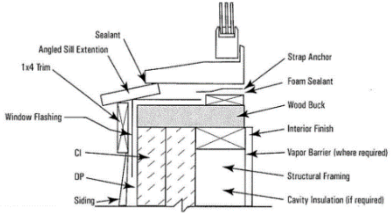
2. Use a code compliant water-resistive barrier (WRB) and flashing details at all penetrations for a continuous drainage plane behind the cladding
   - WHY? All claddings leak! Also, codes generally require a WRB behind all cladding types.

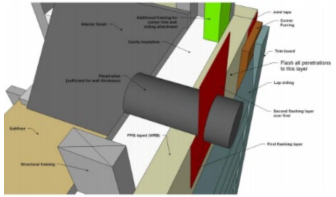


Building Science Concept #1 – Rain Water Control

- Refer to DRR 1410-05 (Using FPIS as a WRB) and DRR 1205-05 (Construction Details) for information on appropriate use of Foam Plastic Insulating Sheathing (FPIS)
- Refer to Window Installation Guides for applications with FPIS







Building Science Concept #1 – Rain Water Control

- Variations in wind-driven rain hazard and performance of cladding types and installation methods are not addressed in the building code.
- If rain water intrusion is not adequately controlled, other building science control measures may be unable to compensate or rendered ineffective.

Building Science Concept #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

Building Science Concept #2 – Air Leakage Control

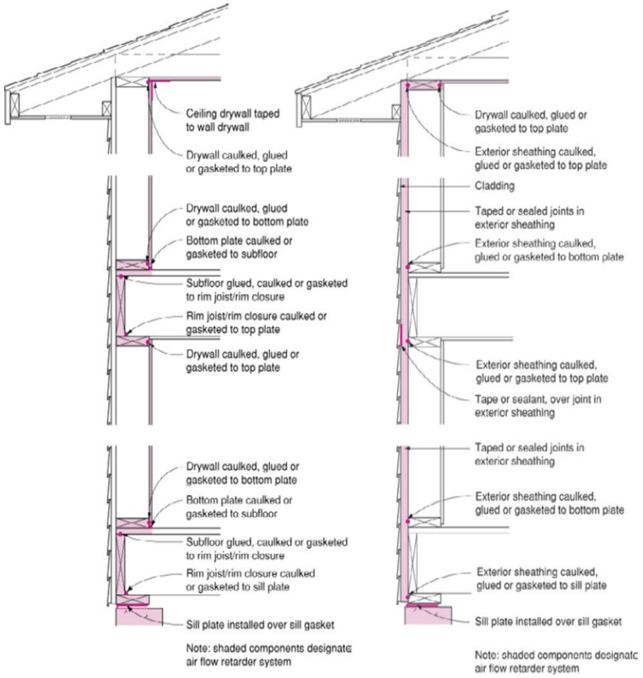
- Air can bypass insulation, rendering insulation less effective
- Increased energy bills

Building Science Concept #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).
- Refer to:
  - Durability by Design: A Professional's Guide to Durable Home Design
  - Air Leakage Guide, US DOE, Building Technologies Program

Building Science Concept #2 – Air Leakage Control

- Many materials and methods of AB installation are available
  - For FPIS, refer to [DRR 1410-06, FPIS Used as an Air Barrier Material in an Air Barrier Assembly](DRR 1410-06).
  - Other methods include:
    - Sealed drywall installation
    - Mechanically attached wraps with sealed joints
    - Adhered membranes
    - Spray-applied coatings
    - Exterior sheathing with sealed joints
    - Closed-cell spray foam



Building Science Concept #2 – Air Leakage Control

- As with the WRB, the AB must be properly sealed at all joints and penetrations and discontinuities in framing assemblies.
- In general, rigid air-barrier materials including FPIS provide better control than flexible, mechanically attached varieties (when not restrained by other material layers).
- With proper design and location in an assembly, some air barrier materials may perform multiple roles.
  - For example, FPIS can serve as insulation, an air-barrier, and a vapor retarder.

Building Science Concept #3 – Control Indoor Relative Humidity

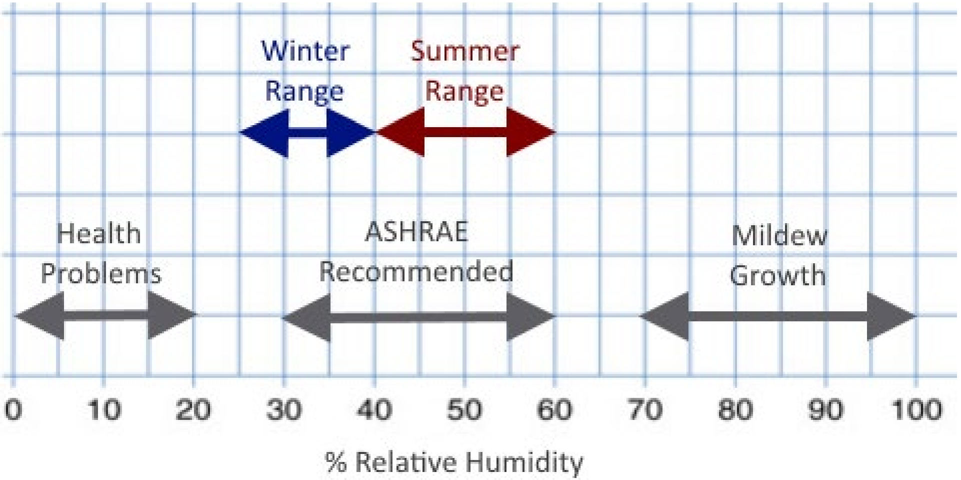
- Like rain water intrusion (BSC #1), excessive indoor relative humidity (RH) can overwhelm any reasonable water vapor control strategy
- BEWARE! Vapor retarder and insulation provisions in the building and energy code are not explicitly related to limits on indoor RH

Building Science Concept #3 – Control Indoor Relative Humidity

- 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
- Proper sizing of AC equipment can help control indoor RH in the summer
  - Dehumidifiers should be considered and used as needed

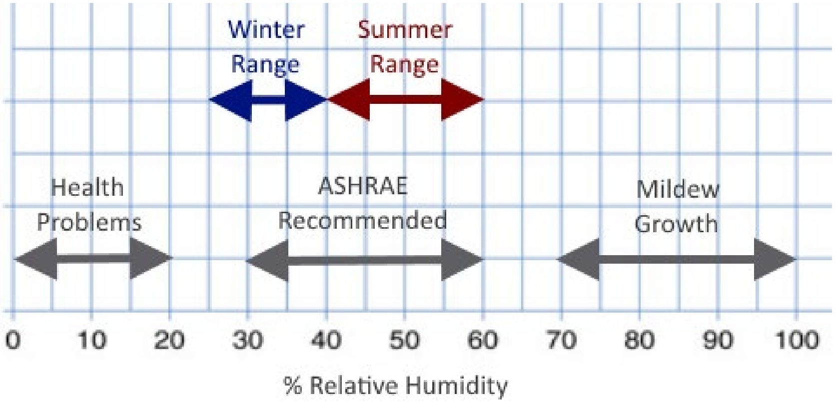
Building Science Concept #3 – Control Indoor Relative Humidity

- Summertime indoor RH should not exceed 60%.
- Winter max recommended indoor RH varies by climate (25% to 40%).
  - In colder climates, a lower indoor RH is needed for water vapor control



Building Science Concept #3 – Control Indoor Relative Humidity

- 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)



Building Science Concept #4 – Control Initial Construction Moisture

- Initial construction moisture mainly affects the initial year of building operation
  - 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 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
- 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.

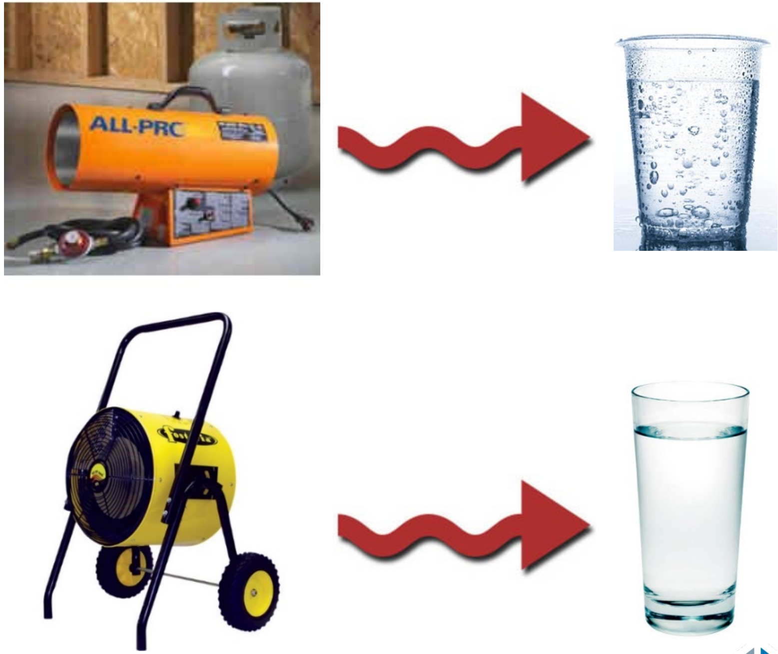
Building Science Concept #4 – Control Initial Construction Moisture

- 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

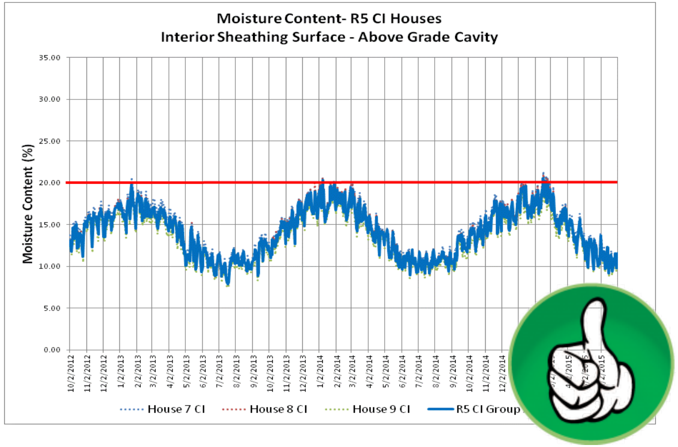
Building Science Concept #4 – Control Initial Construction Moisture

- 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.)



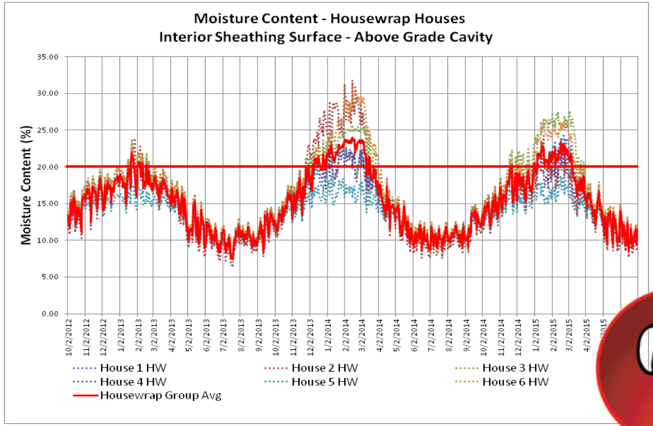
Building Science Concept #5 – Control Water Vapor

- Water vapor control involves two simple concepts:
  - Minimize the risk of the assembly getting wet due to moisture vapor diffusion (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 below 20% MC
- Right – moisture cycling above 20% MC

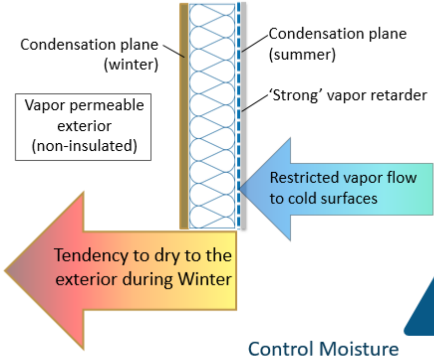


Building Science Concept #5 – Control Water Vapor

- While simple in concept, this practice involves many design considerations depending on the method used to control water vapor:
  - 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)
  - Cavity insulation R-value and its WVP
  - Exterior insulation R-value (continuous insulation) and its WVP

Building Science Concept #5 – Control Water Vapor

- Ability to dry in at least one direction (inward or outward) is recommended in most conditions
  - “Safety factor“ for incidental non-diffusion moisture sources (e.g., rain intrusion or moist air exfiltration)
  - FPIS walls can help reduce effect of moist air leakage (the more CI the better)
  - Double vapor barrier assemblies should be avoided in areas with severe wind driven rain hazard



