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Critical Layers in High-R Wall Assemblies

By: Elden Lindamood

Learning Objectives:

1. Learn the roll of each of the 4 layers of all wall assemblies.
2. Discuss the inherent properties of common layer options.
3. Learn how each layer may impact the other layers.
4. Explore the consequences of moving the layers within the wall assembly.
5. Discuss safe versus risky assembly choices.
6. See examples of where these layers are represented in a number of high-R assemblies.
7. Learn what the codes used to require, what they require now, and where they are likely heading.

The Wall

Making buildings since 4800 BC

Cairn of Barnenez, Brittany, France

Walls through the ages

Necropolises of Cerveteri and Tarquinia

Italy, 700 BC

Parthenon

Greece, 440 BC

Colosseum

Italy, 70 AD

Basically all piles of stone in varying degrees of refinement

Walls through the ages

Horhyji Temple

Japan, 600 AD

Oldest surviving wood framed structure

Fairbanks House

Dedham, MA ca. 1640

Oldest surviving timber frame house in North America

Balloon framed (light framed) house

Delaware, 1840’s

Basically all piles of sticks in varying organizational hierarchies

Walls through the ages

Sod

900's AD – 1900's

Brick

7000 BC - Present

Glass

Connecticut, 1949

"It seemed like a good idea at the time…"

Walls through the ages

Platform framing – 1940’s

Plywood invented in 1865, but the 4’x8’ sheet in 1928

OSB was invented in the 1970’s

Housewrap invented in 1960s, but didn’t see popular use until 1980’s

Smaller sticks, and all sorts of marketing

“Its the way we’ve always done it.”

How long has “always” been?

So, what have we been doing for a long time?

The R-21 Cavity wall:

- Code compliant
- Proven, with few problems
- Hard to screw up
- Easy and quick
- No guess work
- Safe

What if you want a better cake?

Can you just add 4 more cups of flour to the box cake?

No. You need to know the ingredients, and what those ingredients do in order to achieve the desired result.

What are the essential ingredients?

- Structure
- Insulation
- Moisture control
- Finishes

Of those ingredients, there are 4 things you must control to end up with a “successful” wall assembly?

What do I mean by successful?

- Structurally sound
- Durable/long-lasting
  - Won’t compost itself
- Buildable
- Cost effective
- Warm?

What do I need to control to achieve this (in order from most important to least)?

- Liquid water
- Air infiltration
- Water vapor
- Thermal conductance

The Codes: 2015 MNRC*

(In Climate Zone 7 anyway)

Regarding Liquid Water:

Section R703 Exterior Covering

R703.1.1 Water Resistance: The exterior wall envelope shall be designed and constructed in a manner that prevents the accumulation of water within the wall assembly by providing a water-resistant barrier behind the exterior veneer…

R703.2 Water-Resistive Barrier: One layer of No. 15 asphalt felt… or other approved water-resistive barrier shall be applied over studs or sheathing of all exterior walls. Lapped and flashed…blah, blah, blah…

*2012 IRC with MN Amendments

The Codes: 2015 MNRC*

(In Climate Zone 7 anyway)

Regarding Air Infiltration:

2015 Minnesota Energy Code (2012 Intl. Energy Conservation Code [IECC])

Section R402.4 Air Leakage: The building thermal envelope shall be constructed to limit air leakage in accordance with R402.4.1 through R402.4.4

Sealed, tested by a third party (3ACH/50), and per manufacturer's instructions. Shall be installed on the exterior side of air permeable insulation.

Commercial code: Can be anywhere in the assembly, but shall be continuous.

Wisconsin Residential Code (2004 UDC) specifically mentions housewrap.

*2012 IRC with MN Amendments

The Codes: 2015 MNRC*

(In Climate Zone 7 anyway)

Regarding Water Vapor Control:

Section R702.7 Vapor Retarders (note: not a “barrier”): A Class I or II vapor retarder is required on the interior side of frame walls in Climate Zones 6 and 7. Class II vapor retarders (Kraft-Faced Fiberglass Batts) are permitted only when specified on the construction documents

Section 702.7.1 Class III vapor retarders shall be permitted where any of the following conditions are met:

Insulated sheathing with R value $\geq$ 10 over a 2x4 wall

Insulated sheathing with R value $\geq$ 15 over a 2x6 wall

We’ll come back to this…

*2012 IRC with MN Amendments

The Codes: 2015 MNRC*

(In Climate Zone 7 anyway)

Regarding Thermal Conductance Control:

Back to the 2015 MN Energy Code book…

Section R402 Building Thermal Envelope

Section R402.1.1 Inslulation…The building thermal envelope shall meet requirements of Table R402.1.1

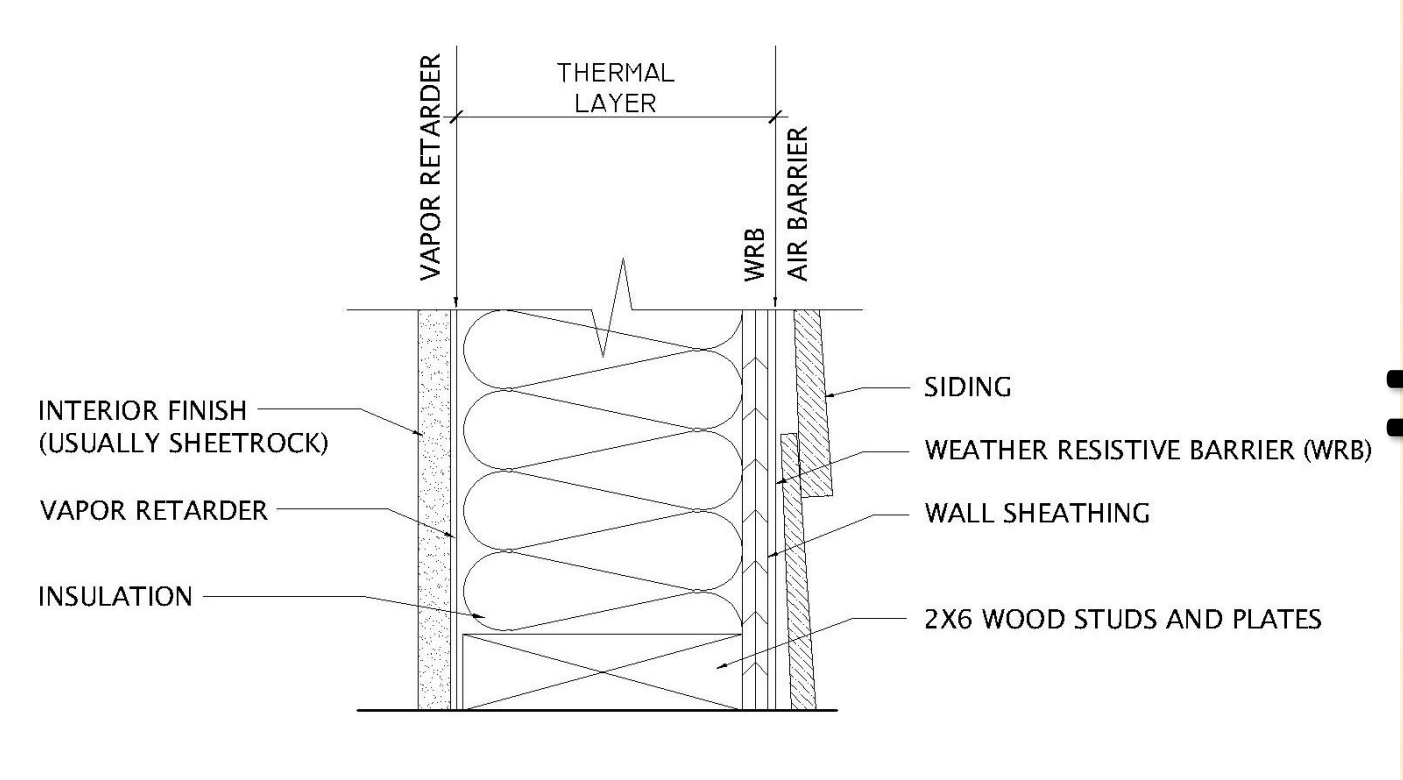
Wood Frame Wall R-Value – R21…This is a MN Amendment

Non-amended is R20+5 or R13+10

*2012 IRC with MN Amendments

The R-21 Code-Built Wall

(In Climate Zone 7 anyway)



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The Critical Layers

- Water Resistive Barrier
- Air Barrier
- Vapor Retarder
- Thermal Layer

Water Resistive Barrier (WRB)

What is the function of the WRB Layer?

- Keep 99.99% of the liquid water out of the wall assembly.

What Materials can function as a WRB?

- 15# building paper or other “approved” materials
- Housewrap
- Liquid applied membranes
- Rigid insulation?
- Component systems
  - Tape?
  - Sealants?
- Others?

Water Resistive Barrier (WRB)

Is it appropriate for the conditions?

Is it lapped and flashed properly?

Air Barrier

What is the function of the Air Barrier?

- To stop the passage of air <u>through</u> the assembly.
  - Why? Convective heat loss.
  - Reduce airborne moisture from entering the assembly

Where does it belong in the assembly?

- Outside air permeable insulation

What is “Tight Enough”?

- 3 ACH/50?
- 0.6 ACH/50?

What Materials can function as an air barrier?

- Polyethylene
- Plywood or OSB
- Housewrap
- Liquid applied membranes
- Spray Foam
- Component systems
  - Tape?
  - Sealants?
- Others?

Air Barrier

Is housewrap an Air Barrier?

Is this an air barrier?
How about now?

