Kohta Ueno

How Do We Really Even Know What We Know? The Testing That Shaped Building Science

Building Science Corporation

ROCKY MOUNTAIN BUILDING SCIENCE SYMPOSIUM

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Course Description

The current building codes include provisions for moisture-safe unvented roofs using spray foam or exterior rigid foam, and for eliminating Class I or Class II vapor barriers/retarders in cold climates, if vapor permeable exteriors and/or exterior insulation are used. Where did these code provisions come from? There is a wealth of building science research and simulations that provided the basis of the finalized code language. Participants will be able to understand the logic behind cold weather interstitial condensation problems and how the modern codes address them.

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Learning Objectives

At the end of this course, participants will be able to answer:

1. Explain the role of cladding ventilation in drying of assemblies
2. Calculate or estimate ratios of interior vs. exterior wall insulation to minimize condensation risks under various conditions
3. Provide details for walls to avoid issues with inward vapor drive condensation/accumulation.
4. Explain the potential risks of vapor-impermeable exterior insulating sheathing, and how to control the risks

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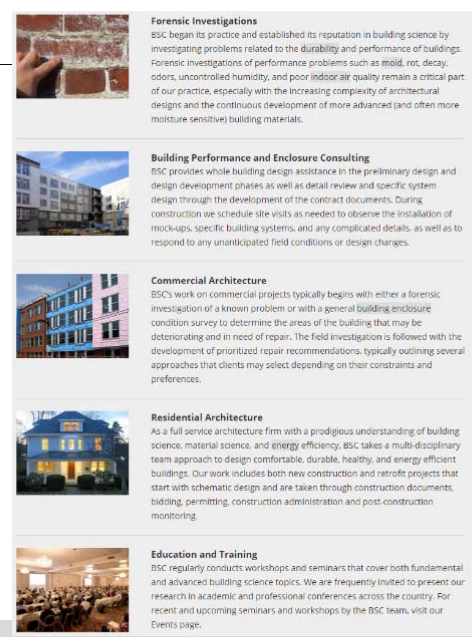
About BSC

- Massachusetts-based consulting firm
- Founded by Joseph Lstiburek ("Dr. Joe")
- Forensics
- Design reviews
- Construction admin
- Research
- Website resources
  - https://buildingscience.com/



Forensic Investigations
BSC began its practice and established its reputation in building science by investigating problems related to the durability and performance of buildings. Forensic investigations of performance problems such as mold, rot, decay, odors, uncontrolled humidity, and poor indoor air quality remain a critical part of our practice, especially with the increasing complexity of architectural designs and the continuous development of more advanced (and often more moisture sensitive) building materials.

Building Performance and Enclosure Consulting
BSC provides whole building design assistance in the preliminary design and design development phases as well as detail review and specific system design through the development of the contract documents. During construction we schedule site visits as needed to observe the installation of mock-ups, specific building systems, and any complicated details, as well as to respond to any unanticipated field conditions or design changes.

Commercial Architecture
BSC's work on commercial projects typically begins with either a forensic investigation of a known problem or with a general building enclosure condition survey to determine the areas of the building that may be deteriorating and in need of repair. The field investigation is followed with the development of prioritized repair recommendations, typically outlining several approaches that clients may select depending on their constraints and preferences.

Residential Architecture
As a full service architecture firm with a prodigious understanding of building science, material science, and energy efficiency, BSC takes a multi-disciplinary team approach to design comfortable, durable, healthy, and energy efficient buildings. Our work includes both new construction and retrofit projects that start with schematic design and are taken through construction documents, bidding, permitting, construction administration and post-construction monitoring.

Education and Training
BSC regularly conducts workshops and seminars that cover both fundamental and advanced building science topics. We are frequently invited to present our research in academic and professional conferences across the country. For recent and upcoming seminars and workshops by the BSC team, visit our Events page.

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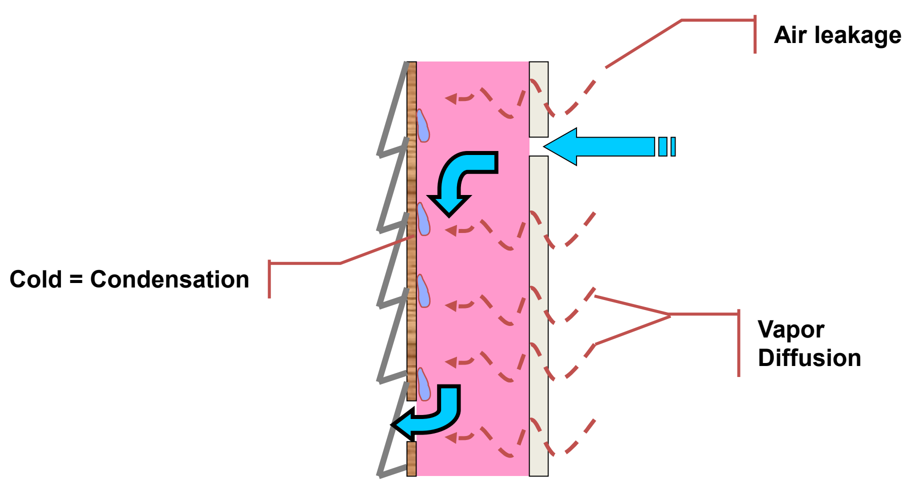
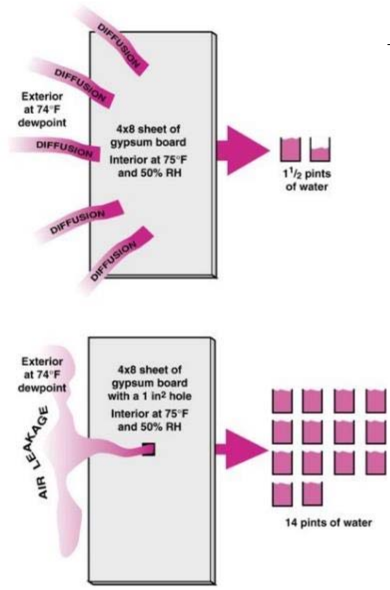
Vapor Retarders: What Problem are we Trying to Solve?

Wall with only Structural Sheathing in Winter



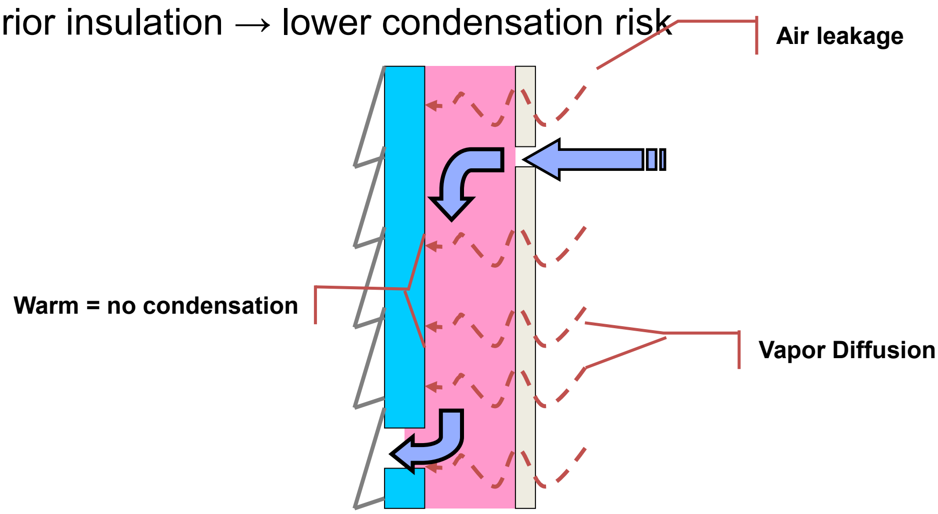
Vapor Diffusion vs. Air Leakage

- Vapor Diffusion
  - more to less vapor
  - no air flow
  - flow through tiny pores
- Air Convection
  - more to less air pressure
  - flow through visible cracks and holes
  - vapor is just along for the ride
- **A "vapor barrier" that doesn't control airflow is pointless**

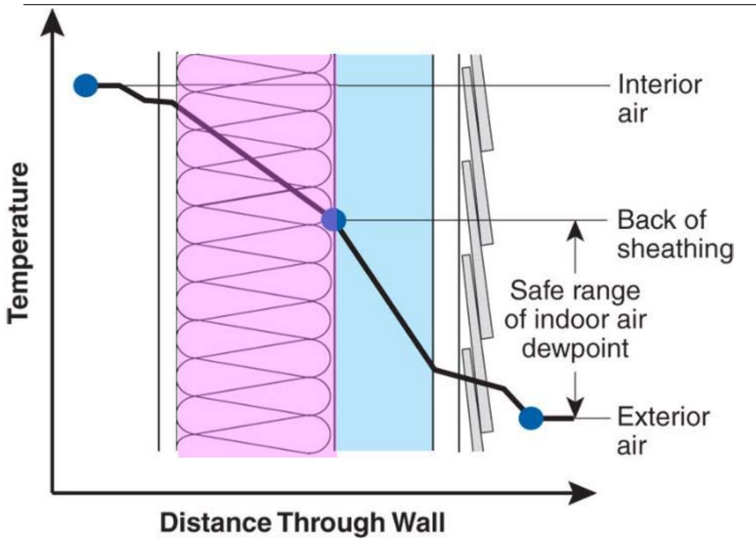


Wall with Insulated Sheathing in Winter

- Exterior insulation → lower condensation risk



Ratio of Exterior-to-Interior Insulation



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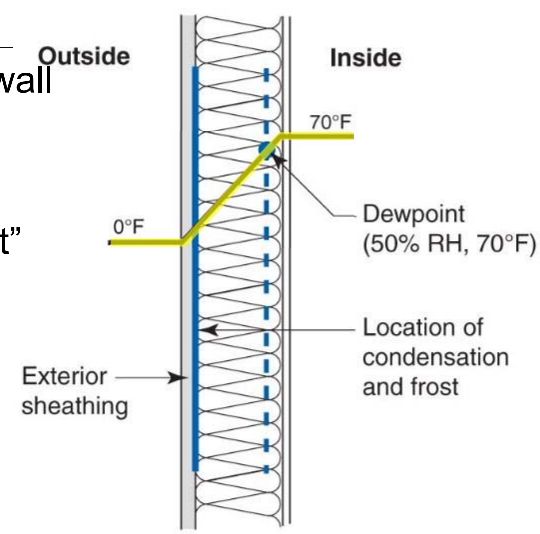
"Where's the Dewpoint?"