Condensation plane (winter)

Vapor permeable exterior (non-insulated)

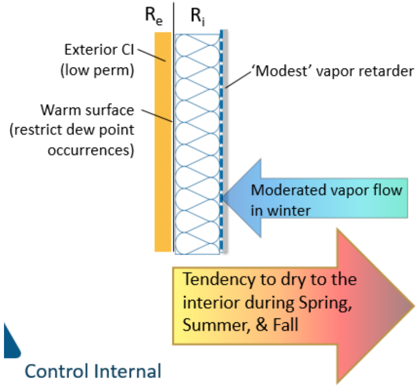
Condensation plane (summer)

‘Strong’ vapor retarder

Restricted vapor flow to cold surfaces

Tendency to dry to the exterior during Winter

Control Moisture Vapor Diffusion



R_e | R_i

Exterior CI (low perm)

Warm surface (restrict dew point occurrences)

‘Modest’ vapor retarder

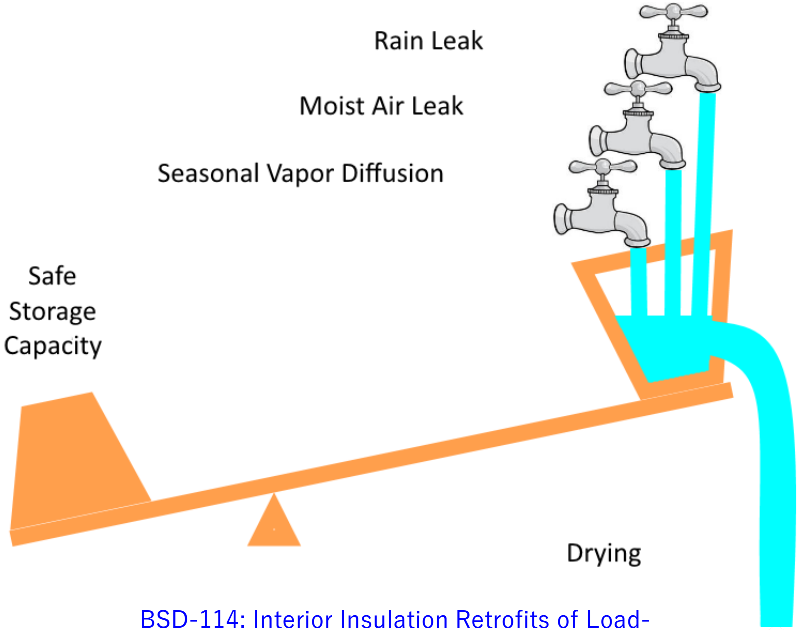
Moderated vapor flow in winter

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

Control Internal Surface Temperatures

Building Science Concept #5 – Control Water Vapor

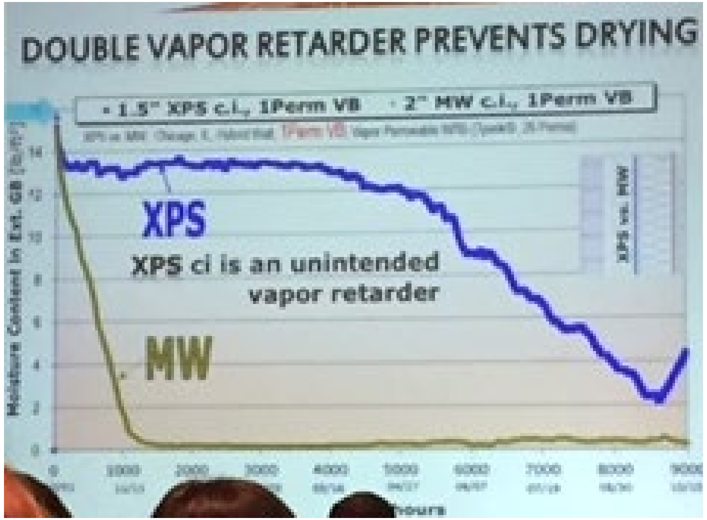
- It is truly a balancing act!
  - Risk of rain water wetting
  - Risk of air-leakage wetting
  - Wetting and drying by water vapor diffusion
- R-value and relative WVP of materials and their location within the assembly matters
  - The ability of materials to store and tolerate moisture also matters
- GOAL: Drying > wetting to control risk of mold or water-sensitive material degradation



[BSD-114: Interior Insulation Retrofits of Load-Bearing Masonry Walls In Cold Climates](#)

Building Science Concept #5 – Control Water Vapor (Addressing Common Misconceptions)

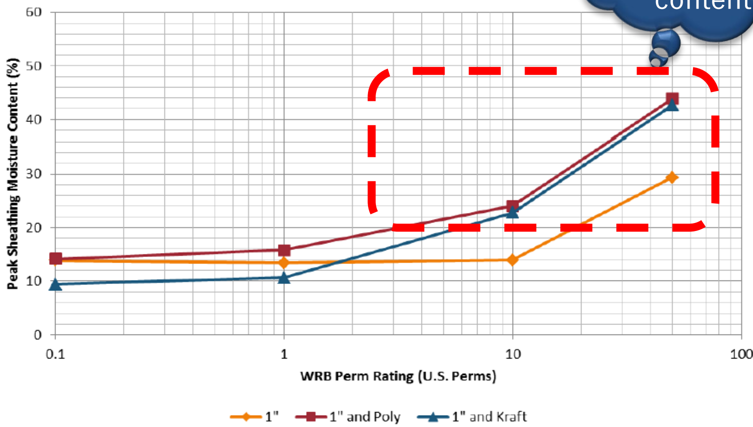
- The key to water vapor control is balancing drying potential and wetting potential.
  - It's a matter of optimization, more is not always better (and neither is less always better)
- For example, it is often said that more vapor permeance is needed on the exterior to promote increased drying rates (see chart)
- But, this is not a balanced or complete design recommendation…it is only part of the story…(next slide)



Slide shown at Green Build AIA/CEU presentation indicating a lower permeance insulation material (XPS) on the exterior has a slower drying rate than a higher permeance material (MW) with a high perm building wrap underneath.

Building Science Concept #5 – Control Water Vapor (Addressing Common Misconceptions)

- When conditions change seasonally to reverse vapor drives, the wall that dries fast at one time of the year can become saturated at another time of the year (see chart)
- Clearly, optimizing the insulation strategy and vapor retarder and WRB properties is important!



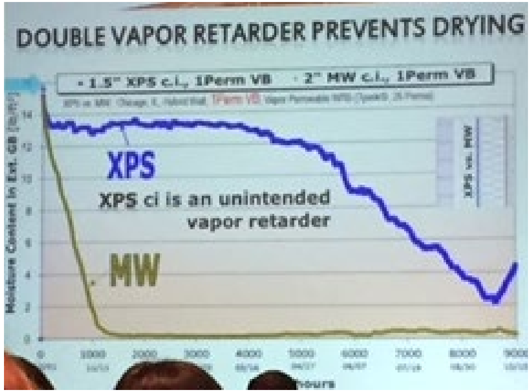
High sheathing moisture content

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*)

Building Science Concept #5 – Control Water Vapor (Addressing Common Misconceptions)

- Also, there are differences in consequences for the two types of the wetting:
  - The first chart (drying rate) deals with localized wetting from a leak and affirms the need for good flashing practices
  - The second deals with wetting over large areas that can occur due to inward moisture drives (too vapor permeable on the exterior) or inadequate wintertime condensation control (sheathing too cold, poor VR, poor AB, etc.).



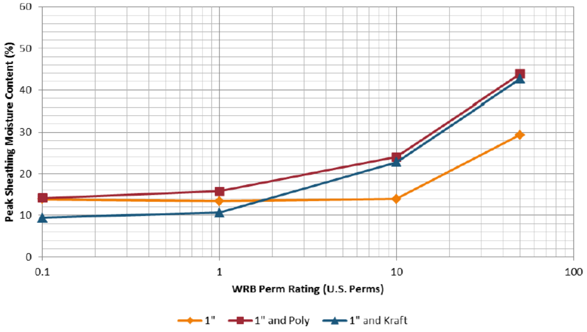


Figure 16. Peak exterior side sheathing MC for 1 in., 1 in.+ Poly, and 1in.+ Kraft at various WRB permeances.

Building Science Concept #5 – Control Water Vapor (Addressing Common Misconceptions)

- Neither consequence is good.
  - FPIS when properly installed can help prevent both localized wetting and wetting over large areas

Green Building Advisor: All About Wall Rot

Water Vapor Control: Putting Building Science Concepts to Practice

- The remainder of this presentation addresses the following water vapor control topics:
  - Terms to know
  - Current building code requirements (e.g., use of vapor retarders)
  - Appropriate design methods and tools
  - Appropriate use of vapor retarders (with and without CI)
  - Additional resources

Terms to Know

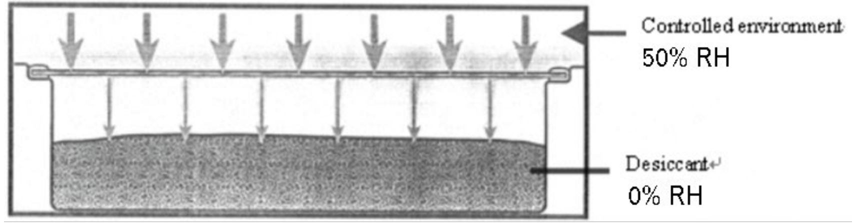
- ***Water vapor permeance*** (WVP): *The property of a building material related to the ability of water vapor to diffuse through it; measured in "**perms**".*
    - This property may vary depending on moisture content of the material as related to its surrounding conditions (e.g., relative humidity) – "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

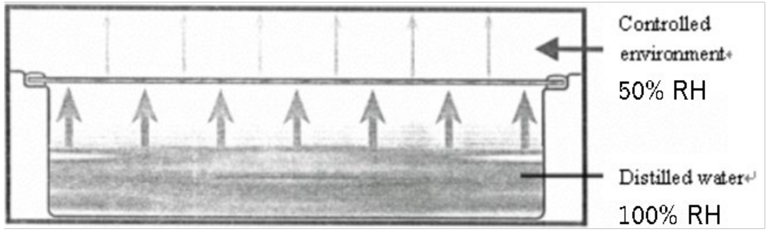
- Don't confuse *water vapor permeance* with *water vapor permeability*
- **Water vapor permeability** is a measure of WVP for a unit thickness of homogenous material
  - Permeability/thickness = WVP
  - But, this math only applies to homogenous materials – not composites, not materials with surface films, etc.!
- Water vapor permeability (more scientific definition):
- The water vapor permeability is 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

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

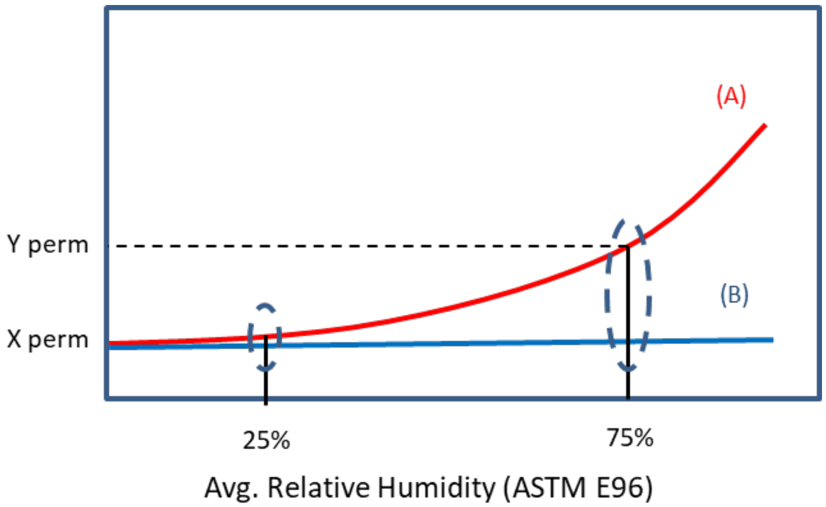


Wet Cup Method

An Outline of Standard ASTM E96 for Cup Method Water Vapor Permeability Testing

Terms to Know

- Water Vapor Permeance
  - Materials that are not hygrophyllic (non-organic) tend to have WVP that changes little with the ambient humidity (A)
  - Materials that are hygrophyllic (organic) tend to have WVP that changes significantly with the ambient relative 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

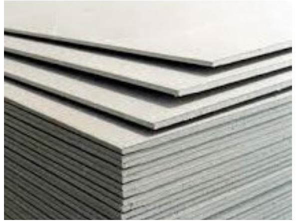
- *[2018 IBC/IRC] VAPOR PERMEABLE. The property of having a moisture vapor permeance rating of 5 perms (2.9 x 10-10 kg/Pa · s · m2) or greater, where tested in accordance with the desiccant method using Procedure A of ASTM E 96. A vapor permeable material permits the passage of moisture vapor.*
- Other classifications: semi-permeable, semi-impermeable, impermeable (varying degrees of vapor retardance)

Terms to Know

- All materials, regardless of what they are called, have some measure of resistance to water vapor flow.
- Some “generic” examples of perm rated materials:

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/pained) to 40 perm (vinyl/vented)

Terms to Know

- Some more “generic” examples of perm rated materials:

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

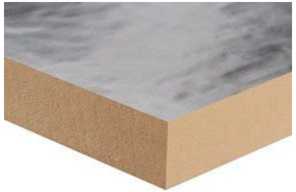
No facer. Depending on type/density. Decreases with increased thickness or added facers

Terms to Know

- Even more “generic” examples of perm rated materials:

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 polyiso insulation < 0.1 perm

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

- **[2018 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)

  —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)

Terms to Know

- Vapor retarder classes in the codes are fairly crude (e.g., a factor of 10 difference within a given class).
- But, they serve a purpose in communicating broad recommendations or generic building code requirements.
- Specific analyses using specific material properties (rather than classes) will give more precise answers.