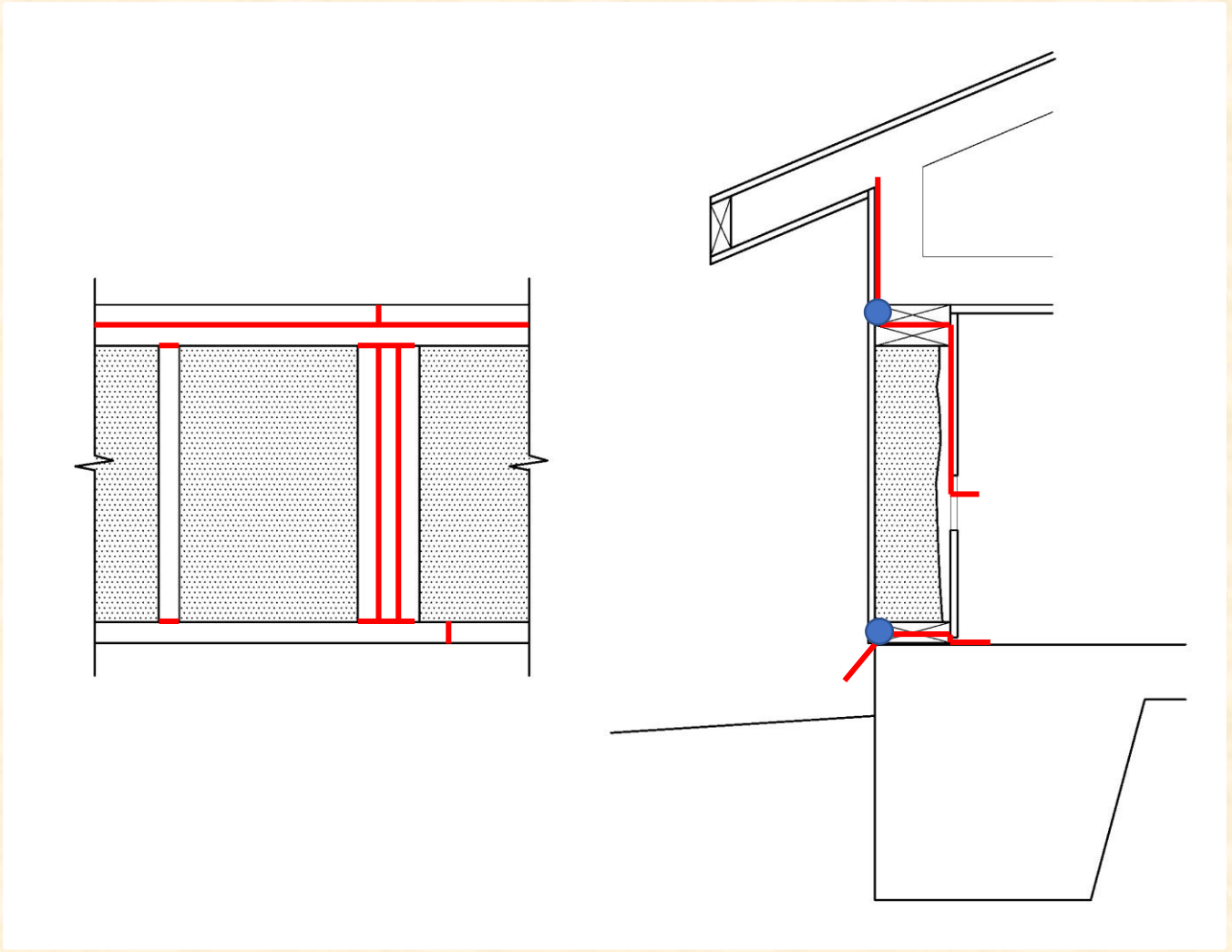
This isn't either.

Air Barrier

Is Spray Foam Cavity Insulation an Air Barrier?

Yes, but it doesn't seal all the joints.

Go ahead and use spray foam, but seal your sheathing to the framing also



Marketing tangent…

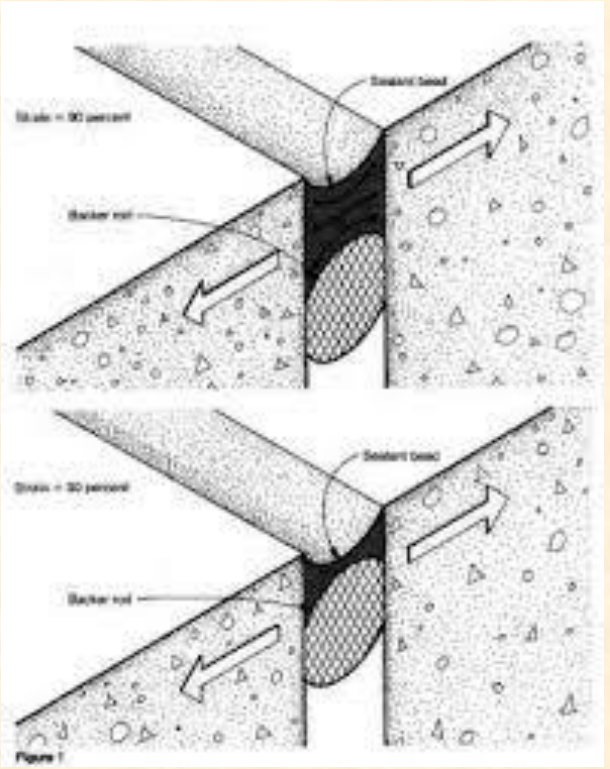
Companies love to sell you products that will “save you time” by functioning as two or more control layers at once…

- Housewraps – WRB and an air barrier in one
- Spray foams – Insulation and air sealing in one easy step. Sometimes a vapor retarder too.
- Structural sheathing systems that are also a WRB, or that have a Thermal Layer of foam bonded on
- Vapor Retarder paints (Or insulating paints)
- Kraft Faced Batts
- Housewraps with a rain screen matrix

Marketing tangent…

Think critically about what it is you are using the product for, and whether it actually serves that function.

- Does spray foam cavity insulation seal all your double plates and ganged studs?
- Is housewrap a good air barrier if it is full of staple and nail holes and isn't sealed at the edges?
- Is the R-5 rigid foam bonded to your structural sheathing enough?
- Does using a product as it is marketed give you impunity when it comes to taking responsibility for how it actually functions in a wall assembly?
- Have you installed the product per the manufacturer's written instructions? The instructions are the code.



Vapor Retarder

What is the function of the Vapor Retarder?

- To SLOW the passage of water vapor INTO the assembly.

Where does it belong in the assembly?

- In our climate, on the warm side of the assembly.
- It must retard the water getting into the assembly, but the water that does get into the assembly must have a way to dry out.

What Materials can function as a vapor retarder?

- Polyethylene
- Plywood or OSB
- Spray Foam
  - 2# foam is, if installed at a given thickness
- Polyolefin “Smart” vapor retarders
  - Variable permeability
- Vapor retarder paint or standard latex paint?
- Watch out for vinyl wallpapers

Vapor Retarder

Vapor Retarder Classes:

- Class I – 0.1 perm or less (Vapor Impermeable)
  - Polyethylene
  - Unperforated foil
  - Some vinyl wall coverings
- Class II – 0.1 to 1 perm (Vapor Semi-impermeable)
  - Kraft Faced fiberglass batts (1.0 +/-)
  - 2# Spray Foam @ 2” thickness (0.98)
  - Vapor Retarder paint (0.45 +/-)
- Class III – 1 to 10 perm (Vapor Semi-Permeable)
  - Standard Latex paint (5-8 +/-)
- Vapor Permeable – greater than 10 perms

Is a Class I vapor retarder always the best?

Vapor Retarder

Permeability of some other common materials

- Plain GWB – 25-50 perms
- Plywood – 5-10 perms
- OSB – 2 perms
- Building paper – 30 perms
- Fiberboard sheathing – 25 perms
- Housewraps – 5-50 perms
- 1” EPS – 1.5 to 5 perms depending on density
- 1” XPS - > 0.1 perm and < 1 perm (with no facings)
- Rigid mineral wool – 30 perms

Thermal Layer

What is the function of the Thermal Layer?

- To reduce *conductive* heat losses through the assembly.
- Reduce or eliminate thermal bridging

What is required by code?

- R-21 cavity
  - This is a MN amendment.
  - Will that be in the next code cycle?

What Materials can function as a Thermal Layer?

- Fiberglass batts
- Spray foam
- Rigid foam board (EPS, XPS, Polyiso)
- Cellulose
- Blown fiberglass
- Rigid mineral wool
- Exotic materials: PCM's and Aerogels

Thermal Layer

You must understand the physical properties of the selected Thermal Layer material to understand how it is going to interact and effect other layers in the system.

- What is its R-value?
- What is its vapor permeability, at the designed thickness?
- What is its air sealing capacity?
- What is its capacity to manage moisture?
- Also, what is the cost?
- And, sometimes, what is the environmental impact of the material?

Inspirational Quote

building

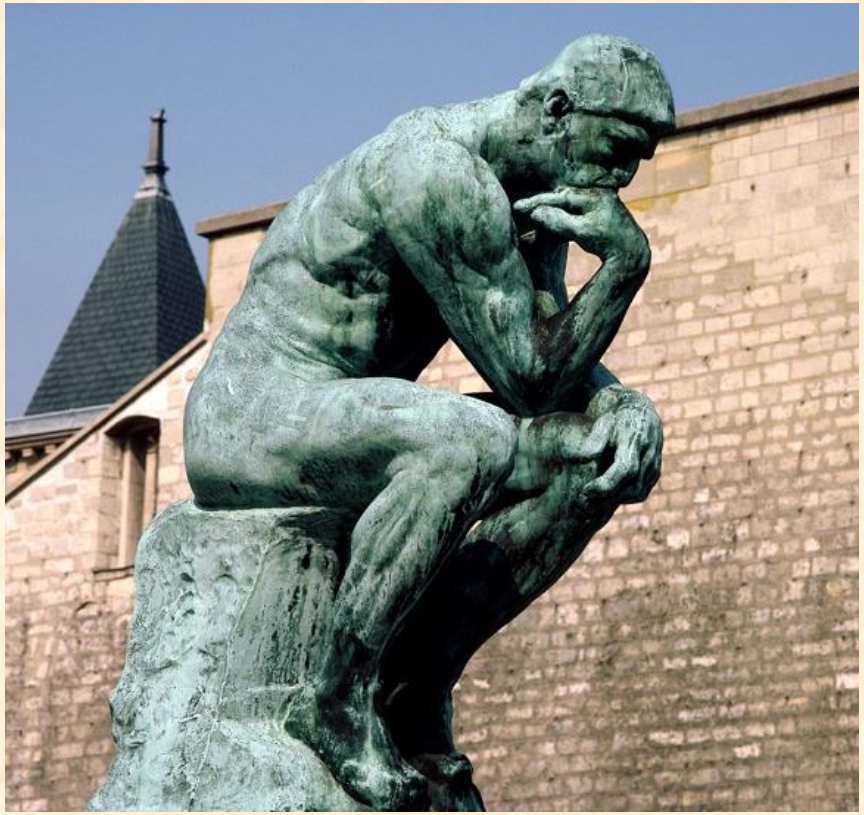
"She blinded me with *science*!"