- "Calculating the dewpoint location" in wall
- Dewpoint = absolute air MC
- Temperature drop through assembly
- "Condensation in the middle of the batt"

- But that's not what happens…



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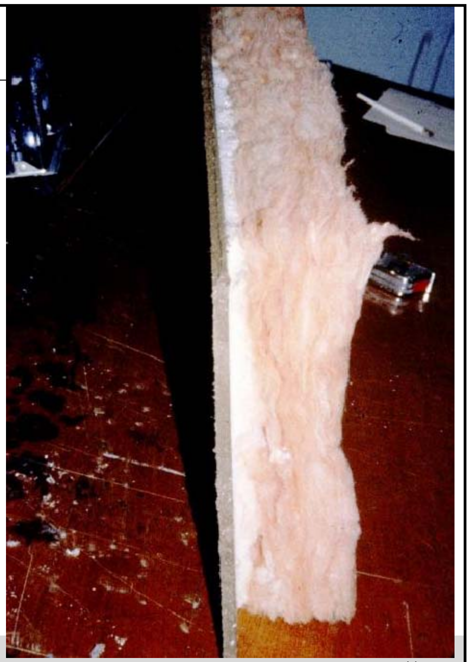
The "Cold Condensing Surface"

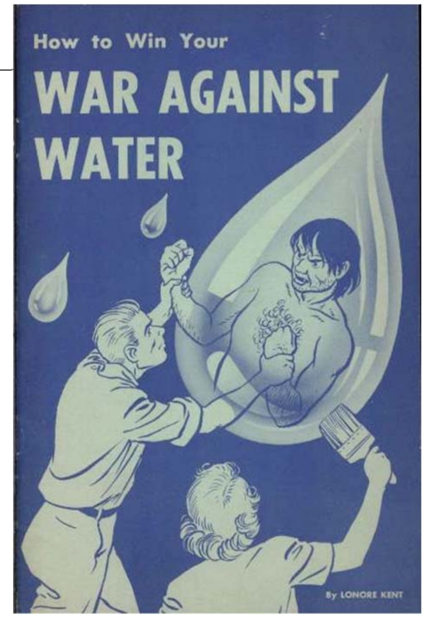
- Condensation or frost occurs at the backside of the sheathing
- Why you see damaged sheathing with condensation problems
- Sheathing has the "thermal mass" to cool off the water vapor and condense/frost
- "Indoor air dewpoint is higher than temperature of cold condensing surface"



Vapor Retarders: History and Building Codes

Vapor Retarder History Lessons

- 1930’s: Insulation added to walls
- Peeling exterior paint
- Exterior cladding colder/wetter
- Paint industry concentrated on vapor diffusion (not air leakage) → vapor barriers



Vapor Retarder History Lessons (Pre 2007)

- 2006 IRC: vapor retarder = 1 perm or less
- Vapor retarders required in walls, floors, and ceilings
  - Not required CZ 1, 2, 3, 4A, 4B
  - Not required “where other means to avoid condensation are provided”
- 2007 Supplement to the IRC: added Class I/II/III and more information

VAPOR RETARDER. A vapor resistant material, membrane or covering such as foil, plastic sheeting, or insulation facing having a permeance rating of 1 perm ($5.7 \cdot 10^{-11}$ kg/Pa · s · m^2) or less, when tested in accordance with the dessicant method using Procedure A of ASTM E 96. Vapor retarders limit the amount of moisture vapor that passes through a material or wall assembly.

N1102.5 Moisture control. The building design shall not create conditions of accelerated deterioration from moisture condensation. Above-grade frame walls, floors and ceilings not ventilated to allow moisture to escape shall be provided with an approved vapor retarder. The vapor retarder shall be installed on the warm-in-winter side of the thermal insulation.

Exceptions:

1. In construction where moisture or its freezing will not damage the materials.
2. Frame walls, floors and ceilings in jurisdictions in Zones 1, 2, 3, 4A, and 4B. (Crawl space floor vapor retarders are not exempted.)
3. Where other approved means to avoid condensation are provided.

Vapor Barriers and the Code

- Class I: 0.1 perm or less (polyethylene, foil facers)
- Class II: 0.1 < perm ≤ 1.0 perm (Kraft facing, vapor retarder paint)
- Class III: 1.0 < perm ≤ 10 perm (Latex primer + paint)

- **Factors of 10 difference between Classes**

TABLE R702.7(1) VAPOR RETARDER MATERIALS AND CLASSES

CLASS	ACCEPTABLE MATERIALS
I	Sheet polyethylene, nonperforated aluminum foil or other approved materials with a perm rating less than or equal to 0.1.
II	Kraft-faced fiberglass batts, vapor retarder paint or other approved materials applied in accordance with the manufacturer's installation instructions for a perm rating greater than 0.1 and less than or equal to 1.0.
III	Latex paint, enamel paint or other approved materials applied in accordance with the manufacturer's installation instructions for a perm rating greater than 1.0 and less than or equal to 10.0.

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2007 Supplement to the IRC Changes

- Class I or II required CZ 5 and higher + CZ4 marine

- Can we change the code so that we don't need polyethylene or Kraft paper in all of those locations?

TABLE R702.7(1) VAPOR RETARDER MATERIALS AND CLASSES

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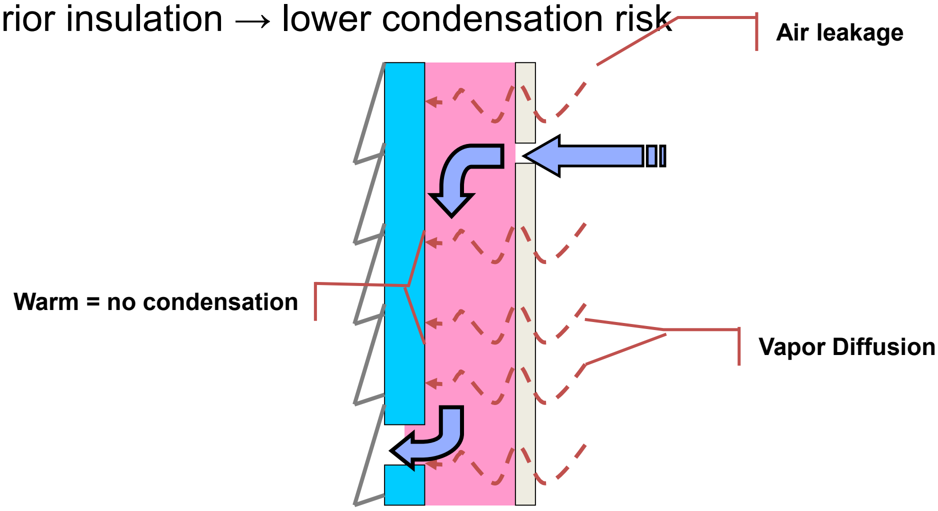
Wall with Insulated Sheathing in Winter

- Exterior insulation → lower condensation risk



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Code Tables-Class III: Exterior Insulation

TABLE N1102.5.1
CLASS III VAPOR RETARDERS

Zone	Class III vapor retarders permitted for:
Marine 4	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 2.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 3.75 over 2x6 wall
5	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 5 over 2x4 wall Insulated sheathing with *R*-value ≥ 7.5 over 2x6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 7.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 11.25 over 2x6 wall
7 and 8	Insulated sheathing with *R*-value ≥ 10 over 2x4 wall Insulated sheathing with *R*-value ≥ 15 over 2x6 wall

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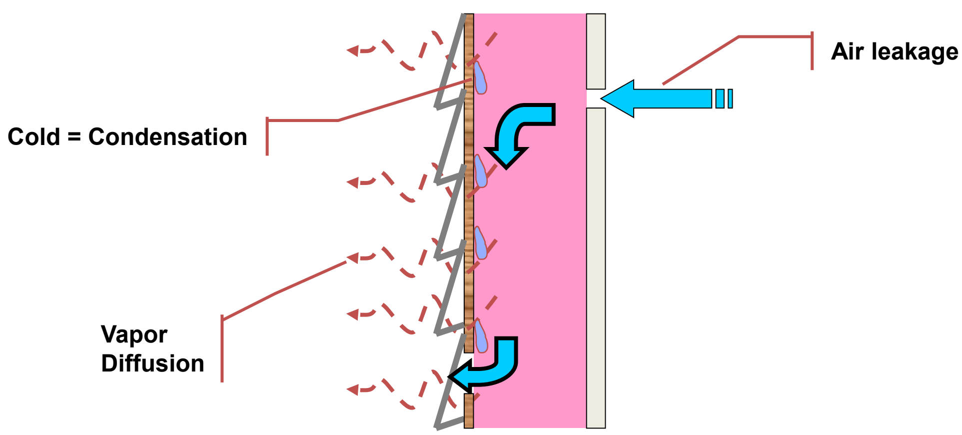
What Are the Ratios (% Exterior)?