Building Codes: Out with the old... in with the new?

- Building codes and construction practice often tend to rely on old conventions…Should this be ignored?
- No! (short answer). Keep the old and bring in the new to make the old more complete and up to date with the 21st century!
- In proper context, conventional wisdom has generally worked, but now is incomplete.

Building Codes: Out with the old... in with the new?

- Conventional wisdom: VR is placed on the “warm-in-winter” side of assembly in colder climates
  - Conventional wisdom still holds true in cold climates
  - Don’t do this in hot/humid climates! -- better to have lower permeance (vapor retarder materials) on the exterior, not the interior (see photo)
- The simplicity of conventional wisdom worked with “old” buildings, old materials, etc. Doesn’t always work so well or reliably today!

Low perm interior finish on interior (warm-in-winter) side of wall in hot/humid climate – perfect for culturing mold colonies!

Caution

- Use of outdated, incomplete, or over-simplified conventions (rules-of-thumb) can result in unexpected moisture problems.
    - When taken out of context, they also can be misused to give perception of advantage of one option or material over another.

Why must “new” be added to the “old”?

- Conventional wisdom only applies to a “permeance controlled” design approach (more on this later) and it is incomplete in view of newer construction materials and practices
- U.S. building codes don’t include the conventional wisdom of having a permeance ratio (i.e. higher perm on outside than inside in cold climates; reverse in hot/humid climates)
- Vapor permeance of materials on the exterior side of the assembly is generally ignored (but is nearly as important as the VR) – REMEMBER: water vapor control is a balance of letting water in and letting it out

Why must “new” be added to the “old”?

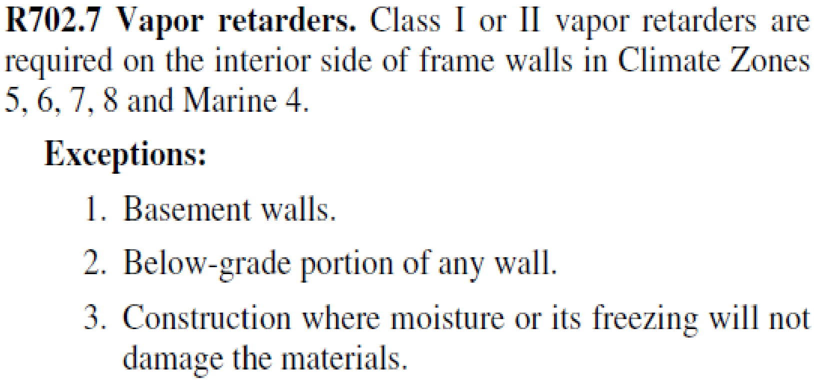
- Absence of exterior permeance control and design property control of these materials which are not “designated” vapor retarders creates uncertainties in performance outcome.
- More cavity insulation creates colder exterior sheathing/siding/membrane surfaces which are more prone to condensation and moisture accumulation and some may be less durable or tolerant.

Why must "new" be added to the "old"?

- Newer energy codes and insulation requirements have created a need for a "temperature controlled" design approach using exterior continuous insulation (more on this later)
  - Some requirements are in the 2009 through 2018 IRC and IBC. But, these are not complete
  - Some requirements are in the 1995 through 2015 NBCC (Canada). But, these are not complete
  - Both together provide a more complete set of solutions. There is a need to unify the knowledge and experience in U.S. and Canada!

Current U.S. Building Code Requirements

- 2018 IBC and IRC provisions are similar (IBC a bit more precise)
- 2018 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!

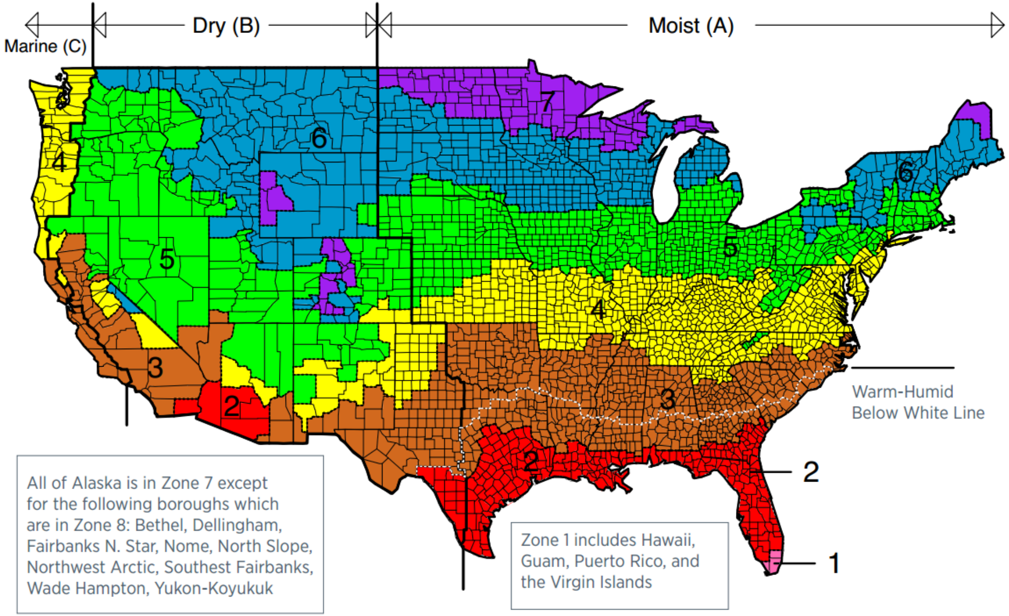


R702.7 Vapor retarders. Class I or II vapor retarders are required on the interior side of frame walls in Climate Zones 5, 6, 7, 8 and Marine 4.

Exceptions:

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

Climate Zones



All of Alaska is in Zone 7 except for the following boroughs which are in Zone 8: Bethel, Dellingham, Fairbanks N. Star, Nome, North Slope, Northwest Arctic, Southest Fairbanks, Wade Hampton, Yukon-Koyukuk

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Climate Zone Definitions (2018 IECC)

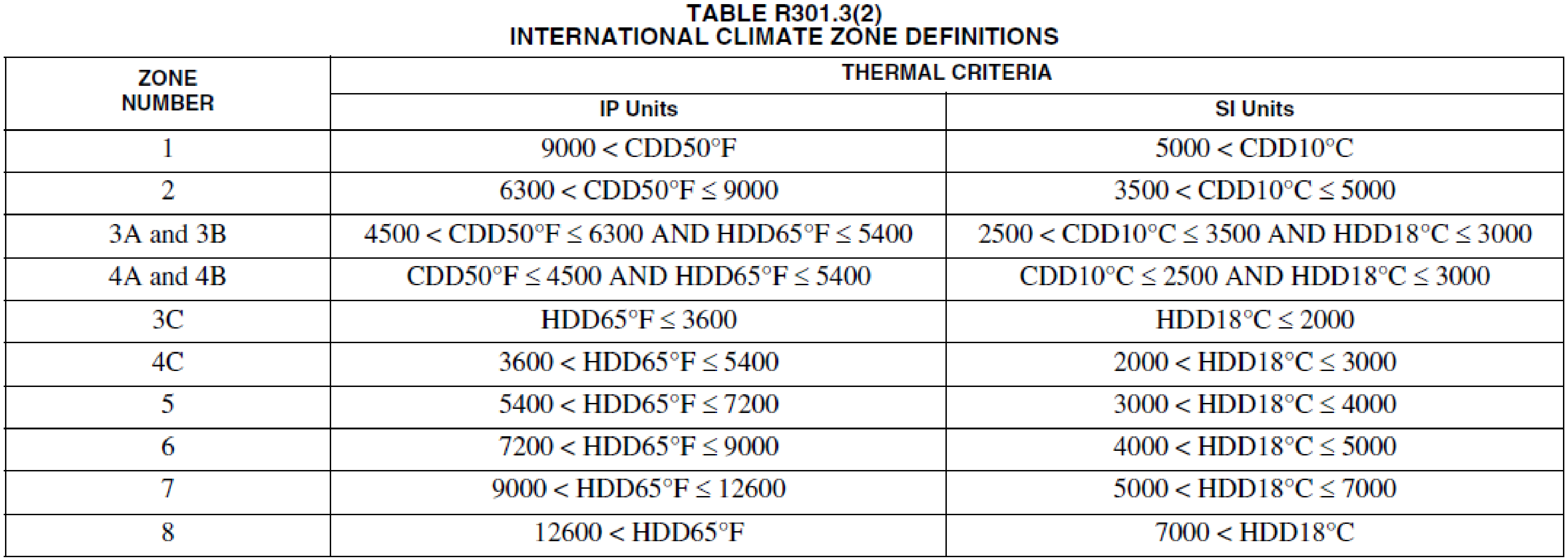


TABLE R301.3(2)
INTERNATIONAL CLIMATE ZONE DEFINITIONS

ZONE NUMBER	THERMAL CRITERIA	
	IP Units	SI Units
1	$9000 < \mathrm{CDD}50^{\circ}\mathrm{F}$	$5000 < \mathrm{CDD}10^{\circ}\mathrm{C}$
2	$6300 < \mathrm{CDD}50^{\circ}\mathrm{F} \leq 9000$	$3500 < \mathrm{CDD}10^{\circ}\mathrm{C} \leq 5000$
3A and 3B	$4500 < \mathrm{CDD}50^{\circ}\mathrm{F} \leq 6300$ AND $\mathrm{HDD}65^{\circ}\mathrm{F} \leq 5400$	$2500 < \mathrm{CDD}10^{\circ}\mathrm{C} \leq 3500$ AND $\mathrm{HDD}18^{\circ}\mathrm{C} \leq 3000$
4A and 4B	$\mathrm{CDD}50^{\circ}\mathrm{F} \leq 4500$ AND $\mathrm{HDD}65^{\circ}\mathrm{F} \leq 5400$	$\mathrm{CDD}10^{\circ}\mathrm{C} \leq 2500$ AND $\mathrm{HDD}18^{\circ}\mathrm{C} \leq 3000$
3C	$\mathrm{HDD}65^{\circ}\mathrm{F} \leq 3600$	$\mathrm{HDD}18^{\circ}\mathrm{C} \leq 2000$
4C	$3600 < \mathrm{HDD}65^{\circ}\mathrm{F} \leq 5400$	$2000 < \mathrm{HDD}18^{\circ}\mathrm{C} \leq 3000$
5	$5400 < \mathrm{HDD}65^{\circ}\mathrm{F} \leq 7200$	$3000 < \mathrm{HDD}18^{\circ}\mathrm{C} \leq 4000$
6	$7200 < \mathrm{HDD}65^{\circ}\mathrm{F} \leq 9000$	$4000 < \mathrm{HDD}18^{\circ}\mathrm{C} \leq 5000$
7	$9000 < \mathrm{HDD}65^{\circ}\mathrm{F} \leq 12600$	$5000 < \mathrm{HDD}18^{\circ}\mathrm{C} \leq 7000$
8	$12600 < \mathrm{HDD}65^{\circ}\mathrm{F}$	$7000 < \mathrm{HDD}18^{\circ}\mathrm{C}$

Current U.S. Building Code Requirements

- IBC and IRC allow for use of a Class III vapor retarder as an alternative to use of a Class I or II vapor retarder.
- Provides requirements for use with vented cladding and some sheathing materials (permeance controlled design)
- Provides requirements for use with exterior continuous insulation (temperature controlled design)

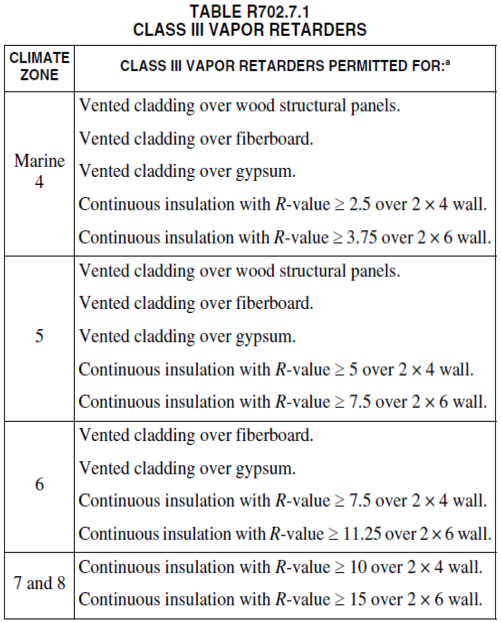


TABLE R702.7.1
CLASS III VAPOR RETARDERS

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.