- Thomas Dolby (1982)

What is the best, and safest, way to combine my ingredients to get the wall I want?

- When you design ANY wall, you need to consider the physical properties of the materials and how they will function as an assembly.
  - This was already done for you in the R-21 cavity wall.
- If you change a component material, you must reassess the entire assembly.
  - What happens if you change the WRB Layer to continuous Ice and Water Shield on the R-21 wall example?
- Beyond the science, it needs to be buildable, cost effective, and modifiable(?)

What questions do I need to ask?



- What is my WRB Layer going to be?
  - What is the siding/cladding?
- What is my Air Barrier going to be?
  - What is my air tightness goal?
- What is my Vapor Retarder going to be?
  - What class of Vapor Retarder do I need?
- What is my Thermal Layer going to be?
  - What is my target R-value?
- How is the assembly going to dry out if (when) it gets wet?
- What are the performance risks of the assembly?
  - How easy is it to mess it up?
- What will the contractor think of it?
  - Do I have “buy-in”?

High-R Walls

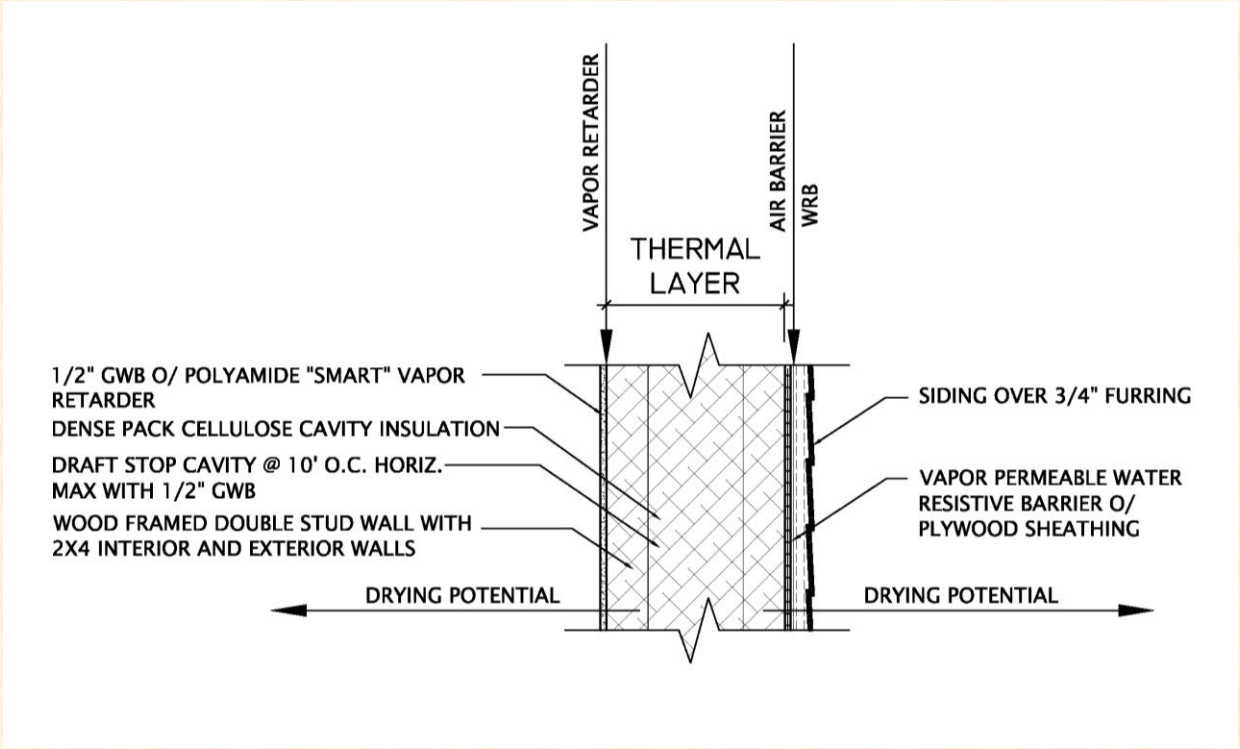
So let's look at some examples of walls that go beyond the code minimum R-21 Cavity wall!

R-30 to R-50+ wall assemblies

- Double stud walls
- Continuous insulation
- Larsen Truss walls
- Lstiburek's "Perfect Wall"
- Other "systems"
- ICF's, SIP's and other stuff

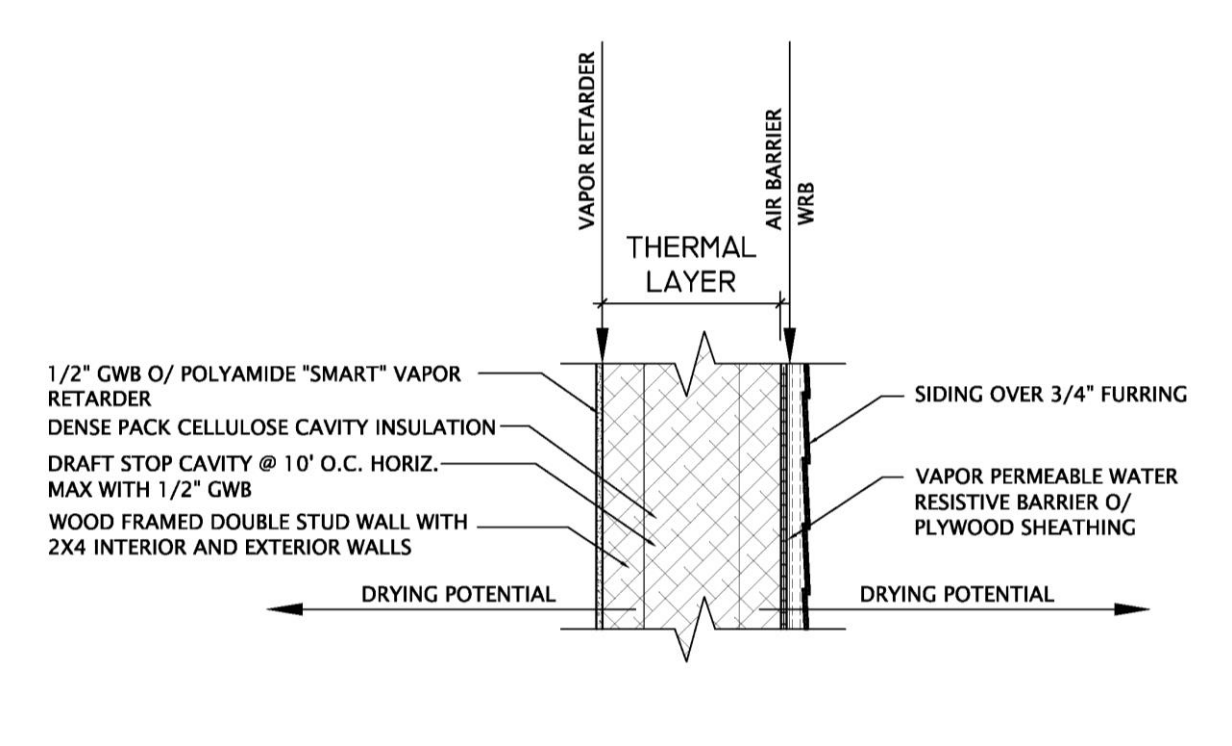
Double Stud Wall

- WRB:
  - Housewrap, #15 Building paper, or Liquid applied membrane
    - Want it to be vapor open for drying to exterior
  - May be cladding dependent
    - The cedar argument hasn't been conclusively resolved to my knowledge
    - Don't use it behind stone veneer claddings
      - Code?
  - Do NOT use impermeable WRB membranes like Ice and Water Shield, even if your interior vapor retarder is variable.
  - What about products with a WRB fused to the surface of structural sheathing?
    - I am still uneasy with un-lapped tapes as a WRB.
  - Liquid applied WRB's have a permeance of 3 to 8 depending on thickness/number of coats.
    - I like a bit more permeance in a double stud wall's exterior surface, but…