- Original calculations & code change by BSC (Lstiburek, Straube, Schumacher)
- Ratios apply to higher-R walls (e.g., flash and batt, double stud wall)
- What happens when you "miss"? (too little exterior insulation)

Climate Zone	Minimum R-Value (2x4)	Minimum R-Value (2x6)	% Exterior Insulation 2x4 (±)	% Exterior Insulation 2x6 (±)
4C	2.5	3.75	16%	16%
5	5	7.5	28%	28%
6	7.5	11.25	37%	37%
7/8	10	15	43%	44%

Outward Drying through Permeable Sheathing

- Permeable sheathing/wrap → "safety valve" for outward moisture



Code Tables-Class III: Vapor Permeable Sheathing

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CLASS III VAPOR RETARDERS

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Exterior Insulating Sheathing (UW Research)

UWaterloo (CZ 6A) Walls

UWaterloo (CZ 6A) Walls

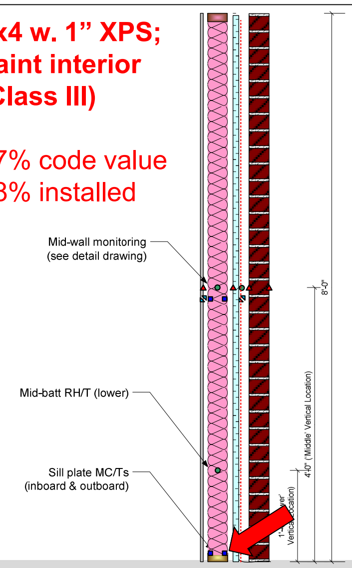
- Walls 2x4 + XPS, 2x6 + paint, 2x6 + poly
- Interior run at 68 F/50% RH year round
- Very challenging interior condition

N1/S1=XPS, paint
N2/S2=paint
N3/S3=polyethylene

UWaterloo (CZ 6A) Walls

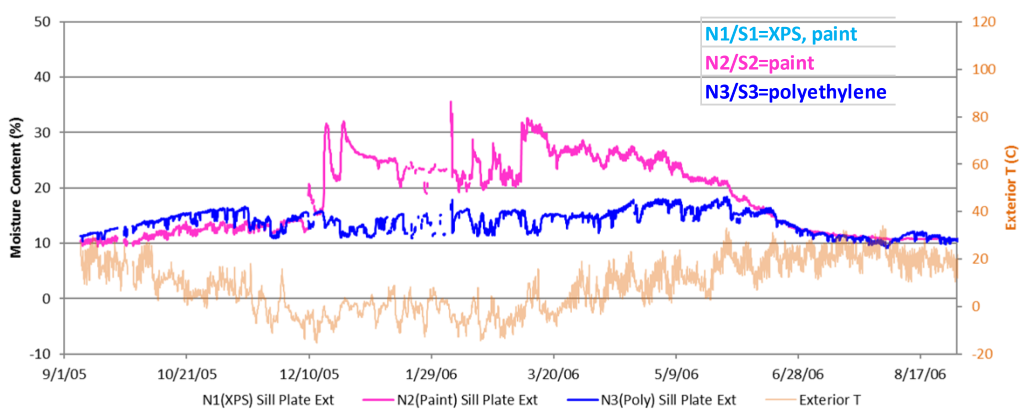
2x4 w. 1" XPS; paint interior (Class III)

37% code value
28% installed



North Side Sill Plate MCs

- 20-30% MC usual "concerning" range
- XPS wall sill plate soaking wet



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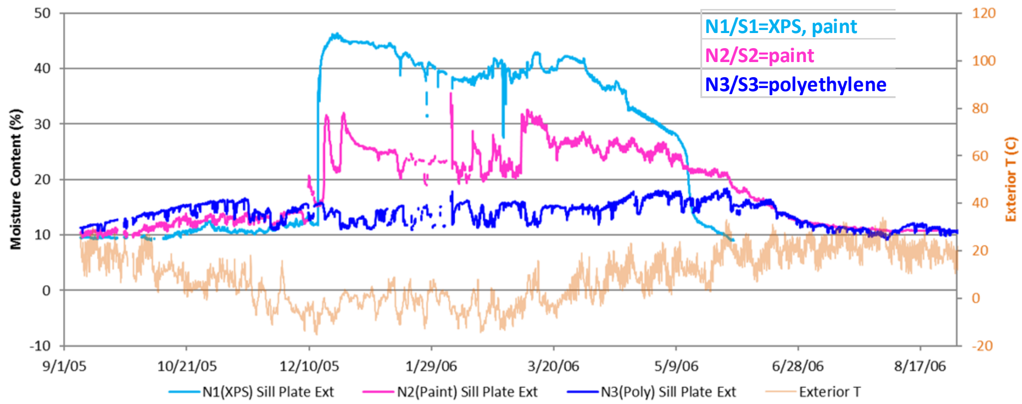


UWaterloo (CZ 6A) Year 1 Disassembly

- Slight spotting on XPS surface
- Wetting event correlated with XPS T>32 F
- Frost accumulation followed by thaw & rundown

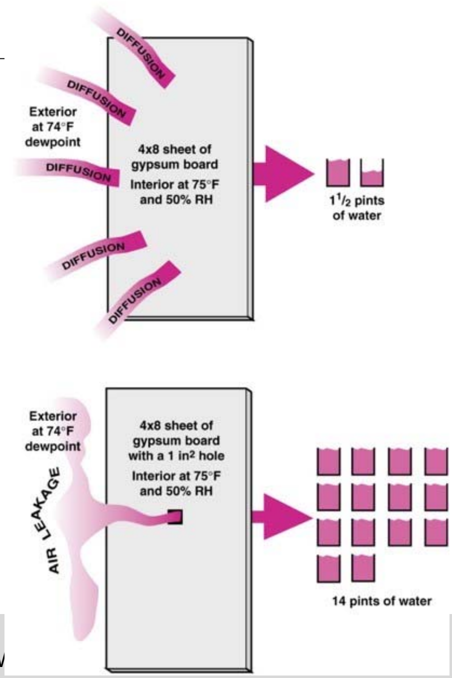
Takeaways

- "Too thin" exterior foam problem, especially at higher interior RHs
- Foam rigid insulation is low perm (no "safety valve")
- Vapor-permeable continuous insulation even safer
- 50% RH challenging… but more realistic now

We Don't Have to Worry About Vapor… Right?

Water Vapor Transport

- Vapor Diffusion
  - more to less vapor
  - no air flow
  - flow through tiny pores
- Air Convection
  - more to less air pressure
  - flow through visible cracks and holes
  - vapor is just along for the ride



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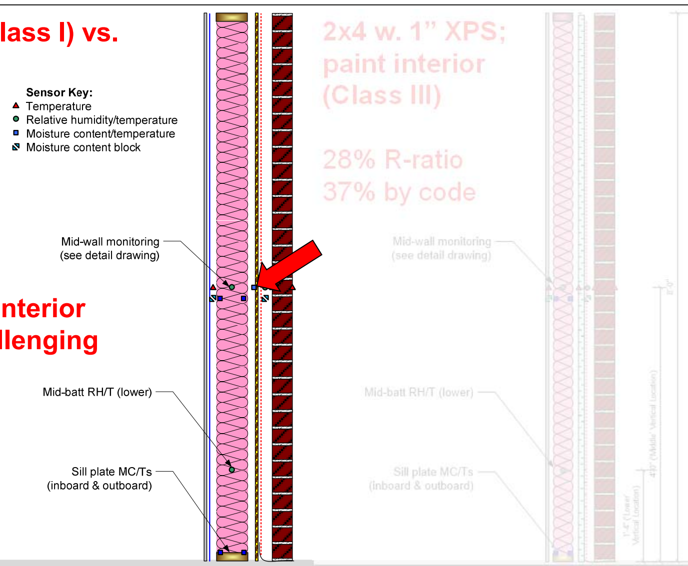
UWaterloo (CZ 6A) Walls

2x6 w. polyethylene (Class I) vs.

2x6 w. paint (Class III)

50% RH interior
Very challenging



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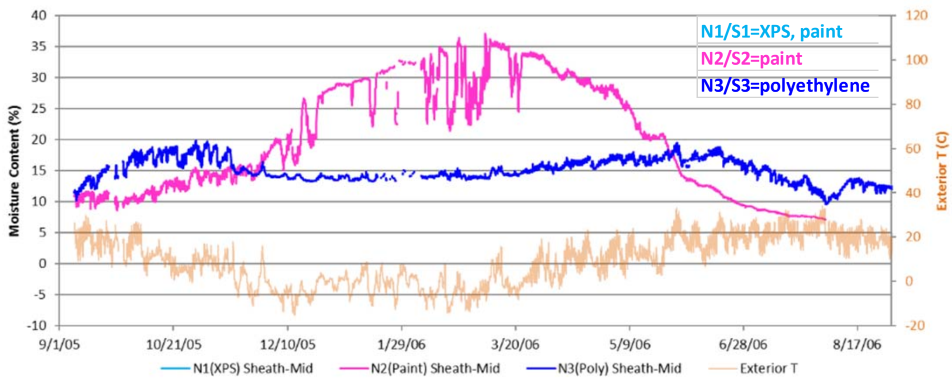
North Side Sheathing

- Polyethylene sheathing stayed dry through winter
- Latex paint interior—35%+ then dried down
- What did the sheathing look like?