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”?

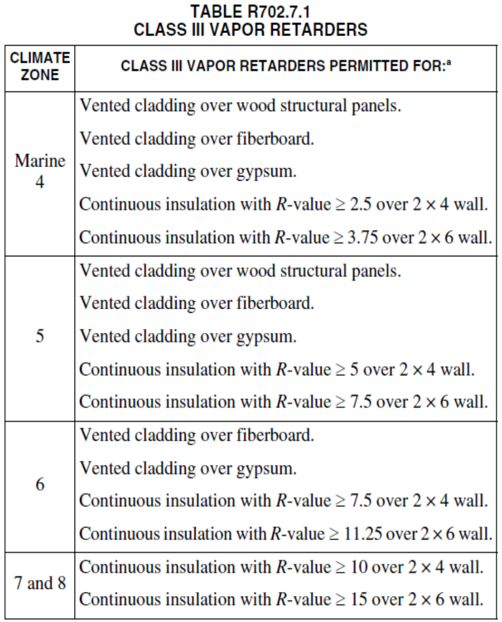


TABLE R702.7.1
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	Vented cladding over fiberboard.
	Vented cladding over gypsum.
	Continuous insulation with *R*-value ≥ 5 over 2 × 4 wall.
	Continuous insulation with *R*-value ≥ 7.5 over 2 × 6 wall.
6	Vented cladding over fiberboard.
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	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.

Current Canadian Building Code (2015 NBC)

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

Current Canadian Building Code (2015 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)

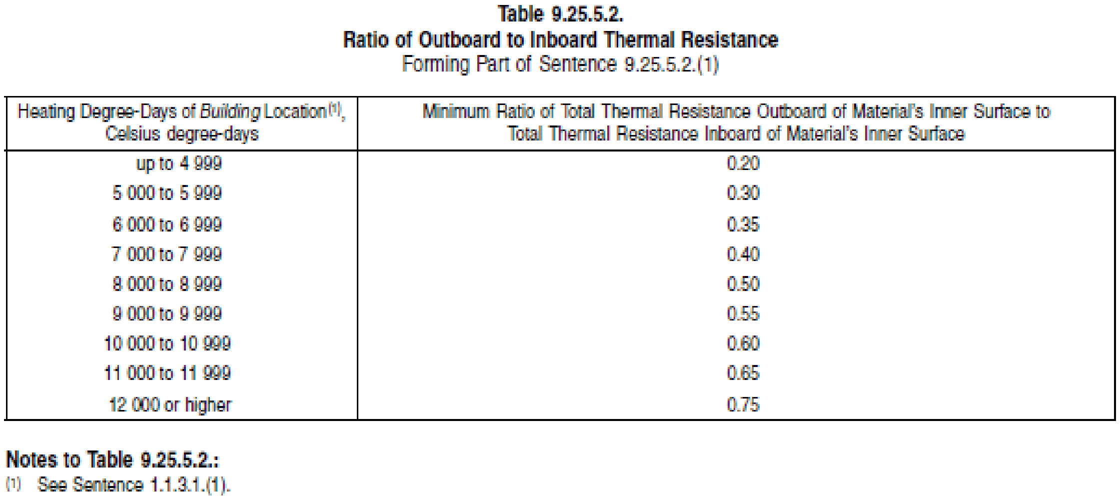


Table 9.25.5.2.
Ratio of Outboard to Inboard Thermal Resistance
Forming Part of Sentence 9.25.5.2.(1)

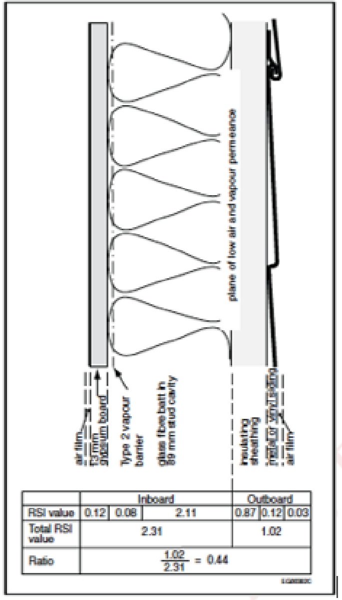
Heading Degree-Days of *Building* Location[1], Celsius degree-days	Minimum Ratio of Total Thermal Resistance Outboard of Material's Inner Surface to Total Thermal Resistance Inboard of Material's Inner Surface
up to 4 999	0.20
5 000 to 5 999	0.30
6 000 to 6 999	0.35
7 000 to 7 999	0.40
8 000 to 8 999	0.50
9 000 to 9 999	0.55
10 000 to 10 999	0.60
11 000 to 11 999	0.65
12 000 or higher	0.75

Notes to Table 9.25.5.2.:

[1] See Sentence 1.1.3.1.(1).

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.
- The insulation ratio keeps the inside of the exterior sheathing warm enough to control condensation/diffusion wetting when used together with <1 perm vapour barrier (Canada).

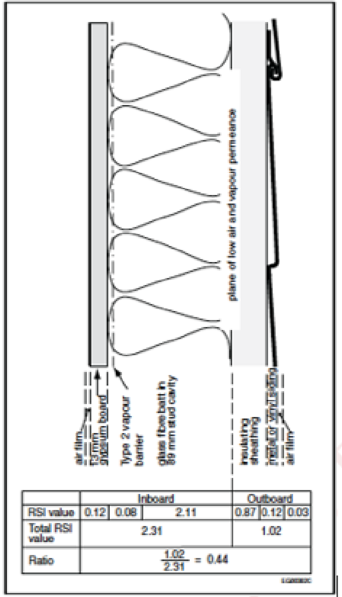


	Inboard			Outboard		
RSI value	0.12	0.08	2.11	0.87	0.12	0.03
Total RSI value	2.31			1.02		
Ratio	$\frac{1.02}{2.31} = 0.44$					

Figure 12. Calculation of Insulation Ratio (2010 NBC Commentary, Figure A9.25.5.2)

The Insulation Ratio Concept

- Can be applied to use with Class I or II interior vapor retarder in US codes.
- Insulation ratio = Re/Ri, where:
  - Re = exterior ci R-value
  - Ri = cavity insulation R-value



	Inboard			Outboard		
RSI value	0.12	0.08	2.11	0.87	0.12	0.03
Total RSI value	2.31			1.02		
Ratio	$\frac{1.02}{2.31} = 0.44$					

Figure 12. Calculation of Insulation Ratio (2010 NBC Commentary, Figure A9.25.5.2)

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.

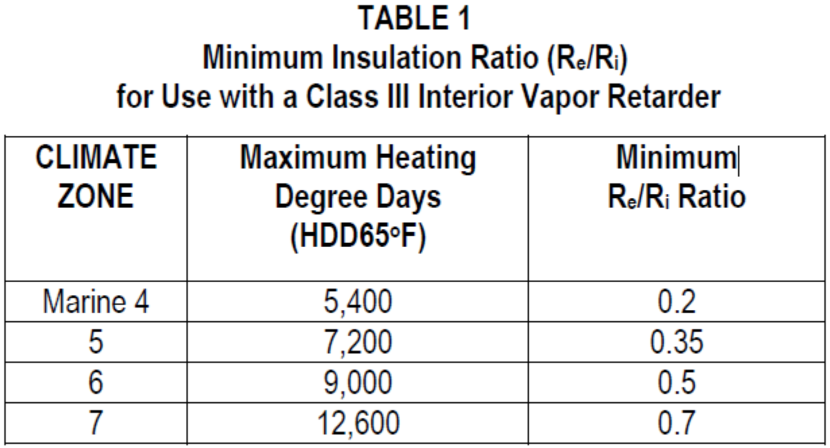
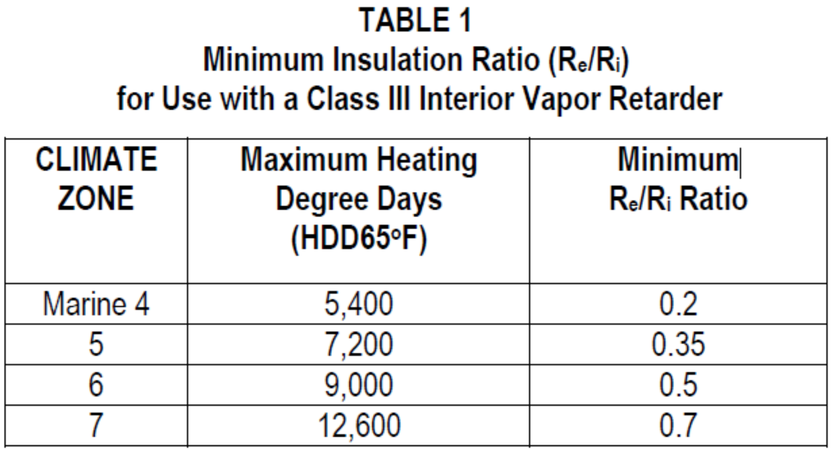


TABLE 1
Minimum Insulation Ratio (R_e/R_i)
for Use with a Class III Interior Vapor Retarder

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

The Insulation Ratio Concept

- Successful performance for nearly 20 years in Canada, even with use of a Class I vapor retarder/barrier on the interior side (e.g., double vapor barrier assembly)
- For the purpose of this presentation, however, double vapor barriers are not recommended in coastal climates with severe wind-driven rain hazard (high potential of non-diffusion sources of moisture entering wall).



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Marine 4	5,400	0.2
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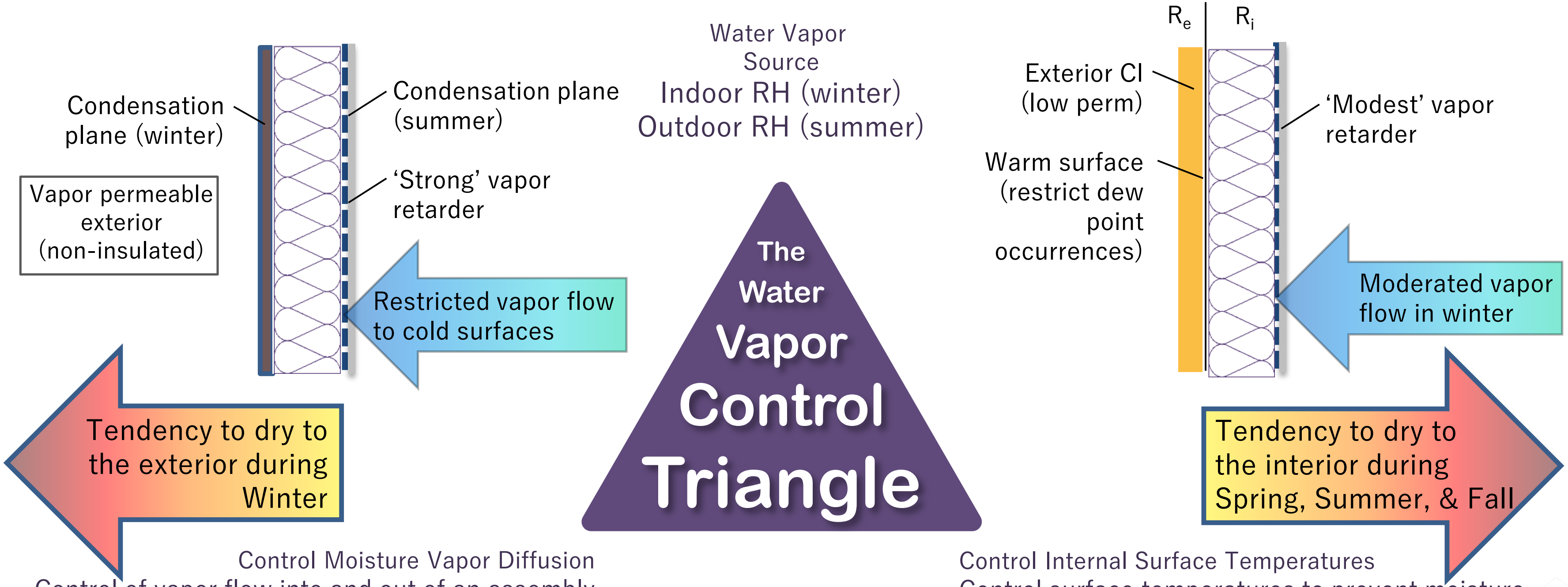
6	9,000	0.5
7	12,600	0.7

