Durability and Moisture Management in Net Zero Commercial Buildings

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RDH Building Science

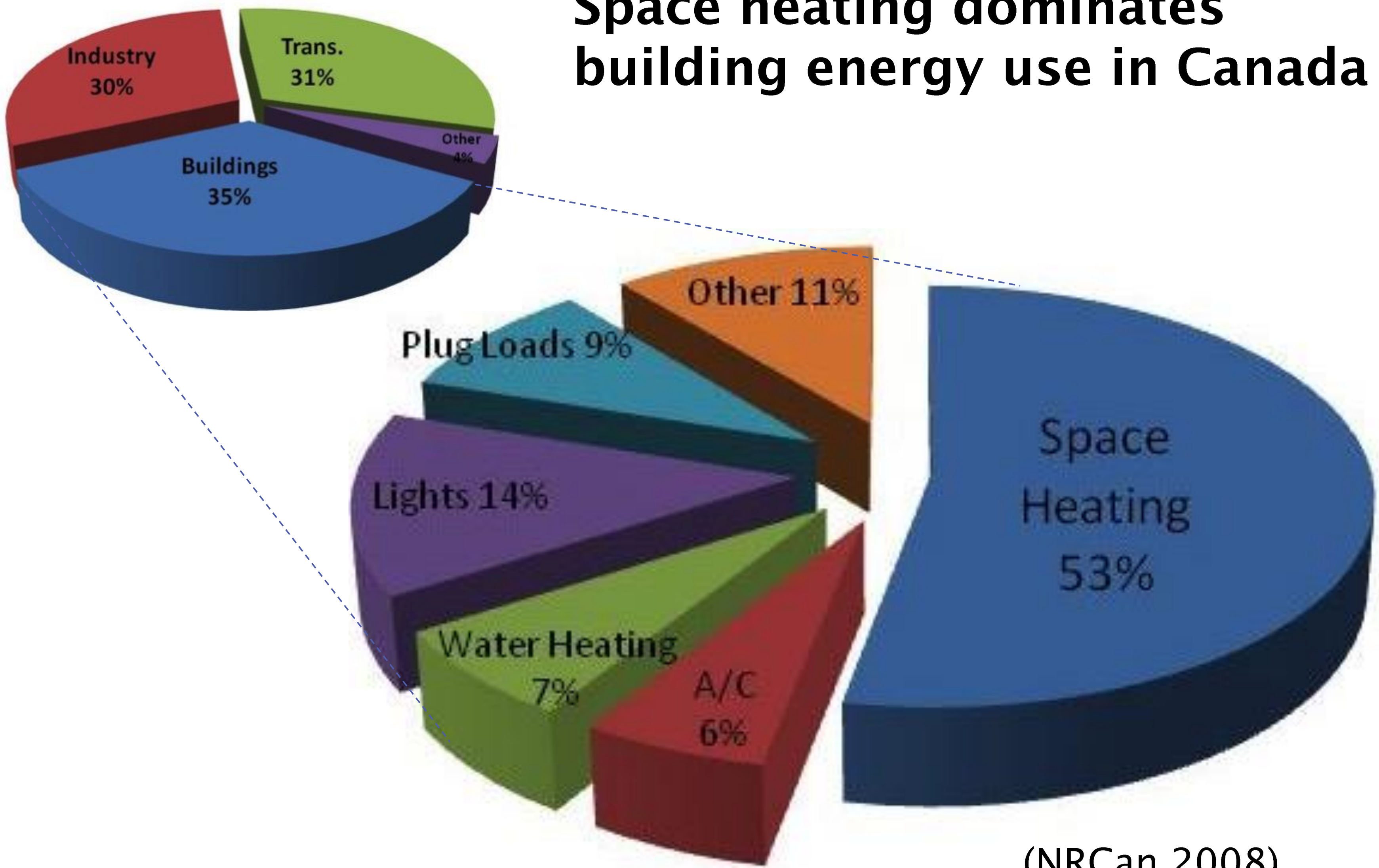
Outline

- → Technical risk
  - → Likelihood and significance of poor technical performance
- → Not schedule or budget related
- → Avoiding = one of our core values to clients