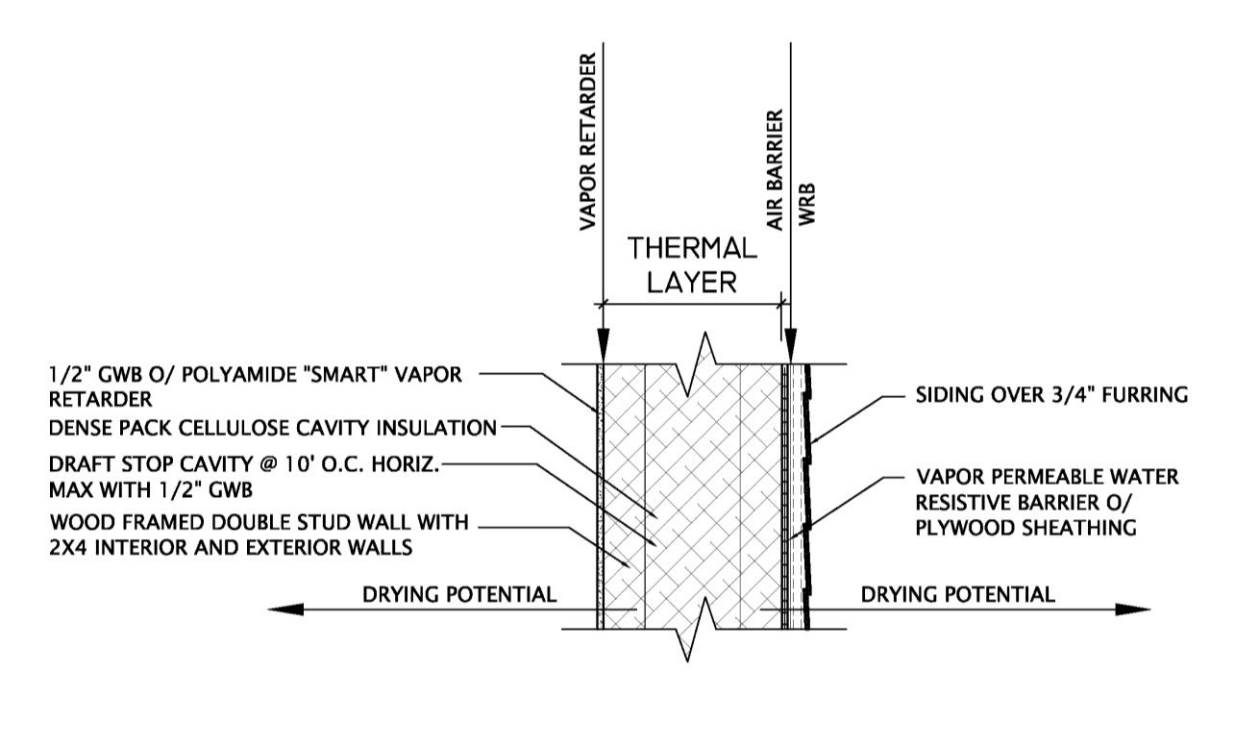
Double Stud Wall

- Air Barrier:
  - Plywood, OSB, liquid applied membrane, caulks and tapes
  - Plywood is more vapor open than OSB
    - Plywood and OSB become more vapor open as RH increases.
    - Both are considered Semi-Permeable (Class III vapor retarders)
    - I prefer plywood, but if the builder prefers OSB, I am usually open to it
  - To tape or caulk sheathing seams…
    - Any sealants should be permanently flexible like urethane or silicone. No latex caulk please.
    - I like tapes better myself, but don't have any verified research on it.
      - Needs to be a tape designed to adhere to substrate.
      - Don't use Tyvek tape on plywood or OSB.
  - NOT Housewrap, as previously stated
  - NOT Ice and Water, as previously stated
  - Liquid Applied WRB's will be air tight, but are subject to lower perm ratings
  - You MUST seal the sheathing to the plates as it goes up



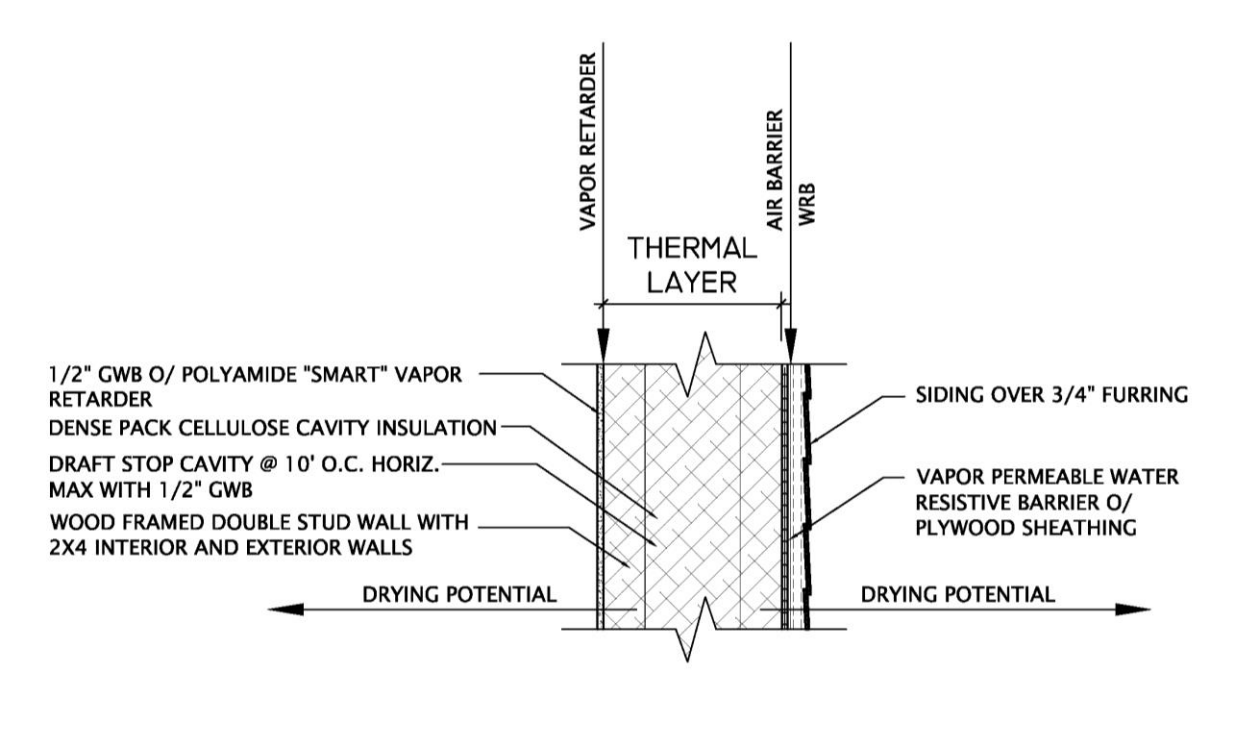
Double Stud Wall

- Vapor Retarder:
  - Polyamide “Smart” retarders (Not polyethylene)
  - You may want to be more vigilant about sealing this than with other High-R wall systems, but do not use this as your air barrier
  - If the exterior sheathing and WRB are VERY vapor open (like Built-rite and Tyvek) then polyethylene on the interior side is less of an issue.
  - Some installation and availability issues with polyamide. Also costs more.



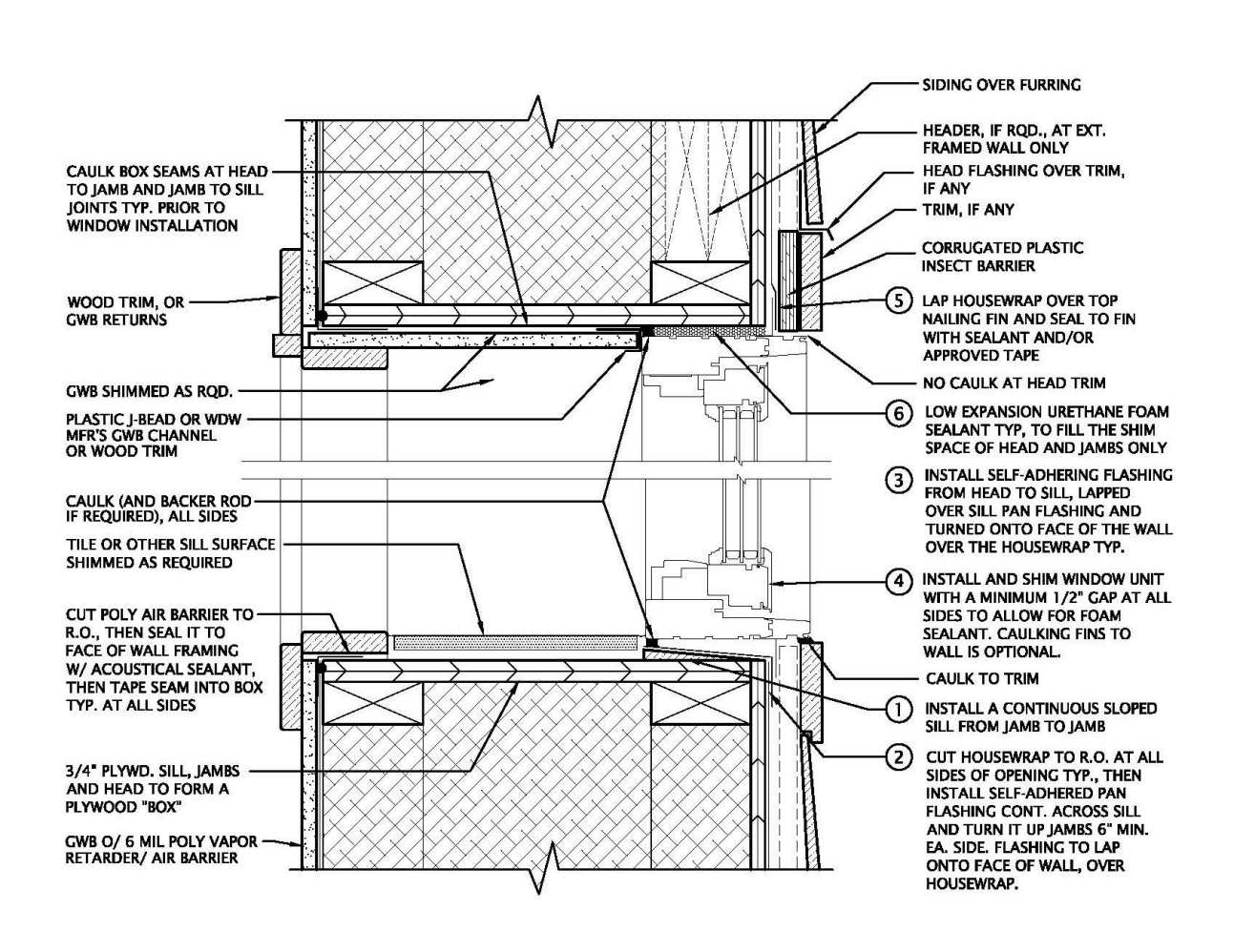
Double Stud Wall

- Thermal Layer:
  - Dense packed Cellulose is our go-to
    - 4 pcf or more
    - Isolate stud bays for better installation
    - Please let go of the “Cellulose settles” narrative
    - Required to have fire blocking?
  - Don’t care for spray foam flash-n-fill solutions.
    - Unnecessarily costly
  - Full foam fill is just too expensive and you can’t make a case for it in my mind
  - Not a big fan of 3-batt layered fill either.
  - Blown fiberglass?
    - Not sure about density/settling