UWaterloo (CZ 6A) Year 1 Disassembly

- "Paint" (only Class III vapor retarder)
- Mold uniform coverage
- Worse on north than south

Vapor Retarder Paint (Class II)

- Vapor Barrier Paint (over existing latex)
  - *0.9-1.7 US Perms*
- Original latex paint
  - *~7-10 US Perms*

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Paint Perm Testing (Dry Cup)

- Vapor Barrier Paint (over existing latex)
  - *0.9-1.7 US Perms*
- Original latex paint
  - *~7-10 US Perms*
- Latex paint published:
  - *2.6-3.5 US Perms* (ASHRAE)
  - *20+ (other papers)*
- We now use 10 perms of latex paint + primer

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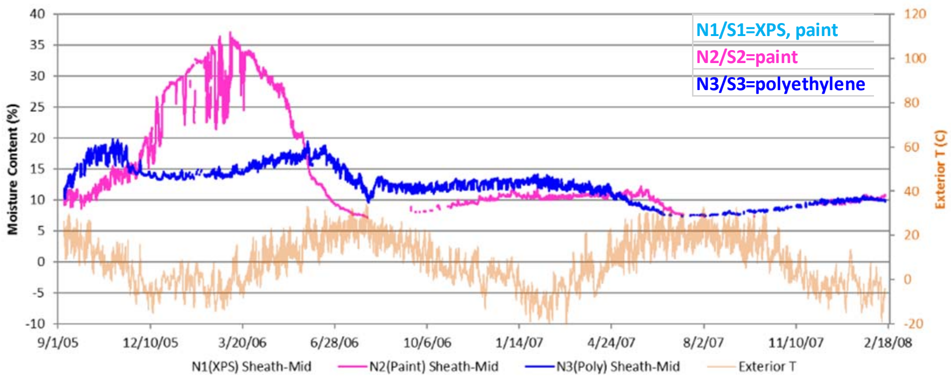
North Side Sheathing

- Winters 2 & 3: paint wall drier than/as dry as polyethylene wall
- Why polyethylene wet? Stored water from summer… more later
- Winter 3: Class II (1 perm) as good as Class I (0.1 perm)



Takeaways

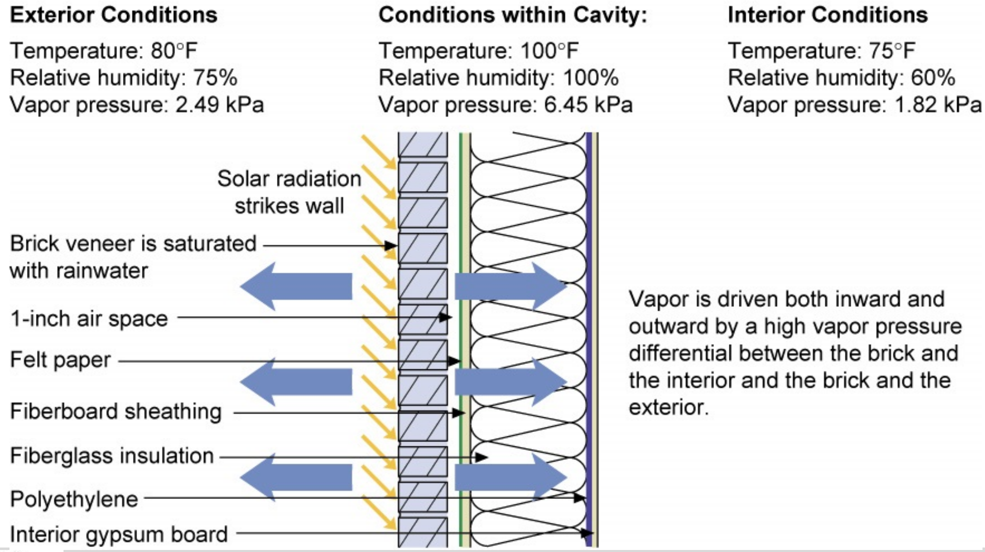
- Class I (polyethylene) works… until things get wet
  - Bulk water—i.e., rain leaks
  - Inward vapor drives—more later
- Class II (VB paint, Kraft, SVR) works great
  - Good cold-climate recommendations in general
  - Even at challenging 50% RH interior
- Why bother with Class I (polyethylene)?
  - Air leakage must be 0.0006 in^2/ft^2 to function 0.1 perm
  - Vs. 2.5 in^2/ft^2 common airtightness #
- Vapor retarder paint on unprimed drywall?

Takeaways: Does Vapor Flow Matter?

- Big failures → air leakage
- Vapor can be the cause of failure IF
  - Wet enough interior conditions
  - Vapor open enough interior vapor control
  - Not enough seasonal drying

Inward Vapor Drives (Reservoir Claddings)

Inward Vapor Drive-Background

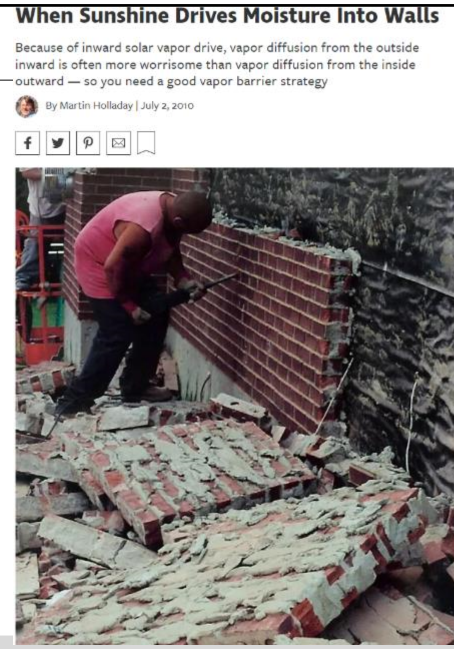


Inward Vapor Drive

- Vinyl wallpaper or polyethylene interior

Real Failures

- Zaring Homes, Cincinnati, 1990s
- "Wet carpet" complaints
- OSB sheathing to fiberboard (Celotex)
- Interior polyethylene (code… or "code")
- Air conditioned interior
- Perfect combination of problems
- Builder went bankrupt
  ($60-70k fix per house, strip brick)



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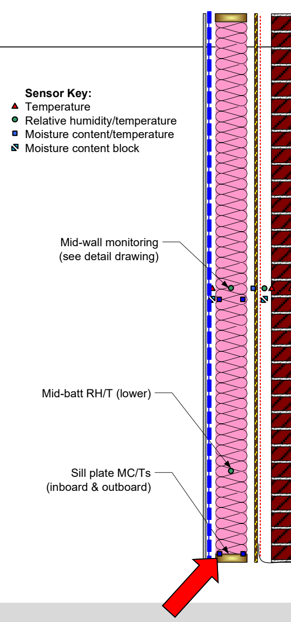
Inward Vapor Drive

- Poorly ventilated brick veneer
- Ontario Canada (6A)
- Wood sill inboard MC



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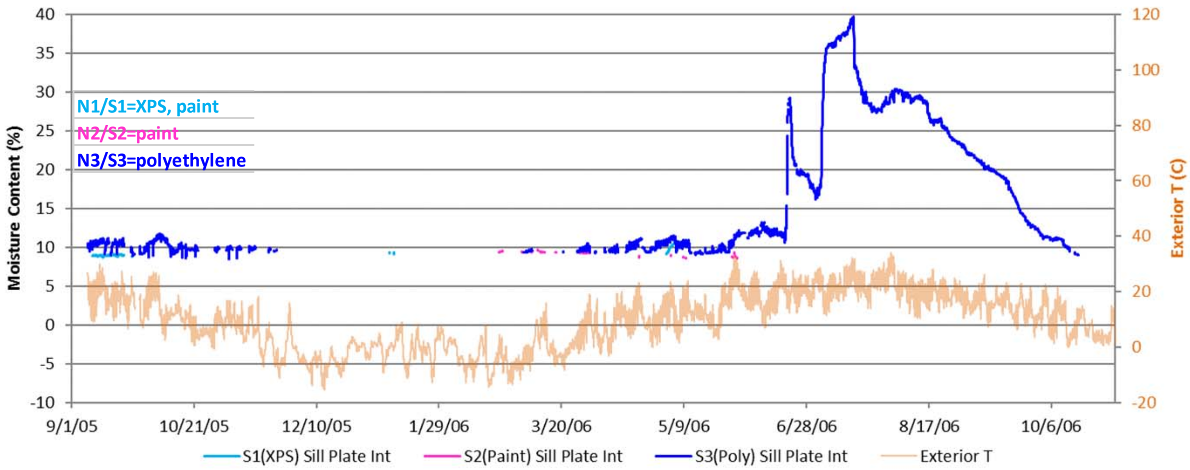
Interior-Side Sill Plate MC

- Only polyethylene wall shows problems



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Sill Plate Wetness (September)

- Soaking wet sill plate
- Run down from polyethylene

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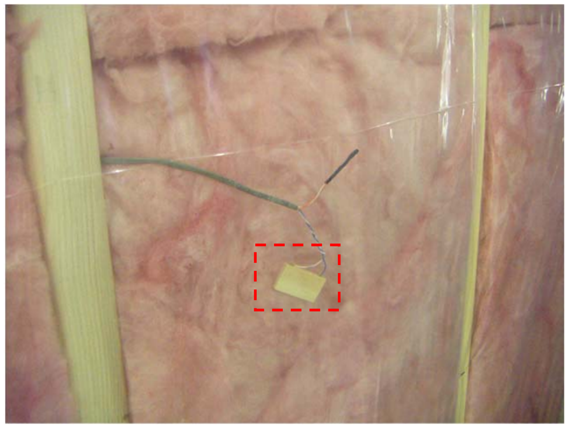
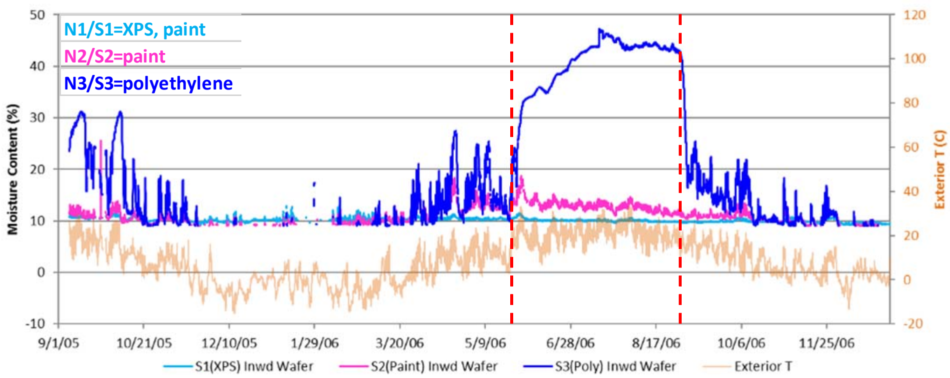
UWaterloo (CZ 6A) VB Wafer

- Surrogate for relative humidity, shows moisture accumulation at interface



Fiberglass-GWB Interface Wafer MC

- Summer #1 (poorly ventilated veneer)
- Spikes & falls due to outdoor temperature
- XPS and paint walls—both fine