→ Section 1: From Current Code Requirements to Net Zero Buildings

Energy Use In Canada

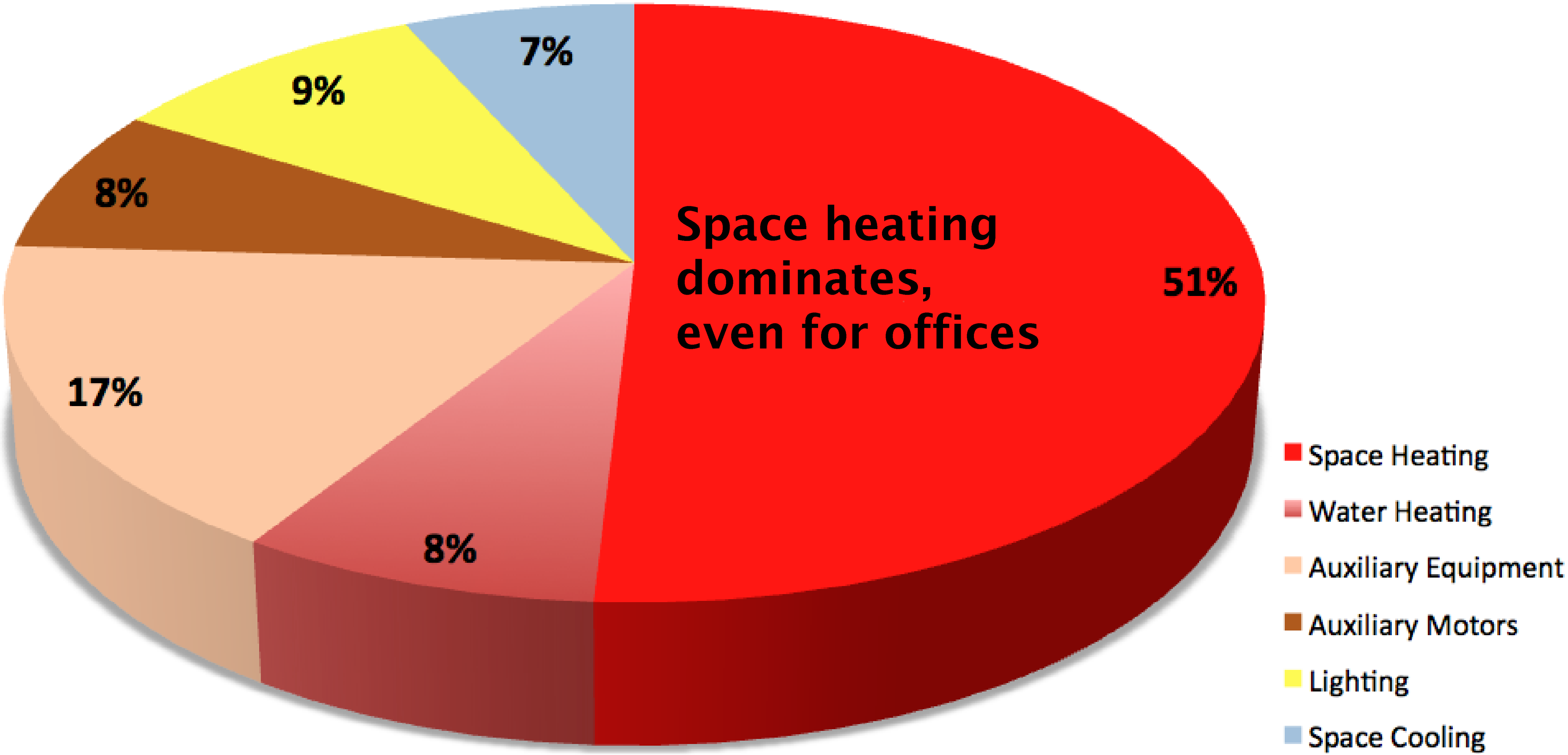
Space heating dominates building energy use in Canada



(NRCan 2008)

Average of Canadian Office Buildings

Space heating load primarily due to: poor insulation, windows, & air leakage



207 million m²

Average 394 kWh/m²

Source: NRCan Office of Energy Efficiency

Trends

- → Higher insulation levels
  - → over R-20/RSI3.5
- → Higher air tightness levels
  - → Testing commercial buildings
- → Effective R-values
  - → Account for thermal bridging
- → Wood-frame 4-6 storey, residential
- → Sub/Urban infill
- → Moving towards Net Zero Energy