Two Design Approaches for Cold Climates



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

R_e R_i

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 humidities

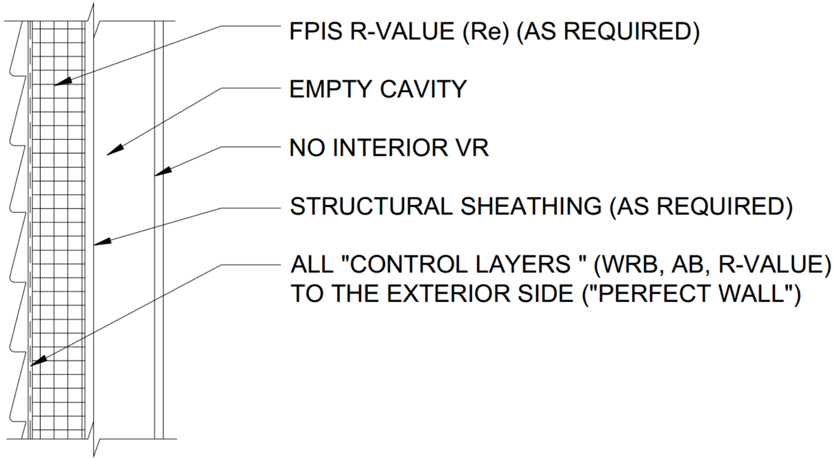
Two Design Approaches

- **Permeance controlled design** applies to walls:
  - Without exterior insulation
  - Or, with vapor-permeable exterior insulation
- Relies on permeance of all interior and exterior layers
  - Both must be checked!

- **Temperature controlled design** applies to walls:
  - With exterior insulation of any permeance, (including very low perm)
- Only requires control of water vapor permeance of interior layers (e.g., vapor retarder)

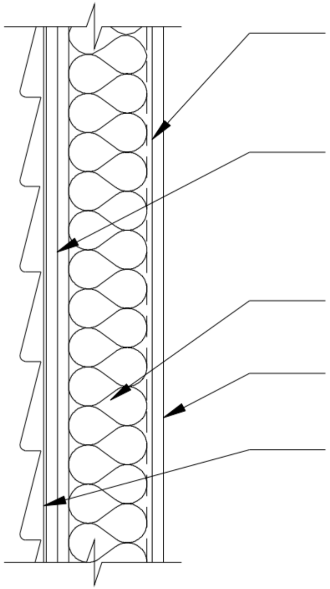
Two Approaches – Many Applications

- The two approaches define a continuum of solutions, combining more or less of one or the other design methodology
  - For example, a wall with all exterior insulation of a very low to moderately low permeance and no interior vapor retarder would be the **extreme** “perfect wall” under the temperature controlled design approach.
  - In this case, more exterior insulation is always better for moisture and thermal control!



Two Approaches – Many Applications

- On the other hand, a wall with cavity only insulation and a Class I vapor barrier on the interior and 100% vapor open on the exterior would be the **extreme** permeance controlled wall for a cold climate
  - Can pose problems during summer AC operation due to high inward water vapor movement.
- In this case, more exterior permeance is not always better!



INTERIOR VAPOR RETARDER (CLASS I, II, OR III) AS REQUIRED

EXTERIOR VAPOR PERMEANCE

NET PERM = $\frac{1}{\left[\left({}^{1}/_{P_1}\right)+\left({}^{1}/_{P_2}\right)+\cdots\right]}$

CAVITY INSULATION R-VALUE

GYPSUM & VR

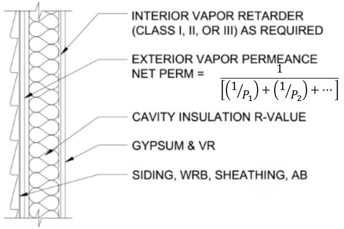
SIDING, WRB, SHEATHING, AB

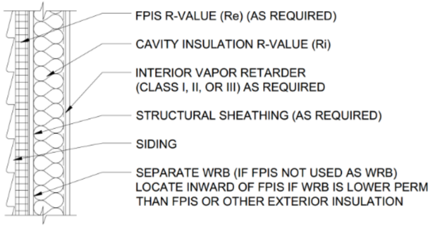
Two Approaches – Many Applications

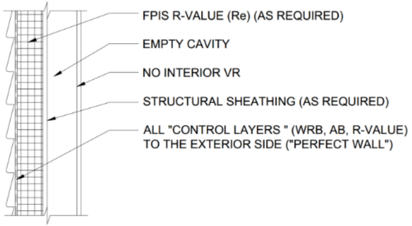
- Thus, a temperature controlled wall can work in any climate with success and is improved with increasing amount of exterior insulation relative to cavity insulation.
- The permeance control approach can be a bit trickier to strike the right balance.

Two Approaches – Many Applications

- Either design method or a blended design with features of both methods (e.g., cavity insulation + continuous insulation + interior vapor retarder) can be used successfully.







- This is what building sciences is all about – providing options for acceptable solutions.

Analytical Design Tools

- Insulation ratios and vapor retarder requirements discussed earlier are “prescriptive” (pre-determined) solutions; they either require no math or very basic math (+ - x /).
- Where alternate solutions are desired or necessary, various means of hygrothermal analysis are available to help.
  - These tools generally require some degree of expertise to properly use the tool and interpret results
  - A professional should be consulted

Analytical Design Tools

- “Static” Analysis Methods
  - Dew point check is simple & conservative
  - Glaser, Kieper, etc. – traditional methods (moderately complexity)
    - Can be done on spreadsheet with available climate data
    - Doesn’t address transient conditions (e.g., moisture storage in materials, solar radiation effects)
    - Can be used to look at monthly and annual trends in wetting and drying by diffusion
    - Moisture surcharge can be applied to account for non-diffusion moisture sources (e.g., incidental rain intrusion or moist air leakage)

- “Transient” Analysis Methods
  - Computer finite element models, often including material databases, technical support, etc.
    - WUFI, hygRIC, etc.
  - Various levels of geometric complexity in modeling heat and moisture transport
    - 1D, 2D, and 3D
  - Various levels of applied physics
    - Moisture storage,
    - Redistribution
    - Water leakage
    - Air leakage flows

Analytical Design Tools

- All analysis methods require judgment and interpretation due to assumptions and uncertainties in knowing:
    - Actual boundary conditions (e.g., indoor relative humidity, air-leakage pathways and orifices)
    - Actual material properties (e.g., actual water vapor permeance of a given product/material)
- Design is much more than just crunching numbers!

Analytical Design Tools

- Additional resources:
  - Moisture Control in Buildings, 2nd Edition, Chapter 10, www.astm.org
  - Assessment of Water Vapor Control Methods for Modern Light-frame Wall Assemblies, ABTG LLC, 2015, www.appliedbuildingtech.com
  - Lstiburek, Ueno, and Musunuru (2015). Modeling Enclosure Design in Above Grade Walls, US DOE, Building Technologies Office

Framework for Water Vapor Control
(using prescriptive “cook book” designs)

- Based on compilation of US and Canadian building codes and practices plus extensive review of literature and analysis of field data to “fill the gaps”
  - Source: Assessment of Water Vapor Control Methods for Modern Light-frame Wall Assemblies, ABTG LLC, 2015 (ABTG website) Appendix A

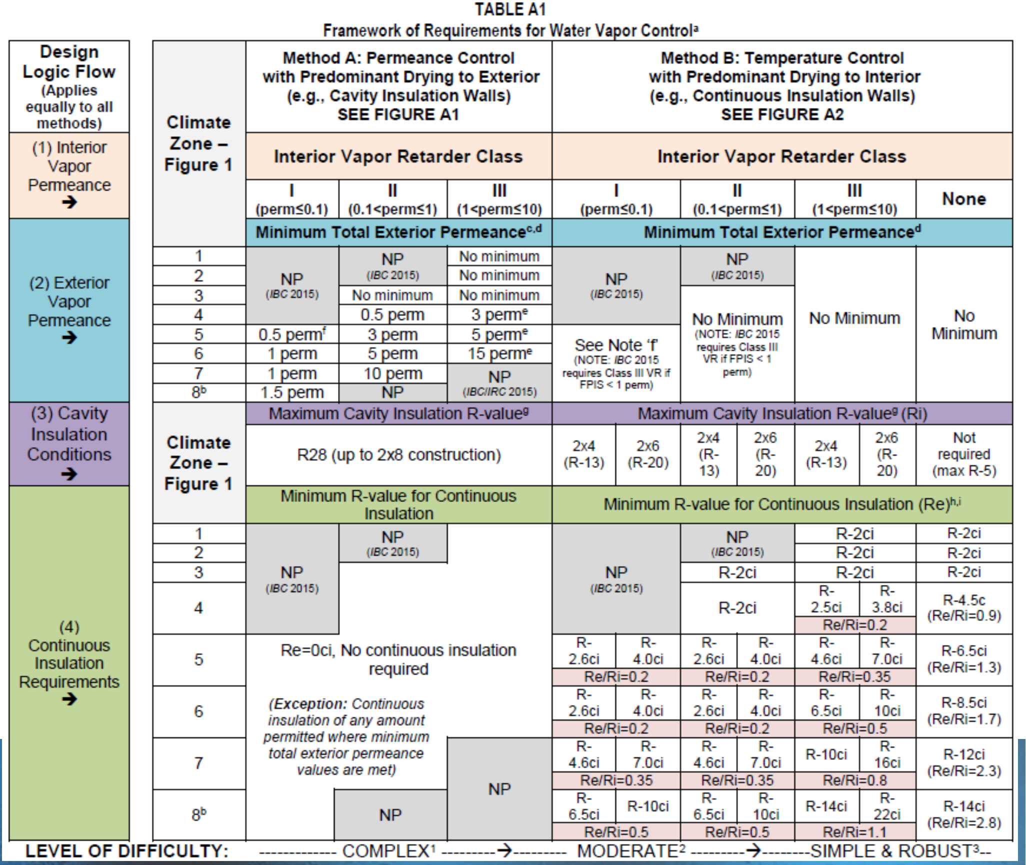


TABLE A1

Framework of Requirements for Water Vapor Control[a]

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			No minimum							
	3		No minimum	No minimum			No Minimum (NOTE: *IBC* 2015 requires Class III VR if FPIS < 1 perm)				
	4		0.5 perm	3 perm[e]							
	5	0.5 perm[f]	3 perm	5 perm[e]	See Note ‘f’ (NOTE: *IBC* 2015 requires Class III VR if FPIS < 1 perm)						
	6	1 perm	5 perm	15 perm[e]							
	7	1 perm	10 perm	NP (*IBC/IRC* 2015)							
	8[b]	1.5 perm	NP								
(3) Cavity Insulation Conditions →	Climate Zone – Figure 1	Maximum Cavity Insulation R-value[g]			Maximum Cavity Insulation R-value[g] (Ri)						
		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)
(4) Continuous Insulation Requirements →		Minimum R-value for Continuous Insulation			Minimum R-value for Continuous Insulation (Re)[h,i]						
	1	NP (*IBC* 2015)	NP (*IBC* 2015)		NP (*IBC* 2015)		NP (*IBC* 2015)		R-2ci		R-2ci
	2								R-2ci		R-2ci
	3						R-2ci		R-2ci		R-2ci
	4						R-2ci		R-2.5ci Re/Ri=0.2	R-3.8ci	R-4.5c (Re/Ri=0.9)
	5	Re=0ci, No continuous insulation required			R-2.6ci Re/Ri=0.2	R-4.0ci	R-2.6ci Re/Ri=0.2	R-4.0ci	R-4.6ci Re/Ri=0.35	R-7.0ci	R-6.5ci (Re/Ri=1.3)
	6	*(Exception: Continuous insulation of any amount permitted where minimum total exterior permeance values are met)*			R-2.6ci Re/Ri=0.2	R-4.0ci	R-2.6ci Re/Ri=0.2	R-4.0ci	R-6.5ci Re/Ri=0.5	R-10ci	R-8.5ci (Re/Ri=1.7)
	7			NP	R-4.6ci Re/Ri=0.35	R-7.0ci	R-4.6ci Re/Ri=0.35	R-7.0ci	R-10ci Re/Ri=0.8	R-16ci	R-12ci (Re/Ri=2.3)
	8[b]		NP		R-6.5ci Re/Ri=0.5	R-10ci	R-6.5ci Re/Ri=0.5	R-10ci	R-14ci Re/Ri=1.1	R-22ci	R-14ci (Re/Ri=2.8)

LEVEL OF DIFFICULTY: ------------- COMPLEX[1] ---------→-------- MODERATE[2] ---------→--------SIMPLE & ROBUST[3]--

Typical “Method A” Wall Assembly

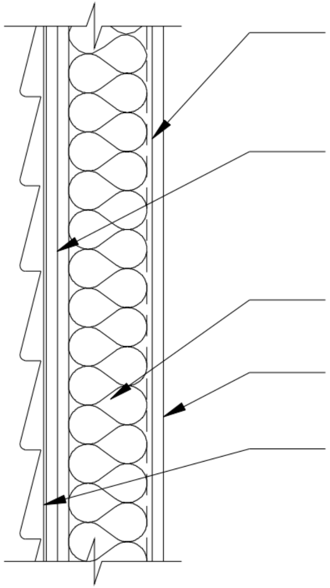
- Cavity Insulation Only (assumed to be vapor permeable cavity insulation)*

*SUPPLEMENTAL GUIDANCE:

For cavities with non-vapor permeable (closed-cell spray foam) insulation, use the Method B approach (see footnote on later slide for Table A3);

Method A also applies to walls with continuous insulation of any amount provided the net exterior WVP meets or exceeds Table A1 values.