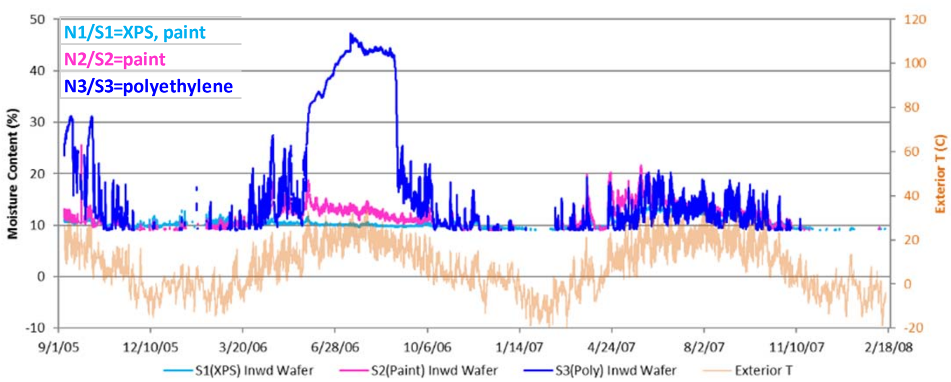


North & South Poly Wafers

- Smelled moldy when walls were opened up
- Summertime is when temperatures allow more growth

Add Better Brick Ventilation (Summer 2)

- Ventilate your problems away…
- Or avoid them to begin with… (XPS)
- Summer 2: "Paint" wall is vapor retarder paint



Takeaways

- Inward drives even occur in cold climates (CZ6A)
  - With poorly ventilated veneer, polyethylene
- XPS (low perm) stops problems
- Vapor-open sheathings (DensGlass, fiberboard) increase risks
  - Permeable exterior insulation
- Stucco, adhered stone: similar issues
- Unintentional vapor retarders

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Decoding the New Code (2018 IRC)

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2018 IRC Wall Vapor Retarder Requirements

- Trying to limit use of impermeable interior in warm climates (both unnecessary and adds risks)
- Note b: Class I **exterior** "requires an approved design"
- Note c: with plastic foam insulation, see Table R702.7(4)

TABLE R702.7(2) VAPOR RETARDER OPTIONS

CLIMATE ZONE	VAPOR RETARDER CLASS		
	CLASS I[a]	CLASS II[a]	CLASS III
1, 2	Not Permitted	Not Permitted	Permitted
3, 4 (except Marine 4)	Not Permitted	Permitted[c]	Permitted
Marine 4, 5, 6, 7, 8	Permitted[b]	Permitted[c]	See Table R702.7(3)

a. Class I and II vapor retarders with vapor permeance greater than 1 perm when measured by ASTM E96 water method (Procedure B) shall be allowed on the interior side of any frame wall in all climate zones.
b. Use of a Class I interior vapor retarder in frame walls with a Class I vapor retarder on the exterior side shall require an approved design.
c. Where a Class II vapor retarder is used in combination with foam plastic insulating sheathing installed as continuous insulation on the exterior side of frame walls, the continuous insulation shall comply with Table R702.7(4) and the Class II vapor retarder shall have a vapor permeance greater than 1 perm when measured by ASTM E96 water method (Procedure B).

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2018 IRC Wall Vapor Retarder Requirements

- Table R702.7(4) Exterior insulation w Class II
- Minimum foam values—avoiding "too thin foam" that is also a wrong-side vapor barrier
- Permeable exterior insulation not addressed?

TABLE R702.7(4) CONTINUOUS INSULATION WITH CLASS II VAPOR RETARDER

CLIMATE ZONE	CLASS II VAPOR RETARDERS PERMITTED FOR:[a]
3	Continuous insulation with R-value ≥ 2.
4, 5 and 6	Continuous insulation with R-value ≥ 3 over 2 × 4 wall. Continuous insulation with R-value ≥ 5 over 2 × 6 wall.
7	Continuous insulation with R-value ≥ 5 over 2 × 4 wall. Continuous insulation with R-value ≥ 7.5 over 2 × 6 wall.
8	Continuous insulation with R-value ≥ 7.5 over 2 × 4 wall. Continuous insulation with R-value ≥ 10 over 2 × 6 wall.

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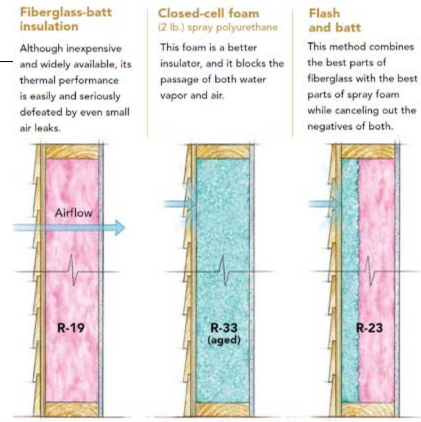
2018 IRC Wall Vapor Retarder

- Flash and batt insulation systems
- Intended for use with closed cell foam
- Basically, use ratios/numbers in existing code tables



R702.7.1 Spray foam plastic insulation for moisture control with Class II and III vapor retarders.

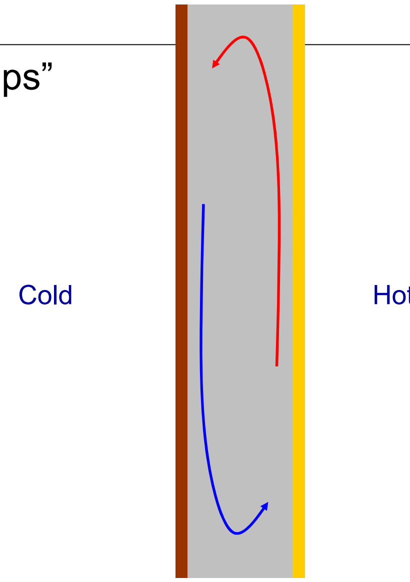
For purposes of compliance with Tables R702.7(3) and R702.7(4), spray foam with a maximum permeance of 1.5 perms at the installed thickness applied to the interior side of wood structural panels, fiberboard, *insulating sheathing* or gypsum shall be deemed to meet the continuous insulation moisture control requirement in accordance with one of the following conditions:

1. The spray foam *R*-value is equal to or greater than the specified continuous insulation *R*-value.
2. The combined *R*-value of the spray foam and continuous insulation is equal to or greater than the specified continuous insulation *R*-value.

Convective Looping

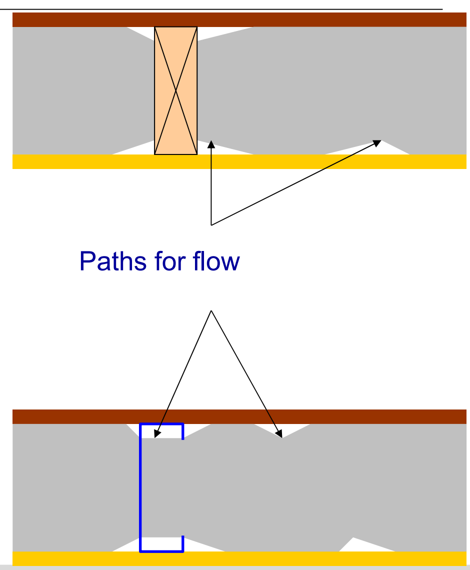
Convection within the assemblies

- Commonly referred to as "Convective Loops"
- Driven by natural buoyancy
- Warm air rises/cool air falls
- Short circuits insulation
- R-value does not take into account the potential of movement of air within an assembly.



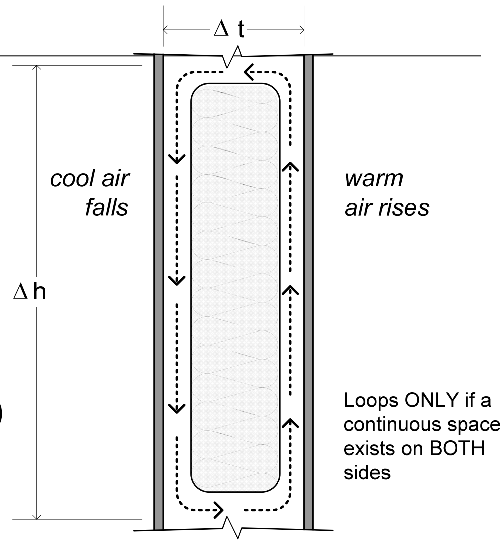
Convection within the assemblies

- Spaces for flow from:
- Compressing batts
- Inset stapling
- Difficulty in filling steel studs



Convection in Fibrous Insulation

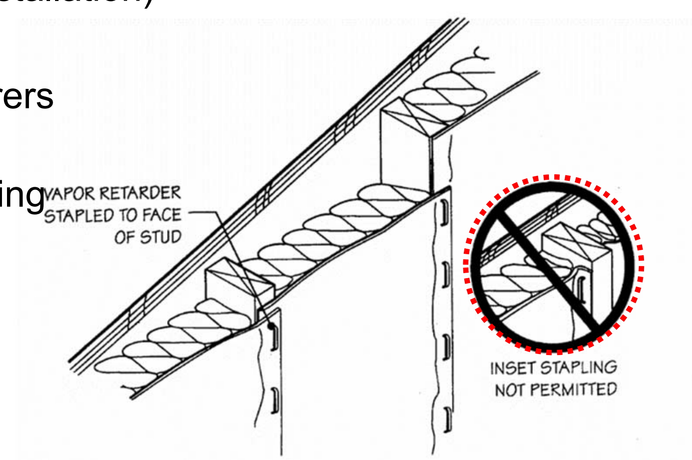
- Function of:
- insulation density
- ΔT across insulation
- air spaces/voids
- cavity height & orientation
- gaps at top/bottom
- Plus moisture movement (Ojanen 1995)