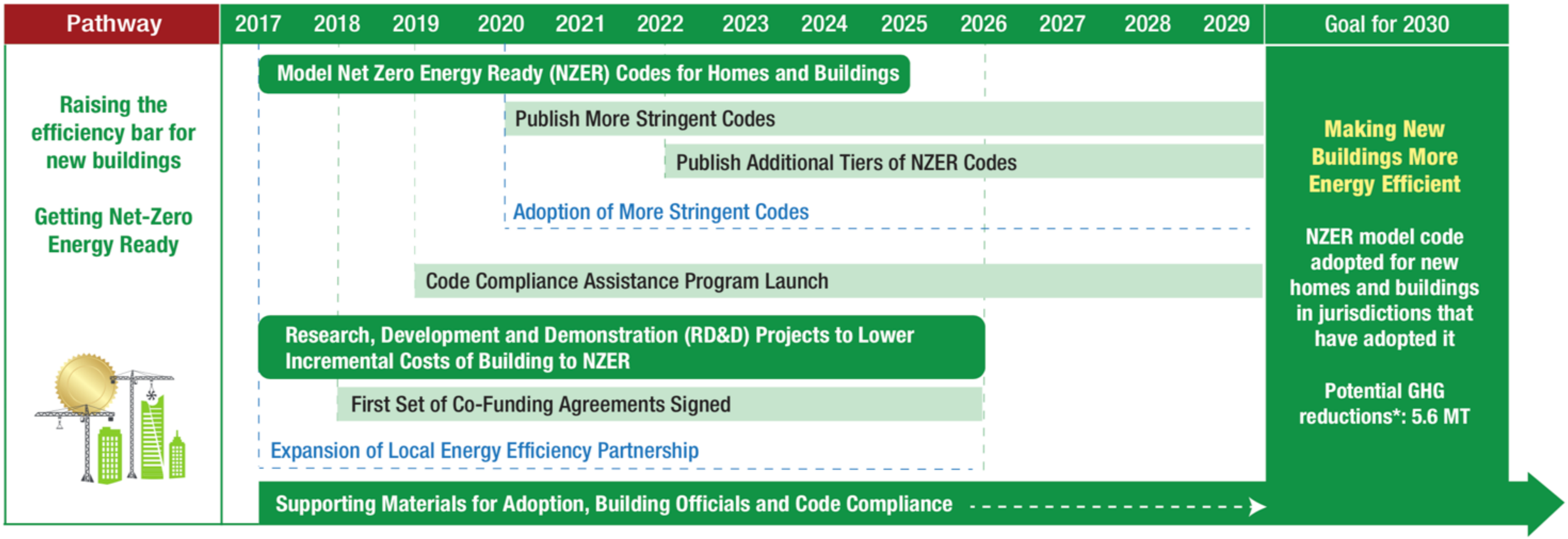
National Building Code of Canada

- Pan-Canadian Framework on Clean Growth and Climate Change calls for
  - adoption of "net-zero energy" ready

GOAL: Federal, provincial, and territorial governments will work to develop and adopt increasingly stringent model building codes, starting in 2020, with the goal that provinces and territories adopt a "net-zero energy ready" model building code by 2030.