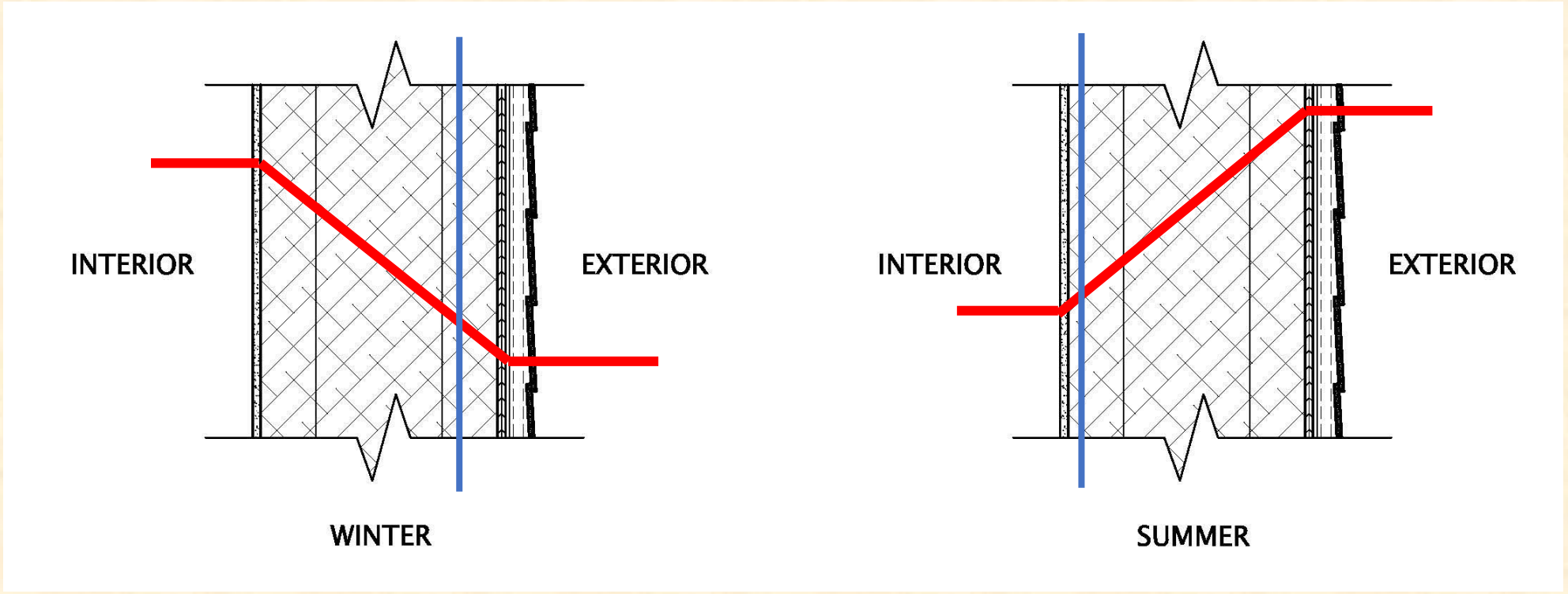
Double Stud Wall

- Other considerations:
  - Probably the least expensive way to get a High-R wall
  - The most environmentally friendly
  - The most risky “on paper”, but field research has shown otherwise.
  - Align studs. Don’t bother staggering them.
  - You can enclose the building before constructing the interior stud wall
  - 12” wall seems to make the most sense if you are going to bother doing it.
  - Need to draft-stop at your top plates.
  - 2x4/2x4 or 2x6/2x4. Either is fine.
  - Box your windows to ease later work and stiffen the wall.
  - Interior wall lintels?
  - Mid-wall sheathing?



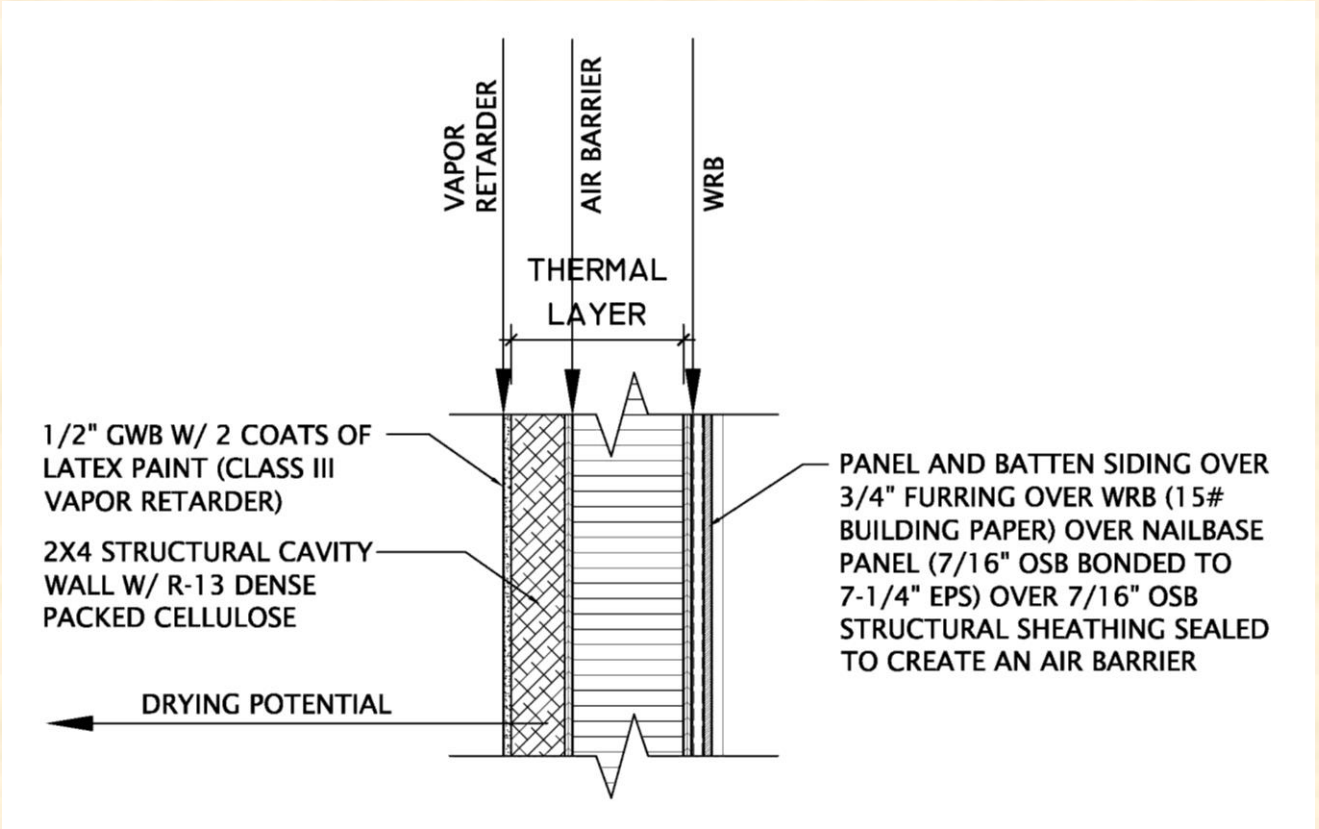
Dew Point Tangent

- Avoid dew points at structural sheathing
  - When I say a wall is “risky”, this is what I am talking about
- What happens in summer if you have interior polyethylene?
- What about vinyl wall covering?