Net exterior WVP of the exterior layers (particularly the WRB) should not exceed 10 perm to control solar-driven inward moisture movement, where direct-applied (unvented) reservoir cladding (adhered veneer, stucco, etc.) is used on buildings with AC during summer.



INTERIOR VAPOR RETARDER (CLASS I, II, OR III) AS REQUIRED

EXTERIOR VAPOR PERMEANCE NET PERM = $\frac{1}{\left[\left(1/P_1\right)+\left(1/P_2\right)+\cdots\right]}$

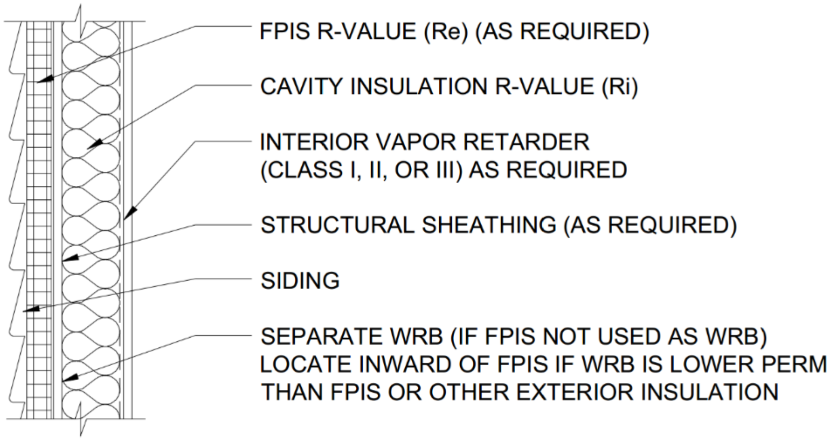
CAVITY INSULATION R-VALUE

GYPSUM & VR

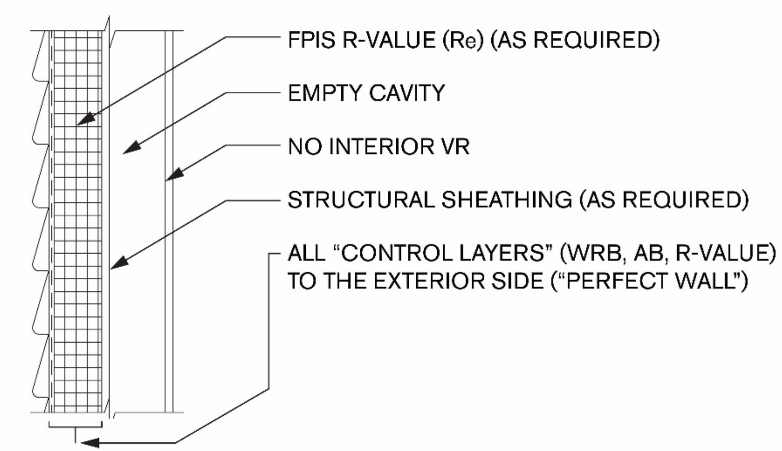
SIDING, WRB, SHEATHING, AB

Typical “Method B” Wall Assemblies

Cavity + Continuous + Interior VR



Continuous Only (No Interior VR)



Note: Arrangement of control layers is material and climate specific.

SUPPLEMENTAL GUIDANCE:

- The net exterior WVP of the WRB and/or exterior insulation should not exceed 10 perm to control solar-driven inward moisture movement, where direct-applied (unvented) reservoir cladding (adhered veneer, stucco, etc.) is used on buildings with AC during summer.
- See also Note 4 on Table A2 next slide to avoid conditions where “double vapor barrier” walls (low permeance on both sides) is considered unacceptable (even more important for walls without exterior insulation in cold or wet climates).

Simplified Framework for Climate Zone 6

- Method A: Permeance Controlled Wall (no exterior insulation)
  - TABLE NOTES 1 & 4 ARE IMPORTANT!
  - *Must evaluate permeance of exterior layers to ensure performance*

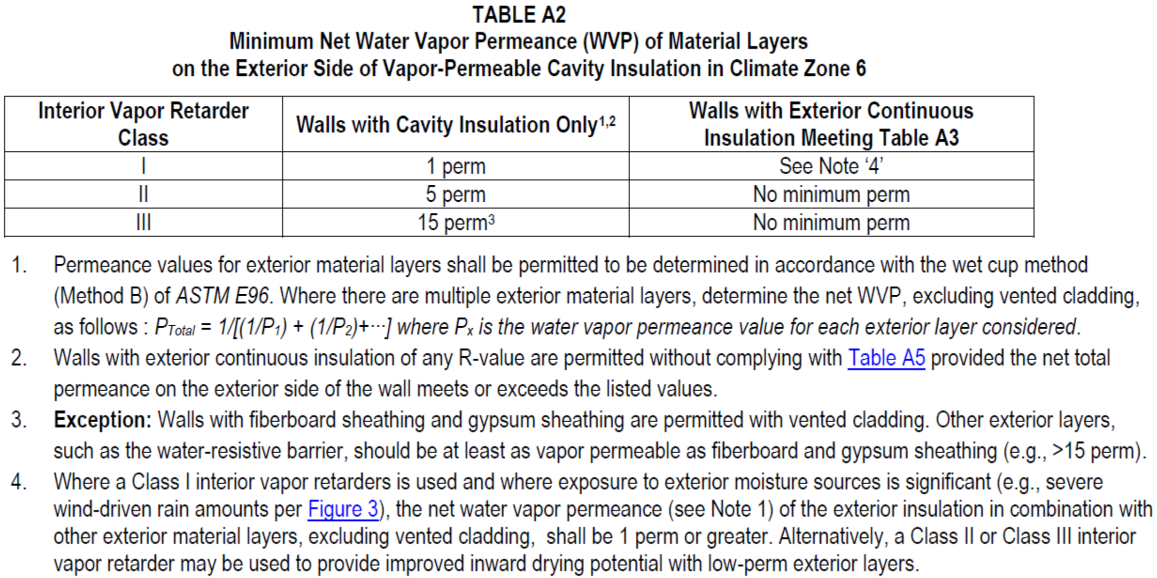


TABLE A2
Minimum Net Water Vapor Permeance (WVP) of Material Layers
on the Exterior Side of Vapor-Permeable Cavity Insulation in Climate Zone 6

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

1. Permeance values for exterior material layers shall be permitted to be determined in accordance with the wet cup method (Method B) of *ASTM E96*. Where there are multiple exterior material layers, determine the net WVP, excluding vented cladding, as follows : $P_{Total} = 1/[(1/P_1) + (1/P_2)+\cdots]$ *where* P_x *is the water vapor permeance value for each exterior layer considered.*
2. Walls with exterior continuous insulation of any R-value are permitted without complying with Table A5 provided the net total permeance on the exterior side of the wall meets or exceeds the listed values.
3. **Exception:** Walls with fiberboard sheathing and gypsum sheathing are permitted with vented cladding. Other exterior layers, such as the water-resistive barrier, should be at least as vapor permeable as fiberboard and gypsum sheathing (e.g., >15 perm).
4. Where a Class I interior vapor retarders is used and where exposure to exterior moisture sources is significant (e.g., severe wind-driven rain amounts per Figure 3), the net water vapor permeance (see Note 1) of the exterior insulation in combination with other exterior material layers, excluding vented cladding, shall be 1 perm or greater. Alternatively, a Class II or Class III interior vapor retarder may be used to provide improved inward drying potential with low-perm exterior layers.

Simplified Framework for Climate Zone 6

- Method B: Temperature Controlled Wall (cavity + continuous insulation)
  - SOLUTION AND VERIFICATION IS VERY SIMPLE: Check insulation R-values (easy) and check vapor retarder used (easy).

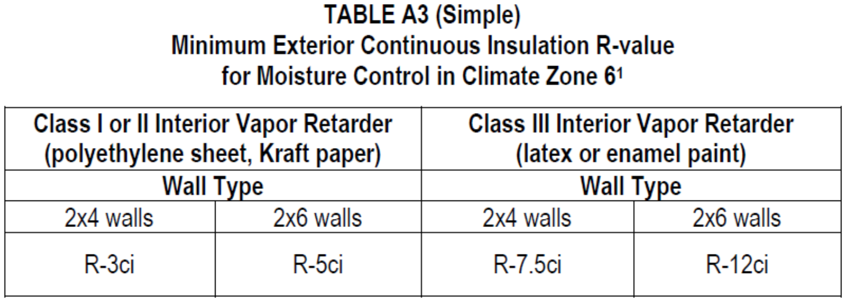


TABLE A3 (Simple)
Minimum Exterior Continuous Insulation R-value for Moisture Control in Climate Zone 6[1]

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

Climate Zone 6 – More Options for CI Amounts

- Lose some table size simplicity, but gain much flexibility and accuracy (still a "cook-book" look up the answer approach)

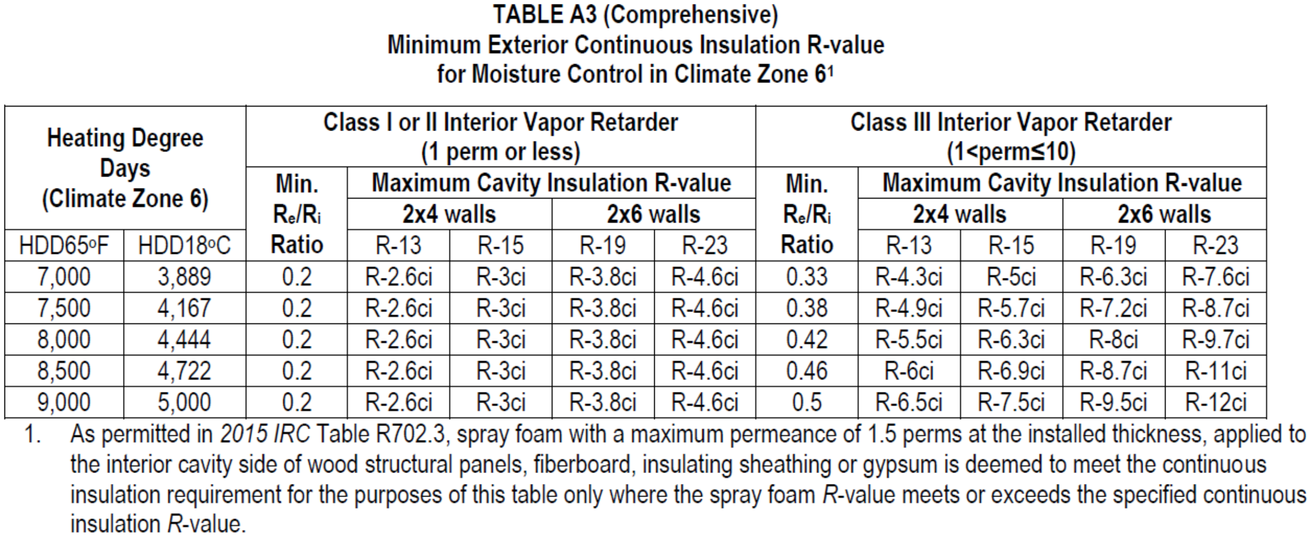


TABLE A3 (Comprehensive)
Minimum Exterior Continuous Insulation R-value
for Moisture Control in Climate Zone 6[1]

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

[1] As permitted in *2015 IRC* Table R702.3, spray foam with a maximum permeance of 1.5 perms at the installed thickness, applied to the interior cavity side of wood structural panels, fiberboard, insulating sheathing or gypsum is deemed to meet the continuous insulation requirement for the purposes of this table only where the spray foam *R*-value meets or exceeds the specified continuous insulation *R*-value.