Critical Path to 2030

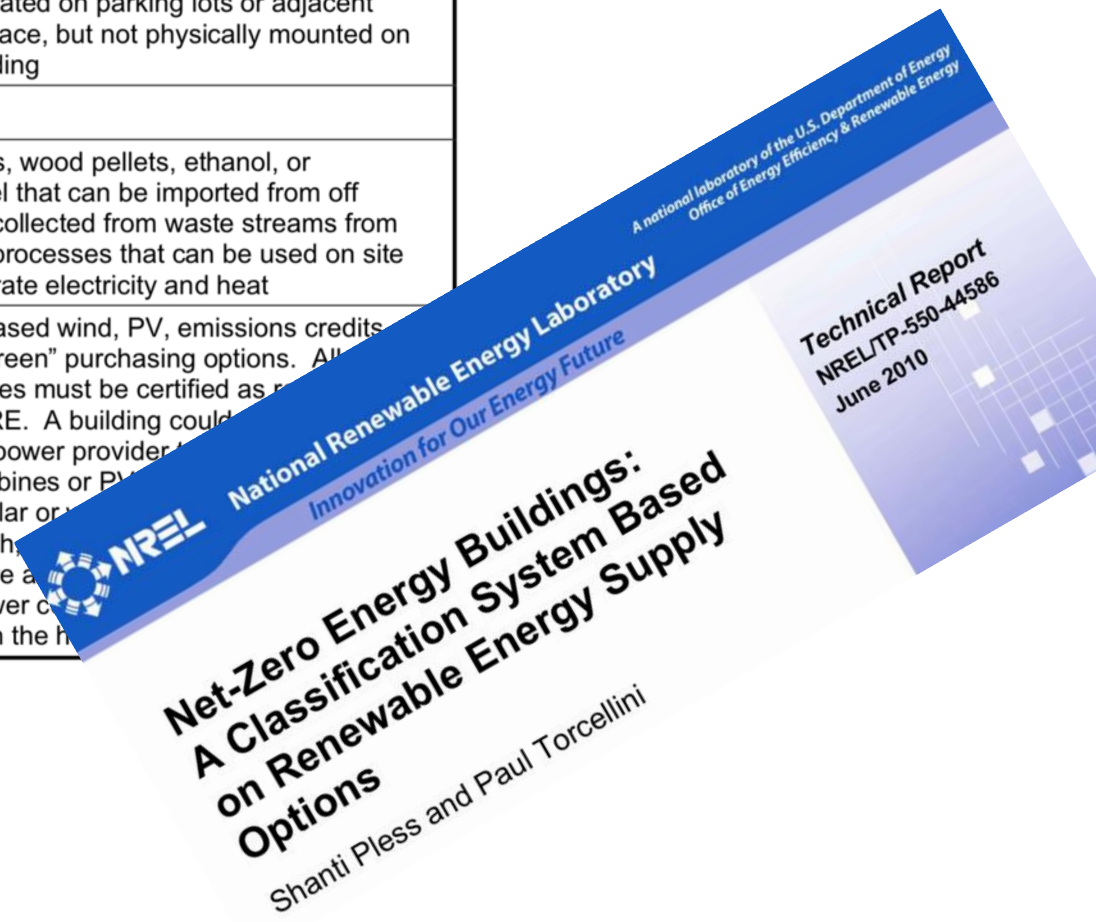
nrcan.gc.ca/pathwayto2030



What is Net Zero Energy Building?

- → Simple: ***A Building that produces as much energy as it consumes over the year***
- → Complications
  - → Can you buy renewable power from elsewhere? (e.g., wind in PEI for Montreal building)
  - → Is energy production only ON *building* or on *site*
  - → Are imported renewables allowed (wood, ethanol)?
  - → Next year, or typical year's weather?
  - → What kind of occupancy?

Option Number	NZEB Supply-Side Options	Examples
0	Reduce site energy use through energy efficiency and demand-side renewable building technologies.	Daylighting; insulation; passive solar heating; high-efficiency heating, ventilation, and air-conditioning equipment; natural ventilation, evaporative cooling; ground-source heat pumps; ocean water cooling
On-Site Supply Options		
1	Use RE sources available within the building footprint and connected to its electricity or hot/chilled water distribution system.	PV, solar hot water, and wind located on the building
2	Use RE sources available at the building site and connected to its electricity or hot/chilled water distribution system.	PV, solar hot water, low-impact hydro, and wind located on parking lots or adjacent open space, but not physically mounted on the building
Off-Site Supply Options		
3	Use RE sources available off site to generate energy on site and connected to the building's electricity or hot/chilled water distribution system.	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or collected from waste streams from on-site processes that can be used on site to generate electricity and heat
4	Purchase recently added off-site RE sources, as certified from Green-E (2009) or other equivalent REC programs. Continue to purchase the generation from this new resource to maintain NZEB status.	Utility-based wind, PV, emissions credits other "green" purchasing options. All purchases must be certified as r added RE. A building could with its power provider wind turbines or PV good solar or approach hardware a The power c maintain the h



Some Detailed Definitions

McCallum Sather / B+H Architects. 96 000 sq ft

Project Successes

Process:

- Establishing the Energy Budget at the project inception became a huge design driver