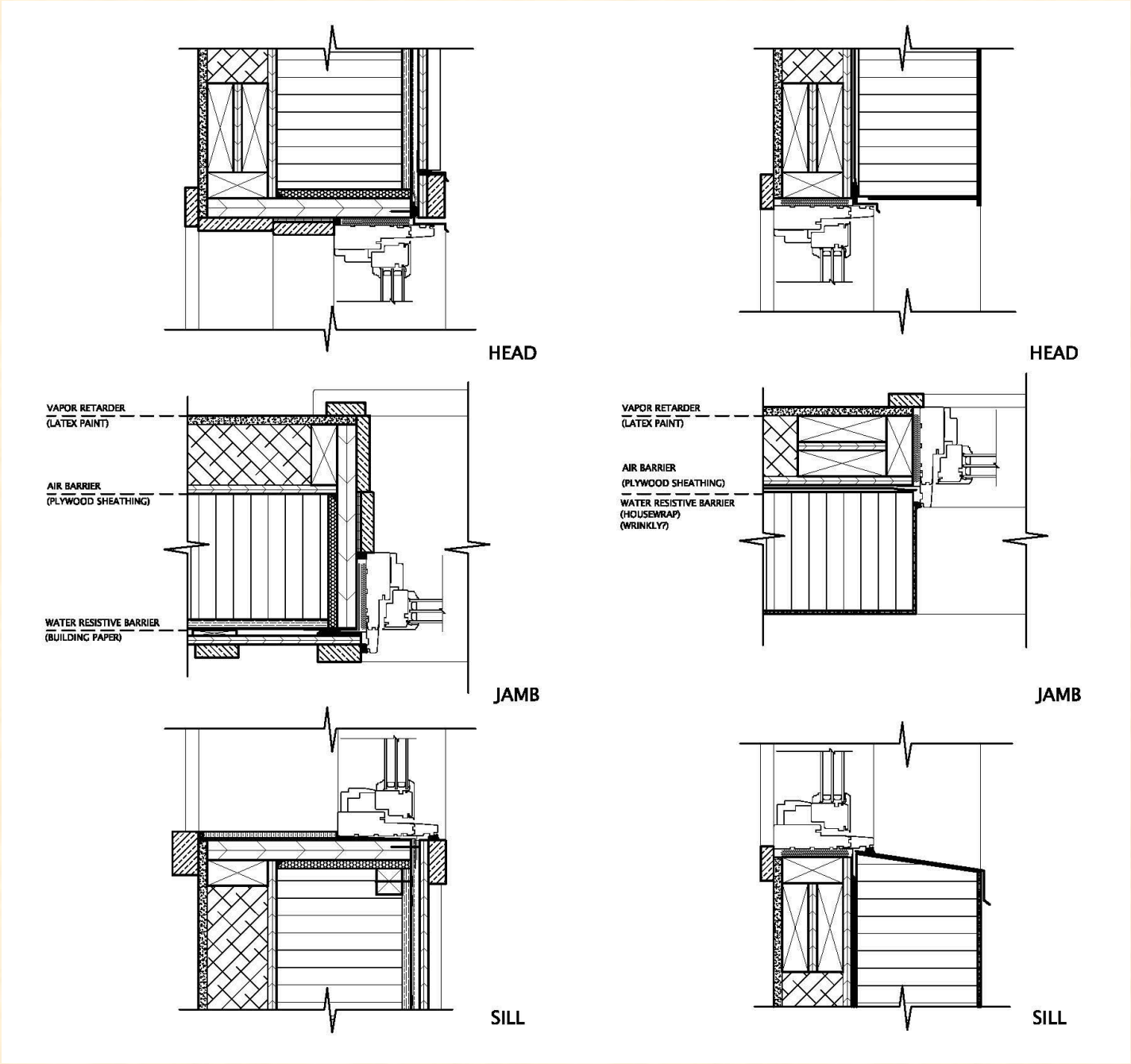
Continuous Insulation (c.i.)

- WRB:
  - Housewrap, #15 Building paper, Ice and Water Shield (sometimes) or Liquid applied membrane
  - The big dilemma here is <u>WHERE</u> is it.
    - Can be at face of insulation, or face of sheathing
    - I prefer face of insulation because of windows
    - This can also depend on what the c.i. is
      - Nailbase panels make the WRB installation easy
      - Rigid mineral wool panels with furring make it more difficult
  - Some foam is approved for use as the WRB, such as foil or fiberglass faced polyiso.
    - Relies on un-lapped tapes
    - But these foams are very low permeability
  - Attachment of the WRB is another significant consideration with c.i.



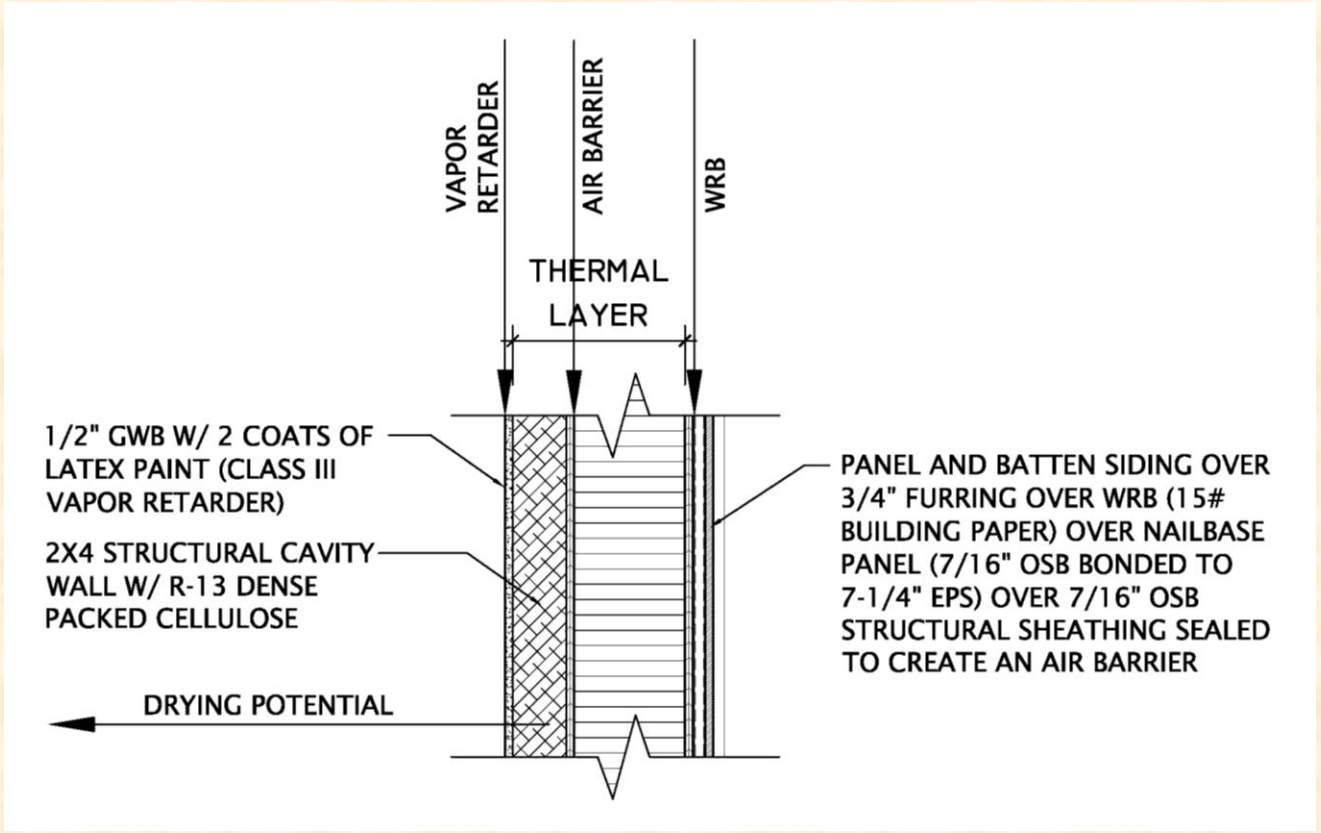
C.I., Innies, Outies, and WRB's tangent

- Moving the WRB to the structural sheathing plane, behind the c.i., may seem like a great idea to the person installing the WRB, but it makes a lot of other things really complicated, especially at openings.
- You'll need a drainage gap behind the c.i. too
- These are considerations you'll need to take into account with c.i. retrofits also



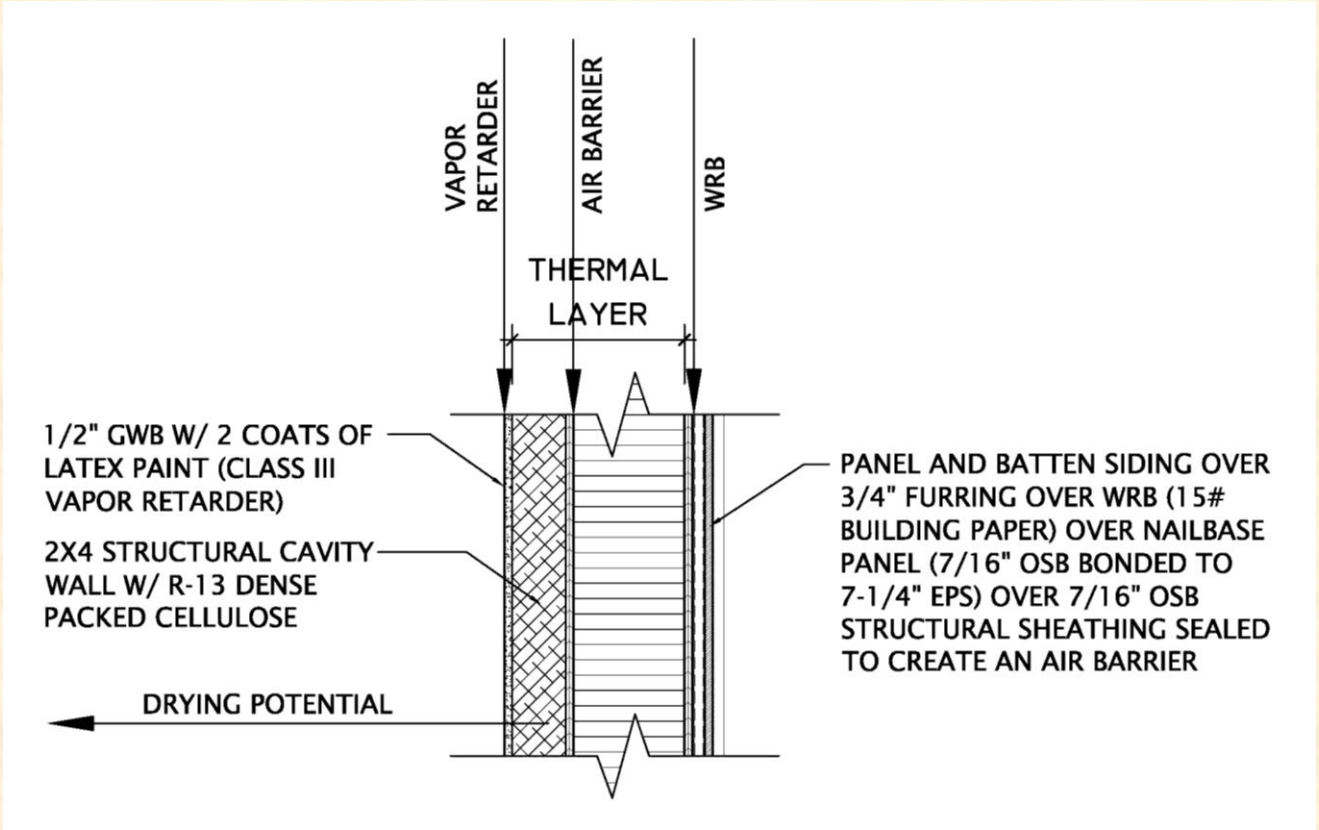
Continuous Insulation (c.i.)