Similarly for Other Climate Zones…

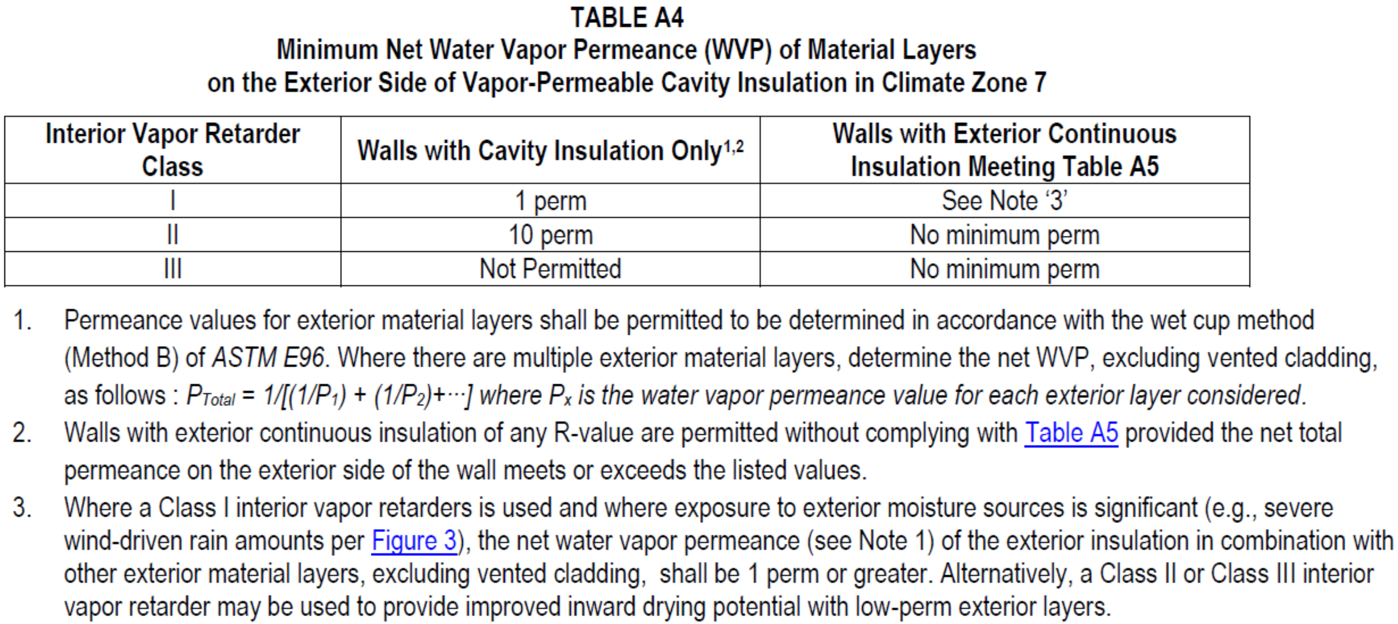


TABLE A4
Minimum Net Water Vapor Permeance (WVP) of Material Layers
on the Exterior Side of Vapor-Permeable Cavity Insulation in Climate Zone 7

Interior Vapor Retarder Class	**Walls with Cavity Insulation Only[1,2]**	**Walls with Exterior Continuous Insulation Meeting Table A5**
I	1 perm	See Note '3'
II	10 perm	No minimum perm
III	Not Permitted	No minimum perm

1. Permeance values for exterior material layers shall be permitted to be determined in accordance with the wet cup method (Method B) of *ASTM E96*. Where there are multiple exterior material layers, determine the net WVP, excluding vented cladding, as follows : $P_{Total} = 1/[(1/P_1) + (1/P_2)+\cdots]$ *where* P_x *is the water vapor permeance value for each exterior layer considered.*
2. Walls with exterior continuous insulation of any R-value are permitted without complying with Table A5 provided the net total permeance on the exterior side of the wall meets or exceeds the listed values.
3. Where a Class I interior vapor retarders is used and where exposure to exterior moisture sources is significant (e.g., severe wind-driven rain amounts per Figure 3), the net water vapor permeance (see Note 1) of the exterior insulation in combination with other exterior material layers, excluding vented cladding, shall be 1 perm or greater. Alternatively, a Class II or Class III interior vapor retarder may be used to provide improved inward drying potential with low-perm exterior layers.

Similarly for Other Climate Zones…

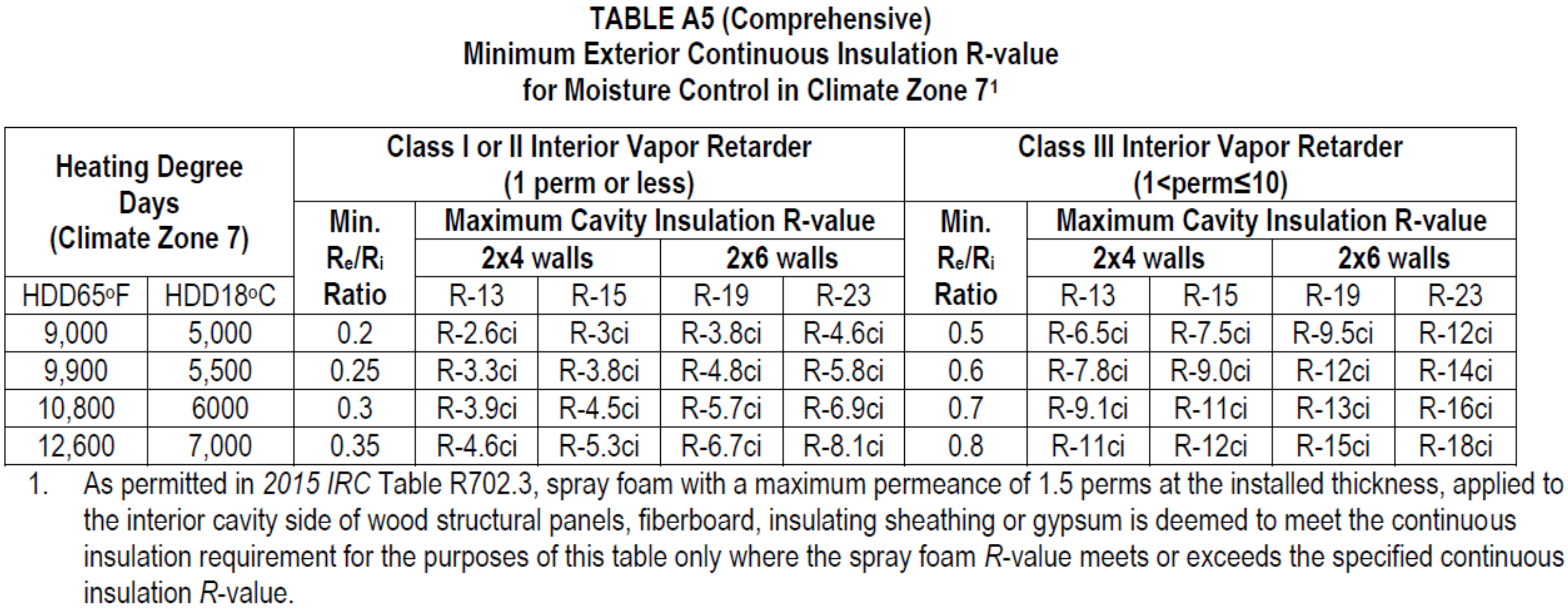


TABLE A5 (Comprehensive)
Minimum Exterior Continuous Insulation R-value
for Moisture Control in Climate Zone 7[1]

Heating Degree Days (Climate Zone 7)		**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
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
9,900	5,500	0.25	R-3.3ci	R-3.8ci	R-4.8ci	R-5.8ci	0.6	R-7.8ci	R-9.0ci	R-12ci	R-14ci
10,800	6000	0.3	R-3.9ci	R-4.5ci	R-5.7ci	R-6.9ci	0.7	R-9.1ci	R-11ci	R-13ci	R-16ci
12,600	7,000	0.35	R-4.6ci	R-5.3ci	R-6.7ci	R-8.1ci	0.8	R-11ci	R-12ci	R-15ci	R-18ci

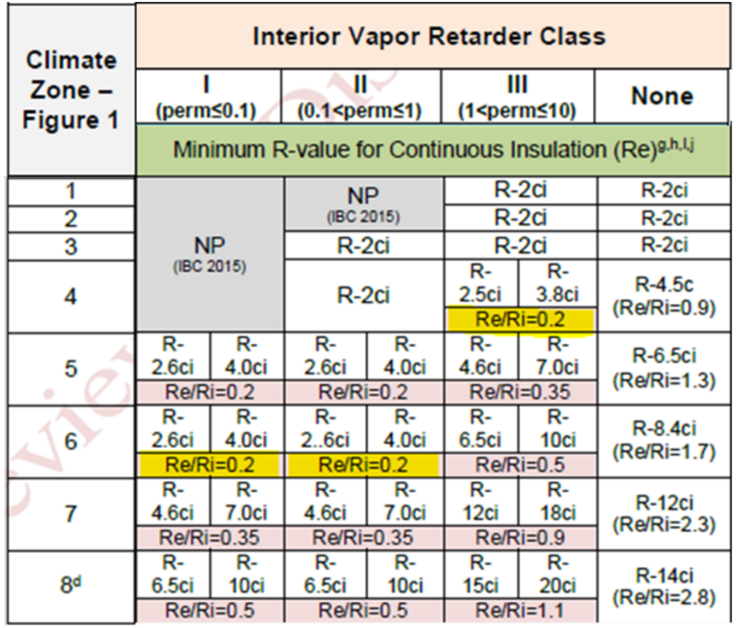
1. As permitted in *2015 IRC* Table R702.3, spray foam with a maximum permeance of 1.5 perms at the installed thickness, applied to the interior cavity side of wood structural panels, fiberboard, insulating sheathing or gypsum is deemed to meet the continuous insulation requirement for the purposes of this table only where the spray foam *R*-value meets or exceeds the specified continuous insulation *R*-value.

Design Example 1

- **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 “Method B” wall in accordance with Table A1 of Appendix A.
  - Find: What is the maximum (coldest) permissible climate zone for this wall when using a Class I, II or Class III interior vapor retarder?

Design Example 1

- Solution: First, determine the insulation ratio, $R_e/R_i = 5/20 = 0.25$.
  - In accordance with Table A1 or A3 (Appendix A), 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.



Climate Zone – Figure 1	Interior Vapor Retarder Class			
	I (perm≤0.1)	II (0.1<perm≤1)	III (1<perm≤10)	None
	Minimum R-value for Continuous Insulation (Re)^{g,h,l,j}			
1	NP (IBC 2015)	NP (IBC 2015)	R-2ci	R-2ci
2			R-2ci	R-2ci
3		R-2ci	R-2ci	R-2ci
4		R-2ci	R-2.5ci R-3.8ci Re/Ri=0.2	R-4.5c (Re/Ri=0.9)
5	R-2.6ci R-4.0ci Re/Ri=0.2	R-2.6ci R-4.0ci Re/Ri=0.2	R-4.6ci R-7.0ci Re/Ri=0.35	R-6.5ci (Re/Ri=1.3)
6	R-2.6ci R-4.0ci Re/Ri=0.2	R-2..6ci R-4.0ci Re/Ri=0.2	R-6.5ci R-10ci Re/Ri=0.5	R-8.4ci (Re/Ri=1.7)
7	R-4.6ci R-7.0ci Re/Ri=0.35	R-4.6ci R-7.0ci Re/Ri=0.35	R-12ci R-18ci Re/Ri=0.9	R-12ci (Re/Ri=2.3)
8^{d}	R-6.5ci R-10ci Re/Ri=0.5	R-6.5ci R-10ci Re/Ri=0.5	R-15ci R-20ci Re/Ri=1.1	R-14ci (Re/Ri=2.8)

Design Example 1

- Alternatively, a more precise use of insulation ratios as shown in Table A5 (Comprehensive) indicates that an R20+5ci wall with a Class I or II vapor retarder works within Climate Zone 7 for up to 9,900 heating degree days (HDD65F).