A: Air Loops Around Insulation
Straube & Burnett 2005

Inset Stapling

- Common practice (drywall installation)
- Forbidden in WA state code
- Allowed by some manufacturers ("tested this way")
- Energy penalty w. inset stapling
  - ~3%+ (Christian et al. 1998)
  - 14% (ORNL)



Washington State University Extension Energy Program (2004)

WA State-Side-by-Side Test Walls

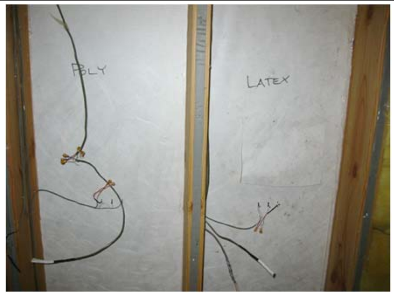
SVR = 'smart' vapor retarder
SVR-F = faced product (inset stapled)

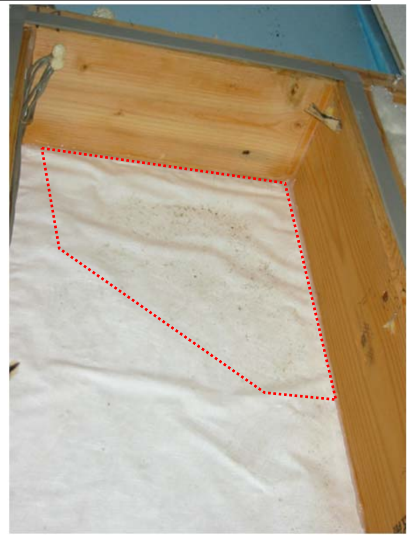
Quick Results of Washington Study

- Wintertime RHs 40-50% (typical for PNW)
- Paint-risky (20-25% MC each winter)
- Kraft-safe, peaks ~18% in winter
- Smart Vapor Retarders
  - Facer-same behavior as Kraft
  - Film-noticeably drier; below 15% MC
- Polyethylene-stayed dry (under 15%)-still cycled seasonally

Disassembly/Decommissioning

- T-111 walls (housewrap on studs)
- Mold spotting on inside of latex paint test wall
- Mapped out wood moisture content (MC)



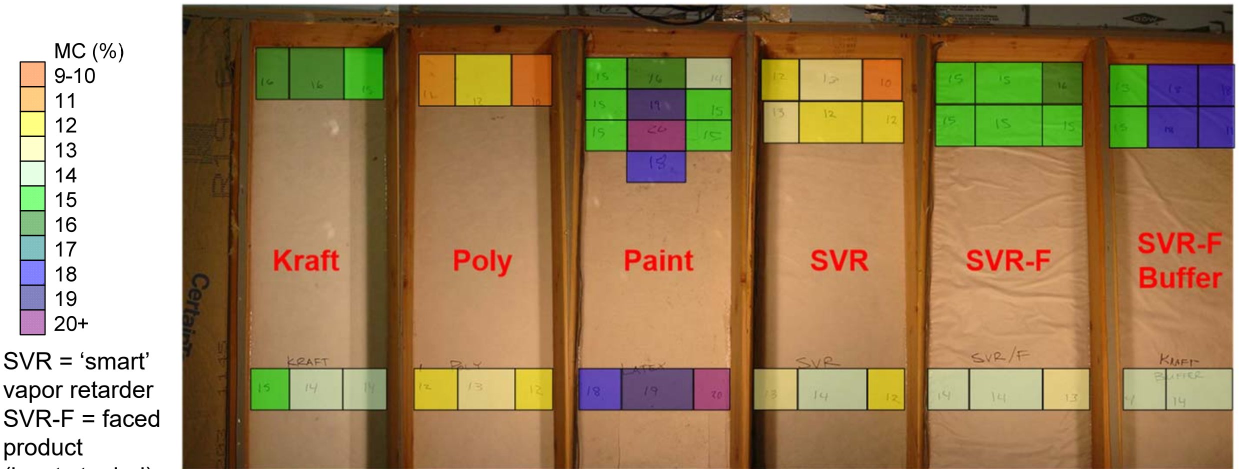


Spatial Sheathing MCs (West)

MC (%)
9-10
11
12
13
14
15
16
17
18
19
20+

SVR = 'smart' vapor retarder
SVR-F = faced product (inset stapled)

Spatial Sheathing MCs (South)



SVR = 'smart' vapor retarder
SVR-F = faced product (inset stapled)

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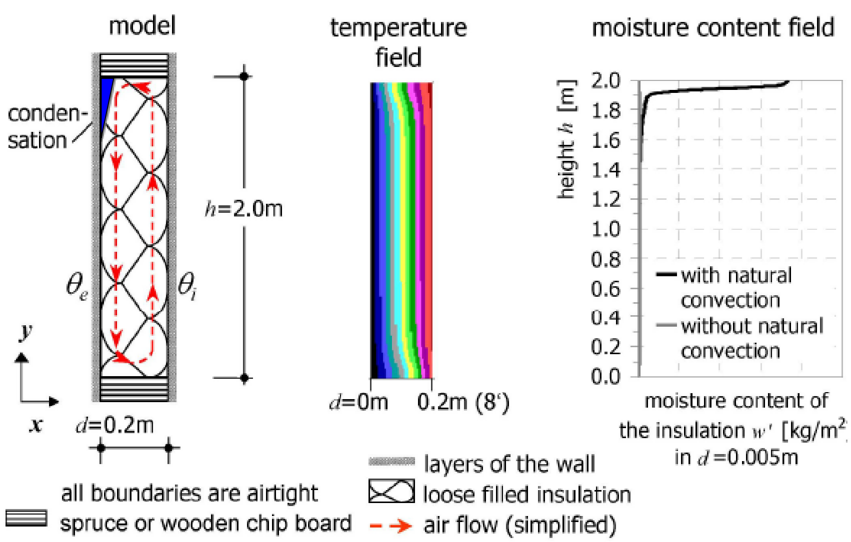
Convective Looping (Reisener et al. 2004)



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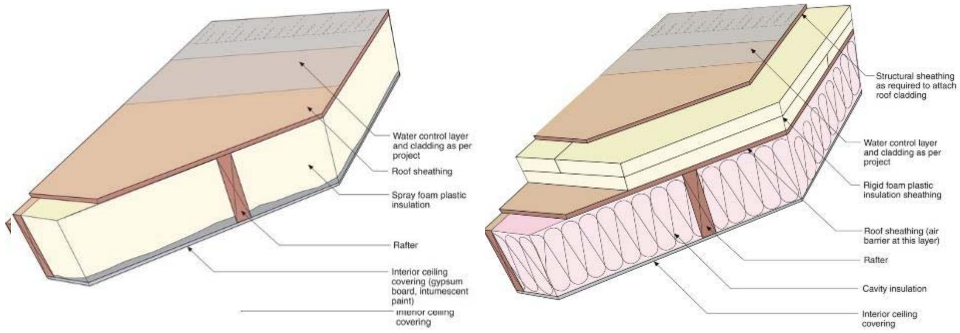
Takeaways: Convective Looping

- Fill cavity completely
  - Small gaps-disproportionate
- No inset stapling
- Letting drywallers design thermal enclosure
- Insulation facer (e.g., Kraft) providing vapor control can get bypassed
- Fiberglass batt (~1.2 PCF) will stop convection if cavity filled (perfectly)
  - But old <1 PCF batt…
- Exterior insulation helps

Unvented Roofs

Spray Foam/Exterior Insulation Roofs

- 2006 IRC onward: R806.5 Unvented attic assemblies
- Minimum R-value of "air impermeable insulation"
  - Actually ratio of R-values (BSI-100 Hybrid Assemblies)
- Nail base needed with rigid foam on roof deck



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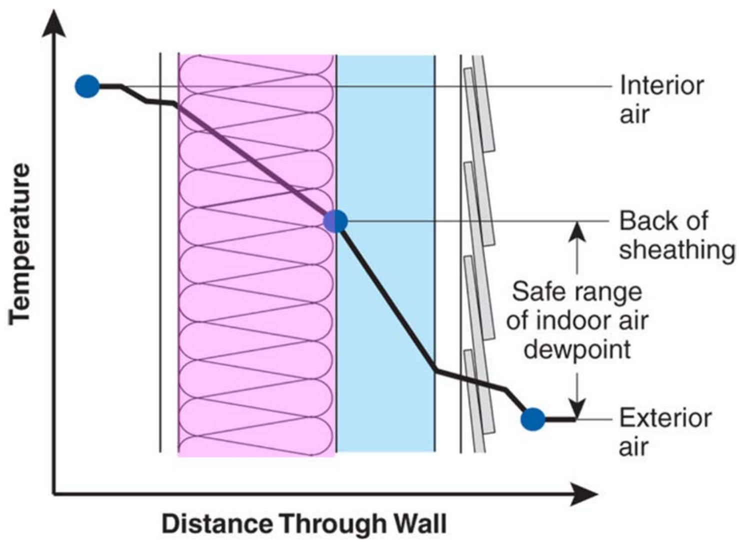
Ratio of Exterior-to-Interior Insulation



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IRC Hybrid Insulation Requirements

- Why R-values instead of ratios?
- "We can't have people calculate in the building codes…"

TABLE R806.5 INSULATION FOR CONDENSATION CONTROL

CLIMATE ZONE	MINIMUM RIGID BOARD ON AIR-IMPERMEABLE INSULATION *R*-VALUE[a, b]
2B and 3B tile roof only	0 (none required)
1, 2A, 2B, 3A, 3B, 3C	R-5
4C	R-10
4A, 4B	R-15
5	R-20
6	R-25
7	R-30
8	R-35

a. Contributes to but does not supersede the requirements in Section N1102.

b. Alternatively, sufficient continuous insulation shall be installed directly above the structural roof sheathing to maintain the monthly average temperature of the underside of the structural roof sheathing above 45°F (7°C). For calculation purposes, an interior air temperature of 68°F (20°C) is assumed and the exterior air temperature is assumed to be the monthly average outside air temperature of the three coldest months.