- Air Barrier:
  - Plywood, OSB, liquid applied membrane, Ice and Water Shield, caulks and tapes
  - Again, the question of WHERE is paramount
  - I prefer it at the structural sheathing, because it is easy to do there
    - At the face of the foam creates continuity problems at the top and bottom of the wall
    - If you are using rigid mineral wool for your c.i., this is your only choice



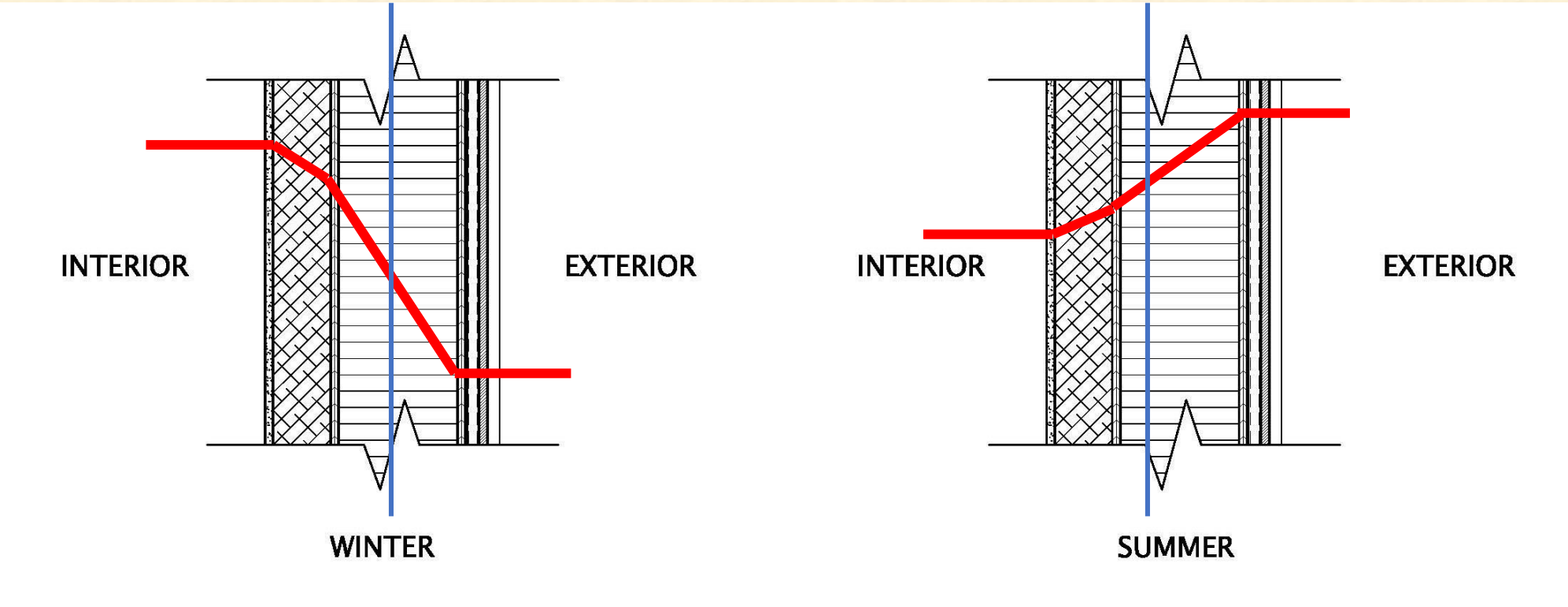
Continuous Insulation (c.i.)

- Vapor Retarder:
  - Polyamide “Smart” retarders (Not polyethylene)
  - The c.i. may be vapor impermeable, so you do NOT want polyethylene, lest you’ll have a double vapor retarder scenario
  - To fill the cavity, or not…
    - If not, then the sheathing is basically the vapor retarder, but it also doesn’t really matter because the dew point will be in the foam
  - What about a Class III vapor retarder?
    - 1 to .7 rule
    - R-21 cavity would require R-15 c.i. to go with a Class III interior Vapor Retarder



C.I. Dew Point Tangent

- Vapor Retarder:
  - The structural sheathing is now warm enough that you won't have condensation



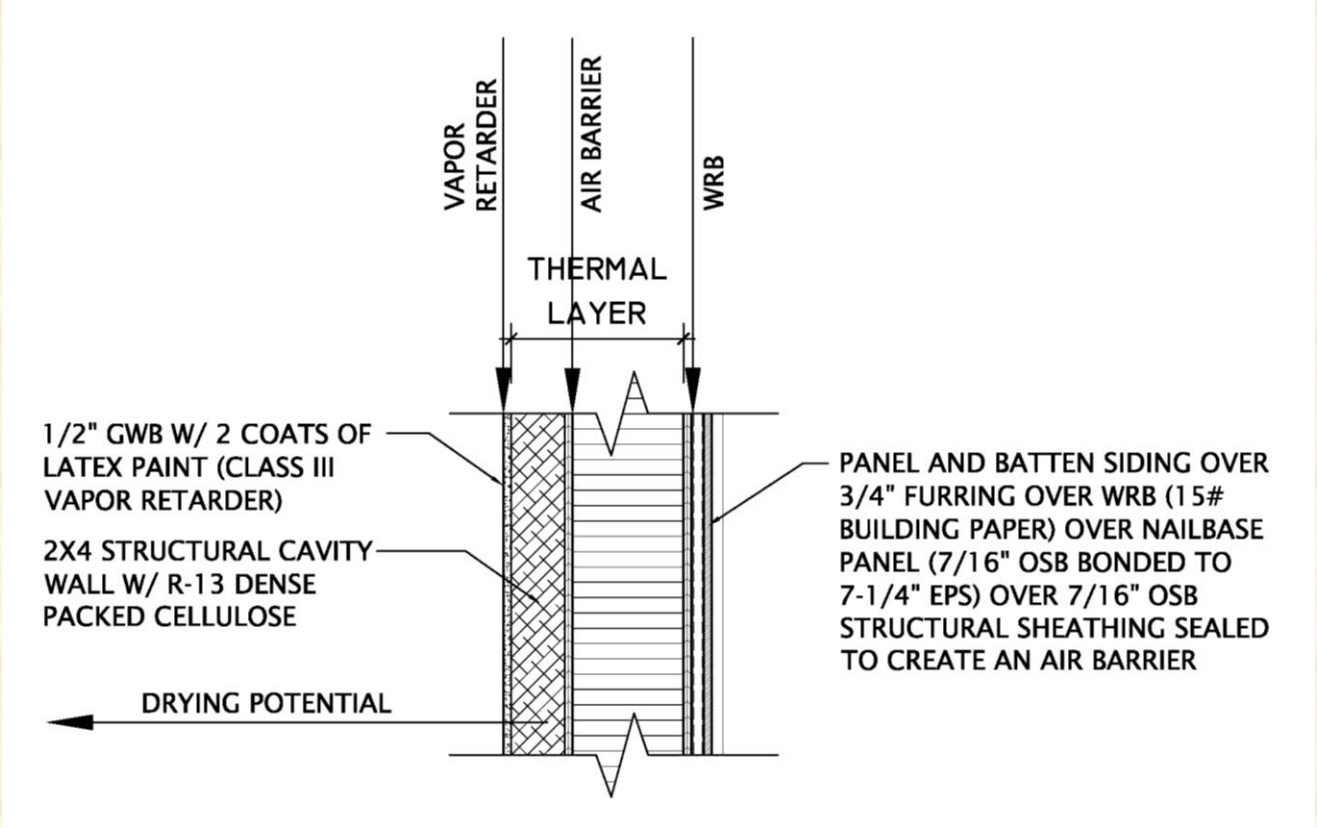
C.I. Class III V.R. Tangent

- Class III Vapor Retarders:
  - If a given ratio of your c.i. is outside the structural sheathing, you can eliminate the polyamide and simply utilize the latex paint as your vapor retarder.
  - That ratio is 1 to 0.7 (or more) cavity to continuous
    - Note, that is NOT 70% continuous
    - Code has given you two options: 2x4 w/ R-10 c.i. and 2x6 w/ R-15 c.i.

- Example: 2x4 w/ R-10:
  - 2x4 with R-11 batts and R-10 cont.
  - 0.7 x 11 = 7.7
  - R-10 > R-7.7, so the wall is “safe”
  - R-21 total
- Example: 2x4 w/ R-10:
  - 2x4 with R-13 batts and R-10 cont.
  - 0.7 x 13 = 9.1
  - R-10 > R-9.1, so the wall is “safe”
  - R-23 total
- Example: 2x6 w/ R-15:
  - 2x6 with R-21 batts and R-15 cont.
  - 0.7 x 21 = 14.7
  - R-15 > R-14.7, so the wall is “safe”
  - R-36 total
- Example: You want an R-45 wall:
  - 45 / 1.7 = R- 26.4 Cavity + R18.6 (or more) c.i.

Continuous Insulation (c.i.)

- Thermal Layer:
  - Continuous: EPS, XPS, Polyiso, Mineral wool
    - Technically a double stud wall has c.i.
  - Cavity: Cellulose, blown fiberglass, fiberglass batts, spray foam
    - I am pretty flexible on this, but wouldn't usually recommend spray foam because of cost and the fact that you've already addressed air tightness at the sheathing
  - I like nailbase panels, but it sometimes depends on the siding choice
  - Where will you install your windows, and what/where is the WRB?
  - Is this the future of the codes?
  - R-11 + 5 is a better wall than an R-21 cavity wall, but you've got to watch the interior vapor retarder or exterior foam type



Continuous Insulation (c.i.)