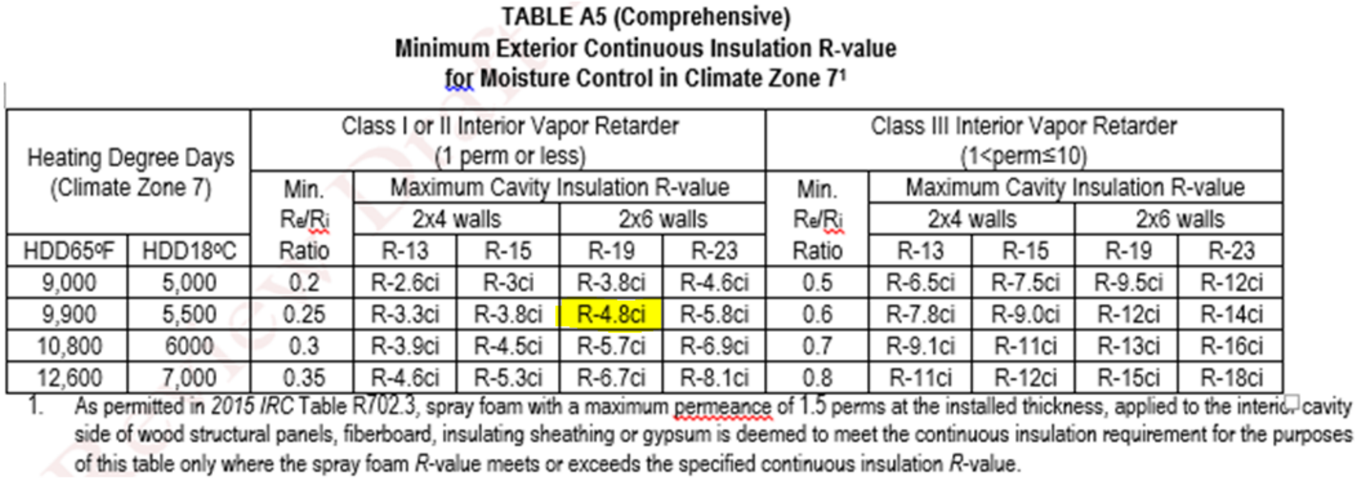


TABLE A5 (Comprehensive)
Minimum Exterior Continuous Insulation R-value
for Moisture Control in Climate Zone 7[1]

Heating Degree Days (Climate Zone 7)		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
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
9,900	5,500	0.25	R-3.3ci	R-3.8ci	R-4.8ci	R-5.8ci	0.6	R-7.8ci	R-9.0ci	R-12ci	R-14ci
10,800	6000	0.3	R-3.9ci	R-4.5ci	R-5.7ci	R-6.9ci	0.7	R-9.1ci	R-11ci	R-13ci	R-16ci
12,600	7,000	0.35	R-4.6ci	R-5.3ci	R-6.7ci	R-8.1ci	0.8	R-11ci	R-12ci	R-15ci	R-18ci

1. As permitted in *2015 IRC* Table R702.3, spray foam with a maximum permeance of 1.5 perms at the installed thickness, applied to the interior cavity side of wood structural panels, fiberboard, insulating sheathing or gypsum is deemed to meet the continuous insulation requirement for the purposes of this table only where the spray foam *R*-value meets or exceeds the specified continuous insulation *R*-value.

Design Example 1

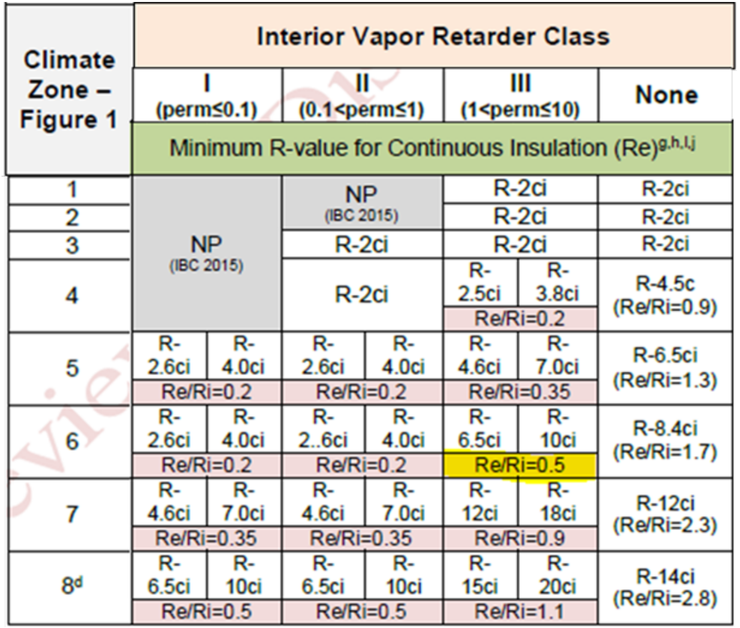
- While this example assembly may be permitted as a prescriptive solution in the energy code, the insulation ratio should be checked as demonstrated in this example as moisture control considerations may “override” the energy code.
- Consequently, the insulation locations and amounts may need to be adjusted to achieve moisture control while also still complying with the required energy code thermal performance in a given climate zone.
- For example, changing to a R13+R10ci insulation strategy using a 2x4 wall which is thermally equivalent will increase the insulation ratio to 10/13 = 0.77, providing much improved water vapor control or the ability to tolerate higher indoor RH conditions and/or much colder climate zones.

Design Example 2

- **Example 2: Getting More Creative with Insulation Ratios**
  - Given: Consider a wall assembly comprised of R15 high density batt insulation in a 2x4 wall, the use of exterior continuous insulation, and R2 insulating (foam backed) vinyl siding. This is a “Method B” wall assembly in accordance with Table A1 of Appendix A.
  - Find: What would be the required R-value (and thickness) of the exterior continuous insulation to use this assembly in Climate Zone 6 with a Class III interior vapor retarder (e.g., latex paint on drywall)?

Design Example 2

- Solution: In accordance with Table A1 a *minimum* R_e/R_i ratio of 0.5 is required (which more precisely applies to the extreme northern boundary of Climate Zone 6). Thus, the exterior continuous insulation amount must be at least R15 x 0.5 = R7.5ci.



Climate Zone – Figure 1	Interior Vapor Retarder Class			
	I (perm≤0.1)	II (0.1<perm≤1)	III (1<perm≤10)	None
	Minimum R-value for Continuous Insulation (Re)[g,h,l,j]			
1	NP (IBC 2015)	NP (IBC 2015)	R-2ci	R-2ci
2			R-2ci	R-2ci
3		R-2ci	R-2ci	R-2ci
4		R-2ci	R-2.5ci R-3.8ci Re/Ri=0.2	R-4.5c (Re/Ri=0.9)
5	R-2.6ci R-4.0ci Re/Ri=0.2	R-2.6ci R-4.0ci Re/Ri=0.2	R-4.6ci R-7.0ci Re/Ri=0.35	R-6.5ci (Re/Ri=1.3)
6	R-2.6ci R-4.0ci Re/Ri=0.2	R-2..6ci R-4.0ci Re/Ri=0.2	R-6.5ci R-10ci Re/Ri=0.5	R-8.4ci (Re/Ri=1.7)
7	R-4.6ci R-7.0ci Re/Ri=0.35	R-4.6ci R-7.0ci Re/Ri=0.35	R-12ci R-18ci Re/Ri=0.9	R-12ci (Re/Ri=2.3)
8[d]	R-6.5ci R-10ci Re/Ri=0.5	R-6.5ci R-10ci Re/Ri=0.5	R-15ci R-20ci Re/Ri=1.1	R-14ci (Re/Ri=2.8)

Design Example 2

- Because the insulating siding provides at least R2 of this exterior continuous insulation, the insulated sheathing only needs to make up the difference of 7.5R – R2 = R5.5.
- Thus, the following insulated sheathing options are possible:
  - 1.5 inches of EPS foam sheathing (~R6),
  - 1'' of XPS (R5) plus an insulated vinyl siding of R2.5 instead of R2, or
  - 1” of foil-faced polyisocyanurate foam sheathing(~R6)

Design Example 2

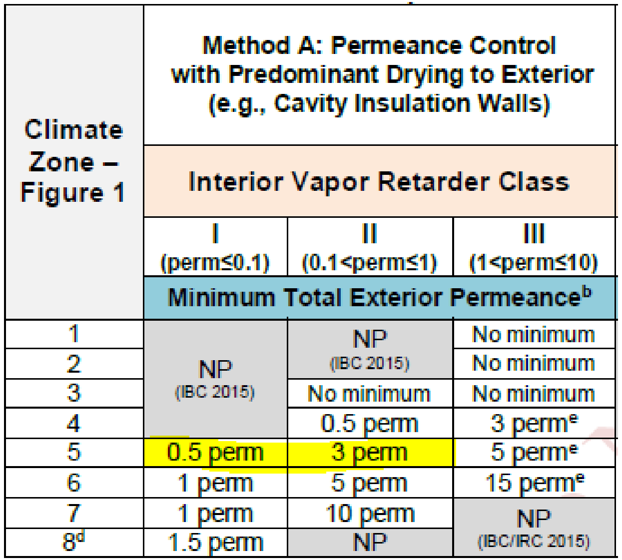
- While the above wall meets the moisture control objective, energy code compliance must also be checked.
- In this case, a U-factor for the assembly should be determined following procedures in the energy code and the ASHRAE *Handbook of Fundamentals* or an approved method.
- For example, if the R15+7.5ci objective is exactly satisfied with a combination of insulating sheathing and insulating siding as discussed above (e.g., R5.5 sheathing and R2 siding), the calculated U-factor of the wood-frame wall assembly is approximately 0.049 with an effective R-value of 20.4.

Design Example 3

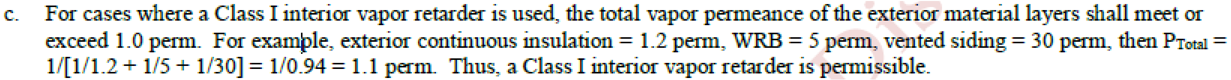
- **Example 3: Verify compliance of a conventional 2x6 (cavity insulation only) wall assembly in Climate Zone 5 with exterior permeance requirements for water vapor control**
  - Given: Assume the energy code requires minimum R-20 cavity insulation and the product used is vapor permeable (e.g., fiberglass, cellulose). This is a “Method A” wall assembly in accordance with Table A1 of Appendix A. 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 (verify with manufacturer) and a vented cladding (e.g., anchored brick veneer, vinyl siding, furred lap siding).
  - Find: What Class of interior vapor retarder is permitted for use with this assembly in Climate Zone 5?

Example 3

- Solution: First, determine the net vapor permeance of the exterior material layers (excluding the vented cladding) in accordance with Note ‘c’ of Table A1. 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 A1 for use with a Class II (e.g., Kraft paper) vapor retarder. Thus, a Class I vapor retarder is required.



Climate Zone – Figure 1	Method A: Permeance Control with Predominant Drying to Exterior (e.g., Cavity Insulation Walls)		
	Interior Vapor Retarder Class		
	I (perm≤0.1)	II (0.1<perm≤1)	III (1<perm≤10)
	Minimum Total Exterior Permeance[b]		
1	NP (IBC 2015)	NP (IBC 2015)	No minimum
2			No minimum
3		No minimum	No minimum
4		0.5 perm	3 perm[e]
5	0.5 perm	3 perm	5 perm[e]
6	1 perm	5 perm	15 perm[e]
7	1 perm	10 perm	NP (IBC/IRC 2015)
8[d]	1.5 perm	NP	



c. For cases where a Class I interior vapor retarder is used, the total vapor permeance of the exterior material layers shall meet or exceed 1.0 perm. For example, exterior continuous insulation = 1.2 perm, WRB = 5 perm, vented siding = 30 perm, then P_{Total} = 1/[1/1.2 + 1/5 + 1/30] = 1/0.94 = 1.1 perm. Thus, a Class I interior vapor retarder is permissible.

Example 3

- However, there are alternatives.
  - For example, one could use a sheathing product with a minimum permeance of 4.3 perm (e.g., ½" plywood sheathing, fiberboard) 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.

Summary

- 5 Building Science Concepts important to moisture-resistant & energy efficient construction
- Terms important to the “trade”
- Current US and Canadian building code provisions for water vapor control, including “gaps” and limits to conventional “rules-of-thumb”
- Appropriate design tools for hygrothermal analysis of assemblies
- Two design approaches to control water vapor – with many applications
- A framework for prescriptive design to control water vapor
- How to apply the framework to wall design examples

Suggested Resources

- Water Vapor Control – ContinuousInsulation.org