IRC Hybrid Insulation Requirements

- Presented as ratios (%) rather than R-values

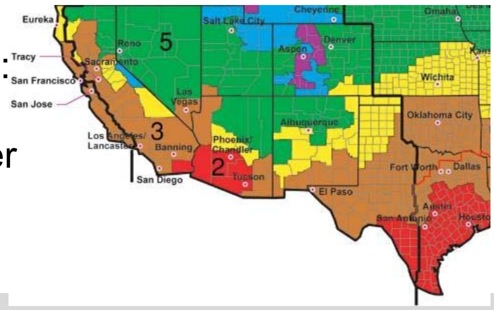
Insulation for Condensation Control*

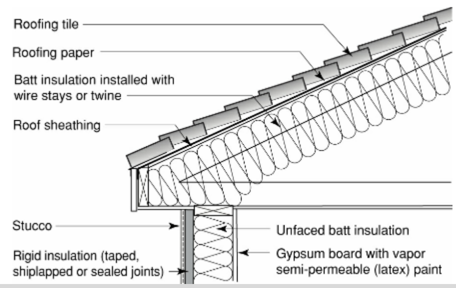
Climate Zone	Rigid Board or Air Impermeable Insulation	Code Required R-Value	Ratio of Rigid Board Insulation or Air Impermeable R-Value to Total Insulation R-Value
1,2,3	R-5	R-38	10%
4C	R-10	R-49	20%
4A, 4B	R-15	R-49	30%
5	R-20	R-49	40%
6	R-25	R-49	50%
7	R-30	R-49	60%
8	R-35	R-49	70%

*Adapted from Table R 806.5 2015 International Residential Code

Climate Zones 2B/3B Tile Roofs

- Experiences in Las Vegas, Phoenix, & Tucson early 2000s
- Production builders—batt or cellulose at roofline, bring ductwork inside
- Drying via roofing paper to airspace under roof tile
- Dry climate: low interior RH in winter





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Unvented Roof Code Language

R806.5 Unvented attic and unvented enclosed rafter assemblies.

Unvented *attics* and unvented enclosed roof framing assemblies created by ceilings that are applied directly to the underside of the roof framing members and structural roof sheathing applied directly to the top of the roof framing members/rafters, shall be permitted where all the following conditions are met:

1. The unvented *attic* space is completely within the *building thermal envelope*.
2. Interior Class I vapor retarders are not installed on the ceiling side (*attic* floor) of the unvented *attic* assembly or on the ceiling side of the unvented enclosed roof framing assembly.
3. Where wood shingles or shakes are used, a minimum $^{1}/_{4}$-inch (6.4 mm) vented airspace separates the shingles or shakes and the roofing underlayment above the structural sheathing.
4. In Climate Zones 5, 6, 7 and 8, any *air-impermeable insulation* shall be a Class II vapor retarder, or shall have a Class II vapor retarder coating or covering in direct contact with the underside of the insulation.
5. Insulation shall comply with Item 5.3 and either Item 5.1 or 5.2:

5.1. Item 5.1.1, 5.1.2, 5.1.3 or 5.1.4 shall be met, depending on the air permeability of the insulation directly under the structural roof sheathing.

5.1.1. Where only *air-impermeable insulation* is provided, it shall be applied in direct contact with the underside of the structural roof sheathing.

5.1.2. Where *air-permeable insulation* is installed directly below the structural sheathing, rigid board or sheet insulation shall be installed directly above the structural roof sheathing in accordance with the *R*-values in Table R806.5 for condensation control.

5.1.3. Where both *air-impermeable* and *air-permeable insulation* are provided, the *air-impermeable insulation* shall be applied in direct contact with the underside of the structural roof sheathing in accordance with Item 5.1.1 and shall be in accordance with the *R*-values in Table R806.5 for condensation control. The *air-permeable insulation* shall be installed directly under the *air-impermeable insulation*.

5.1.4. Alternatively, sufficient rigid board or sheet insulation shall be installed directly above the structural roof sheathing to maintain the monthly average temperature of the underside of the structural roof sheathing above 45°F (7°C). For calculation purposes, an interior air temperature of 68°F (20°C) is assumed and the exterior air temperature is assumed to be the monthly average outside air temperature of the three coldest months.

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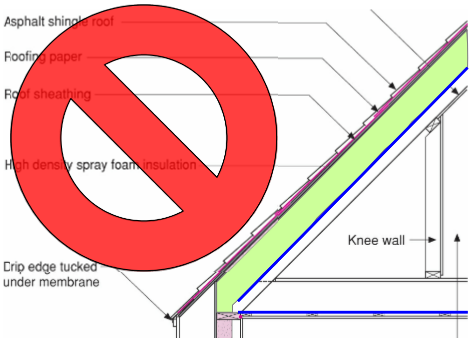
Unvented Roof Code Language (Class I VBs)

2. Interior Class I vapor retarders are not installed on the ceiling side (*attic* floor) of the unvented *attic* assembly or on the ceiling side of the unvented enclosed roof framing assembly.

- Don't turn roof into double vapor barrier (Class I) unnecessarily
- Shingles + underlayment = 0.65 perm (Class II vapor retarder)



Unvented Roof Code Language (Wood Shingles)

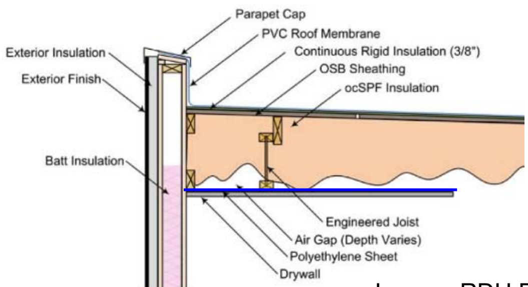
3. Where wood shingles or shakes are used, a minimum 1/4-inch (6.4 mm) vented airspace separates the shingles or shakes and the roofing underlayment above the structural sheathing.

- SPF or rigid foam = limited downward drying
- Drainage mat under wood shingles/shakes
- Full batten/cross batten installation

Unvented Roof Code Language (Foam Permeance)

4. In Climate Zones 5, 6, 7 and 8, any *air-impermeable insulation* shall be a Class II vapor retarder, or shall have a Class II vapor retarder coating or covering in direct contact with the underside of the insulation.

- ccSPF OK by itself (CZ 5-6-7-8); ocSPF needs vapor retarder
- U Waterloo/CUFCA research—open cell lets too much moisture thru
- "Direct contact with underside of insulation"—likely bypass if air space between two materials

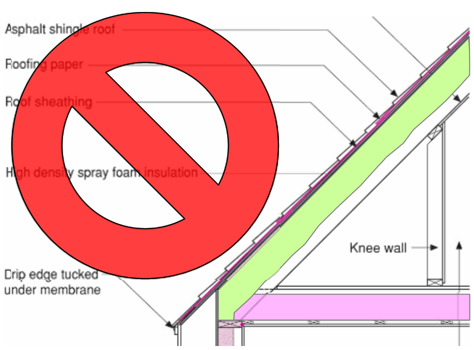


Images RDH Building Science Laboratories

Unvented Roof Code Language (Roofline vs. Ceiling)

5.1.3. Where both *air-impermeable* and *air-permeable insulation* are provided, the *air-impermeable insulation* shall be applied in direct contact with the underside of the structural roof sheathing in accordance with Item 5.1.1 and shall be in accordance with the *R*-values in Table R806.5 for condensation control. The *air-permeable insulation* shall be installed directly under the *air-impermeable insulation*.

- Roofline + ceiling insulation = "cold attic" w. interior air
- Spray foam roofline + acoustic batt in attic floor (noisy mice?)



Unvented Roof Code Language (Cut & Cobble)

5.3. Where preformed insulation board is used as the air-impermeable insulation layer, it shall be sealed at the perimeter of each individual sheet interior surface to form a continuous layer.

Musings of an Energy Nerd GBA PRIME

Cut-and-Cobble Insulation

Does it ever make sense to cut rigid foam into strips and insert the strips between your studs or rafters?

By Martin Holladay | November 22, 2013

- "Cut and Cobble" roofs piecing together rigid foam board
- Adds risks—air barrier imperfections at interior of assembly
- Not BSC's recommendation or addition to the code language

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Cut & Cobble Roof, Central MA

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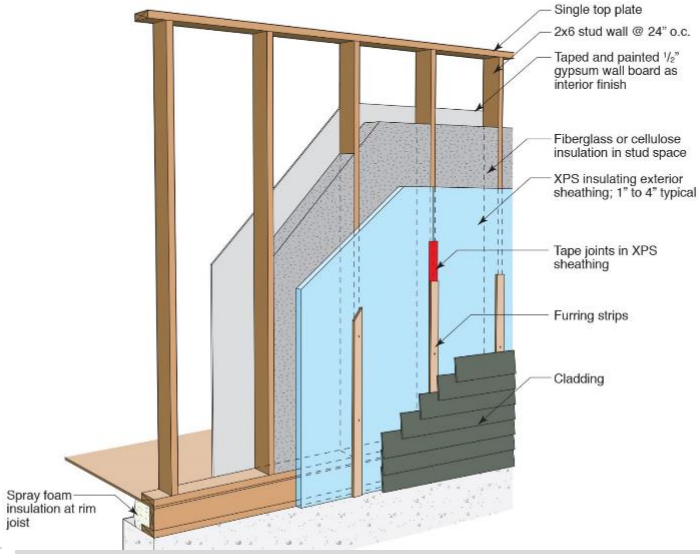
Cut & Cobble Monitoring Results

- Not ideal experiment (with & w/o DV comparison)
  - (Trying to fix friends' houses, not rot them)
- Still worrying high wood MCs ~30% peaks
- Peaks occur in spring (May), not winter—???
- What goes in vs. what comes out
  - In via air leakage/out via vapor diffusion → hard
  - Airtightness was ~6 ACH 50; air leaks @ roof
  - Trapped moisture—foil-faced polyiso below?
  - Small diffusion vent surface area
- Still OK-no condensation/dripping, but still high MCs/RHs each spring