- WHY C.I.?: Its all about the thermal bridging
  - Let's compare two walls…

2x6 wall w/ R-21 cavity insulation

A 2x6 stud is about R-7, and framing accounts for about 25% of a stud wall w/ studs @ 16" o.c.

Thus R-7 x .25 + R-21 x .75 =

R-17.5 total wall R-Value

2x4 wall w/ R-13 cavity + R-10 c.i.

A 2x4 stud is about R-4.5, and framing accounts for about 25% of a stud wall w/ studs @ 16" o.c.

Thus R-4.5 x .25 + R-13 x .75 + R-10 c.i. =

R-20.9 total wall R-Value

- Almost 20% better in the same space
- Structural sheathing is warmer

C.I. Type Tangent

C.I. Options:

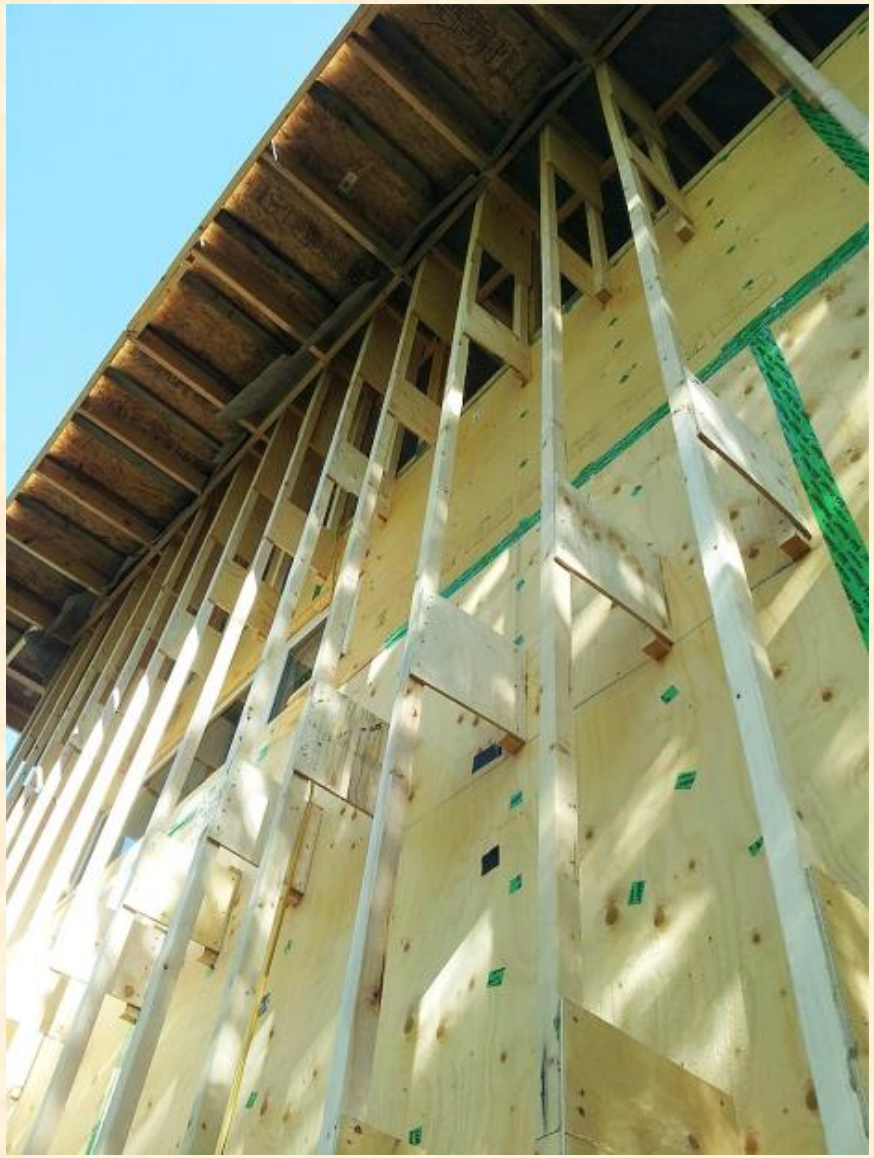
- EPS – R3.5-R5 per inch depending on density.
  - I usually use R-3.8/inch
  - Some permeability (if unfaced)
  - Cheapest
  - Most environmentally friendly foam board (arguably)
- XPS – R5 per inch
  - Less permeability
  - Shrinkage?
- Polyiso - R5.8/inch
  - Perm rating depends on facing (foil, fiberglass)
- Rigid Mineral Wool – R4 per inch
  - Available in different densities/compressive strength
- Wood fiber Board – R3.3 per inch
  - Environmentally friendly
- Cellulose – R3.6 per inch
  - Environmentally friendly
  - Difficult to install on exterior assemblies
- Spray foams – R3.7 to R6.5 per inch

Continuous Insulation (c.i.)

- Other considerations:
  - How will you attach your windows and siding
  - Furring or not
  - How many layers?
  - Do you need a rain-screen?
  - Will codes require a rain-screen soon?
    - If so, how will you achieve it?
  - How thick should the c.i. be?
  - Rodent and insect control

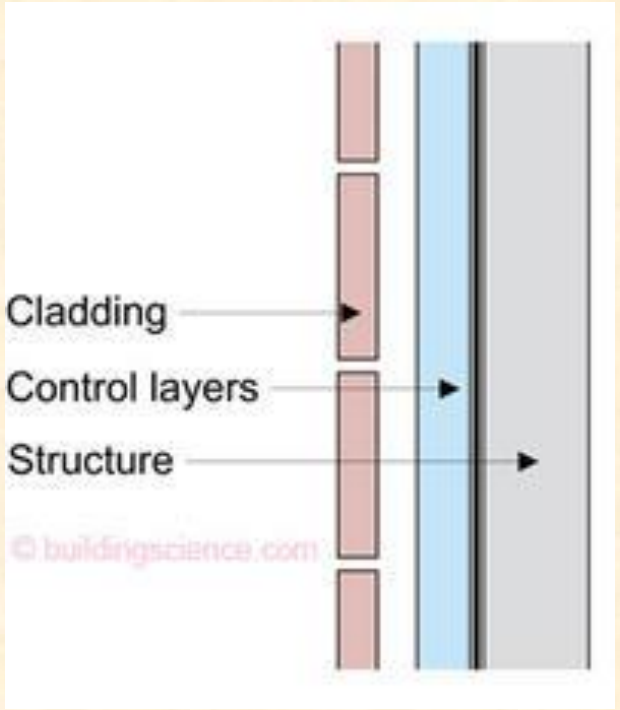
Other walls

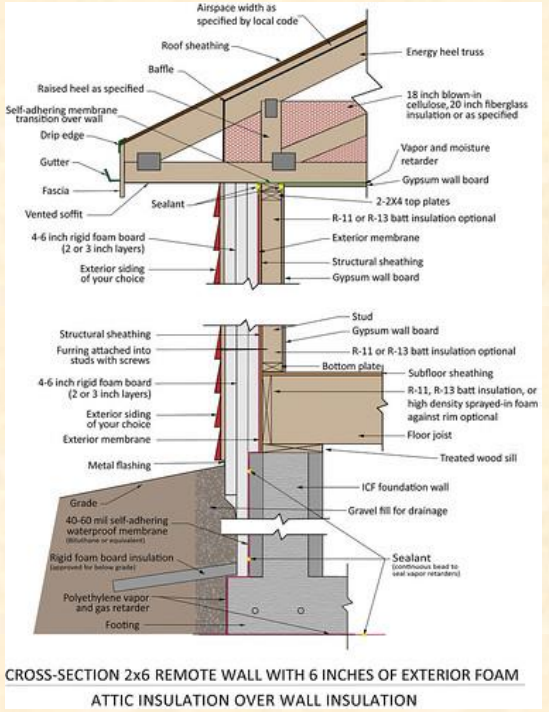
- Larsen Truss walls (and similar “modified” hybrids):
  - Moves most (or all) of the insulation outside of the structural wall
  - Great for the wall, not so great for the person installing the cellulose
    - Unless pre-filled like some pre-fab construction being done
  - Requires “innie” windows, which I don’t like
  - Bottom of wall is a difficult area to detail
  - I have a difficult time understanding why people do this, but…



Other walls

- Lstiburek's "Perfect wall", the PERSIST wall, and the REMOTE wall:
  - Move all the layers to the outside of the structure
  - Protects the structure from heat and cold
  - Read all about it in Building Science Corp.'s on-line document BSI-001: The Perfect Wall





CROSS-SECTION 2x6 REMOTE WALL WITH 6 INCHES OF EXTERIOR FOAM
ATTIC INSULATION OVER WALL INSULATION

Other walls

- SIP walls
  - Vapor control and air control are critical
  - EPS has the lowest environmental impact of all the rigid foams
  - Some SIP manufacturers will reclaim/recycle waste foam
  - 8” wall for R-30
  - 10” wall for R-40…ish

Other walls

- ICF walls
  - For me, only if you increase the R-Value with added foam
    - Different ICF systems address this differently
  - Large environmental impact, but storm resistant
  - May leave interior vapor retarder off entirely, especially in a southern climate
  - All materials in the assembly are rot-proof
  - Expensive
  - Inflexible for future alterations

Conclusions

- You must have all four of the critical wall layers for a successful high-R wall assembly
- You must consider the building science when designing and building high-R walls
  - Can your wall dry?
- Some systems are well tested and represented, some or not
- Designers – Consider the builder's preferences, and bring them on early in the process if possible
- Builders – Consider the designers reasons for what is specified, and don't make changes without discussing it with the designer
- Make sure you are following the component manufacturer's installation instructions
- Don't assume a marketing claim is true, or that it absolves you from thinking critically
- It will be interesting to see what the default "code built wall" will become in the near future as c.i. and rainscreens become the requirements
- There may be no "one size fits all" solution to wall assemblies

Thank You