Exterior Continuous Insulation

Exterior Rigid Foam (Taped Seams)



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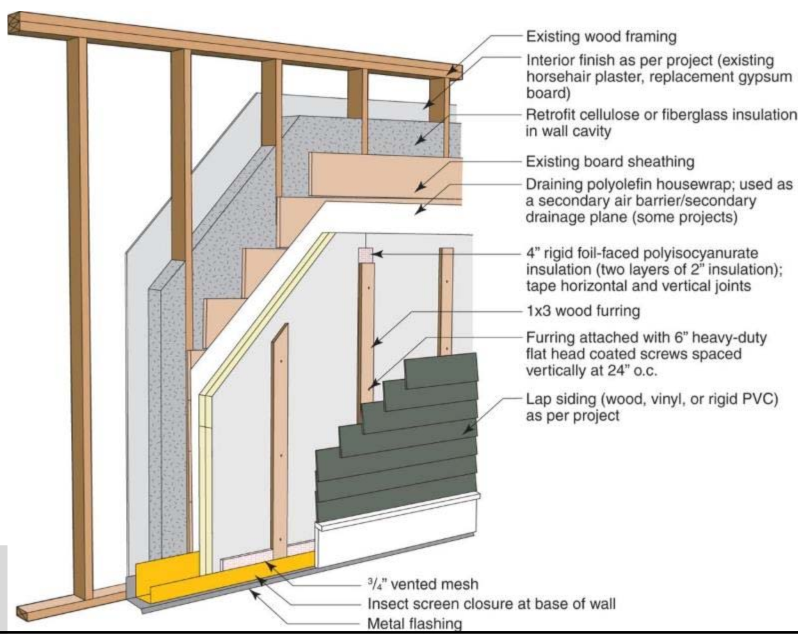
4" Polyisocyanurate Foam Retrofit



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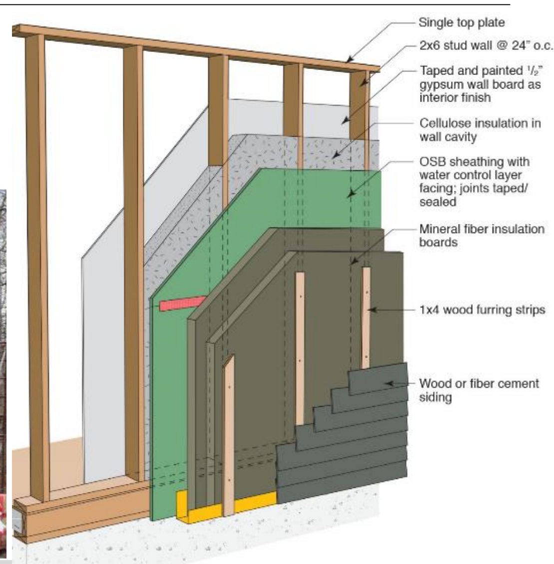
Mineral Fiber Insulation



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4" Polyisocyanurate Foam

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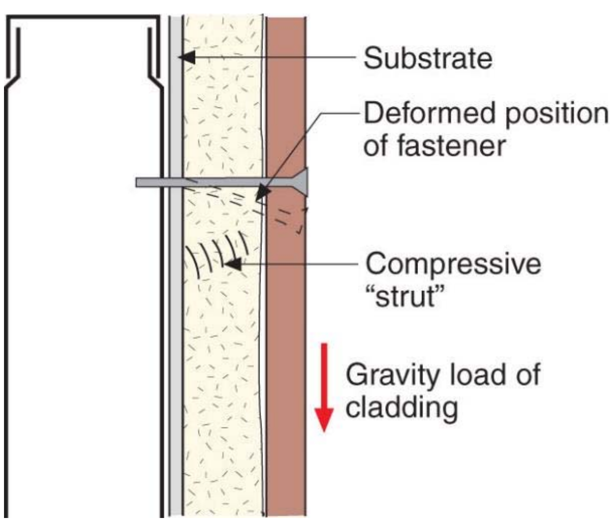
Foam Sheathing Cladding Attachment

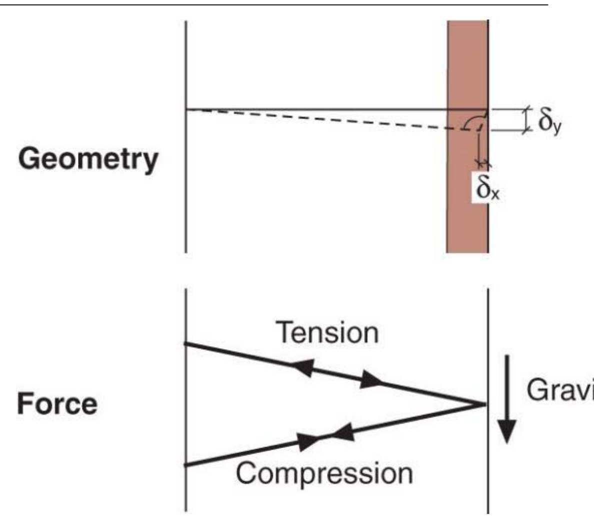
250 lbs/113 kg load (7.8 psf): <0.003” deflection

Wood siding ~2 psf
Fiber cement 2-3 psf
Stucco 8-10 psf

Image c/o Petersen Engineering

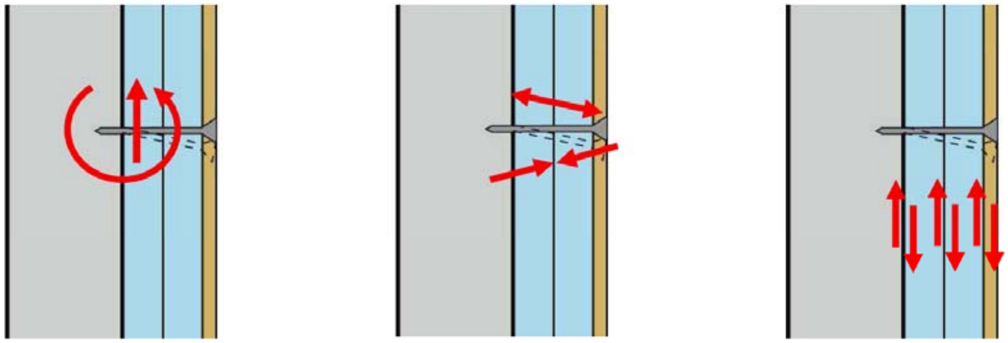
Foam Sheathing Cladding Attachment





BSC Cladding Attachment Research

- System Mechanics



Shear and rotational resistance provided by fastener to wood connections

Rotational resistance provided by tension in fastener and compression of the insulation

Vertical movement resistance provided by friction between layers

Full System Laboratory Tests

- Looked at initial response full system capacity as well as long term sustained loading
- Used full scale samples to limit variations in fastener installation

Recommendations

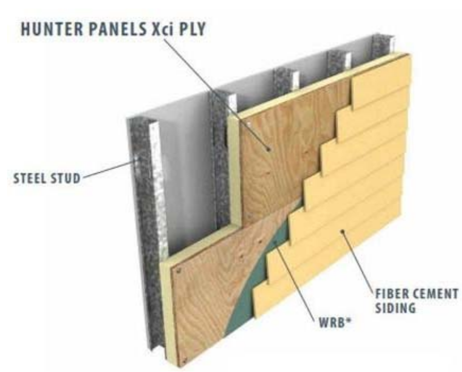
- Based on the results of the testing it is currently recommended to use a maximum load per fastener of no more than 10lbs for up to 4" of insulation

Cladding weight (psf)	16" oc Furring	24" oc Furring
5	18	12
10	9	6
15	6	4
20	4	3
25	3	2

Nailbase Panels as Continuous Insulation

- Insulation inboard of structural sheathing (not as good)
- Structure/shear strength sufficient or not?
- End up with 2 layers of sheathing (redundant)


Huber ZIP-R Sheathing



Closing

- This concludes The American Institute of Architects Continuing Education Systems Course
- How Do We Really Even Know What We Know? The Testing That Shaped Building Science
- Course #: (TBD - waiting on final approval from AIA)
- Provider: Huber Engineered Woods
- Provider #: K094
- Contact: Anna Moore
- Email: Anna.Moore@huber.com

AIA Continuing Education Provider

Questions?

Kohta Ueno
kohta [at] buildingscience [dot] com

Presentation will be available at:
https://buildingscience.com/past-events

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U.S. Department of Energy | Energy Efficiency & Renewable Energy

Document Resources

- Building Science Digest 106: Understanding Vapor Barriers
  https://buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers
- Building Science Digest 163: Controlling Cold-Weather Condensation Using Insulation
  https://buildingscience.com/documents/digests/bsd-controlling-cold-weather-condensation-using-insulation
- Info-305: Reservoir Claddings
  https://buildingscience.com/documents/information-sheets/reservoir-claddings
- BA-1501: Monitoring Double-Stud Wall Moisture Conditions in the Northeast
  https://buildingscience.com/documents/bareports/ba-1501-monitor-double-stud-moisture-conditions-northeast/view
- Field Monitoring of Wall Vapor Control Strategies in the Pacific Northwest (2008)
  http://aceee.org/files/proceedings/2008/data/papers/1_8.pdf
  https://buildingscience.com/sites/default/files/Field_Monitoring_of_Wall_Vapor_Control_Strategies.pdf
- Understanding Vapour Permeance and Condensation in Wall Assemblies
  https://www03.cmhc-schl.gc.ca/catalog/productDetail.cfm?cat=151&
  itm=11&lang=en&sid=qxCMd3n4oxk6YDbNMKQNZ9zUZasinu4FRQToR3qpJxsaRXWFU917m0RPnadvkk2o&fr=14883
  03573869
- The History of Peeling Paint, Insulation, and Vapor Barriers
  https://www.greenbuildingadvisor.com/article/the-history-of-peeling-paint-insulation-and-vapor-barriers