Impacts: Net Zero Targets Achievable

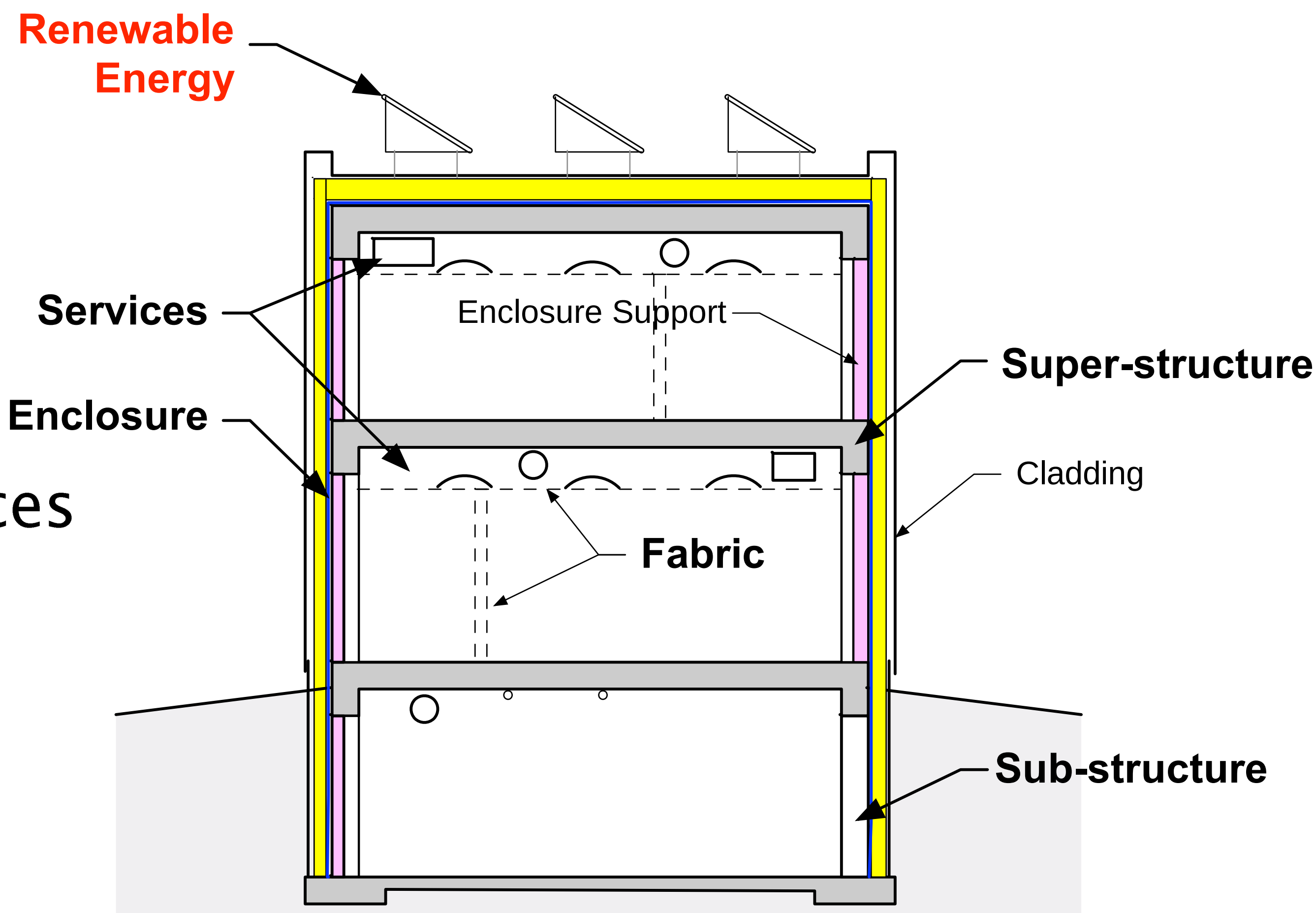
- Net Zero Energy
- CaGBC Net Zero Carbon

35% WWR, R-7 window, R-25 wall, R-40 roof
Average enclosure R-10 (windows + opaque)
Energy use: 71kWh/m^2/yr
Energy production: 71 kWh/m^2/yr on-site

High performance enclosure

Building Components

- → Primary components: *Enclosure, Structure, Services* and *Fabric*
- → NZE adds *Renewable Energy*
- → NZE focus on
  1. Enclosure
  2. Energy
  3. then Services



Early-Stage Decisions

→ Important decisions **are often at start of design**

→ Assuming .. Site is known, program fixed, and area estimated.

→ Form (Box? Egg?)

→ Space Dimensions

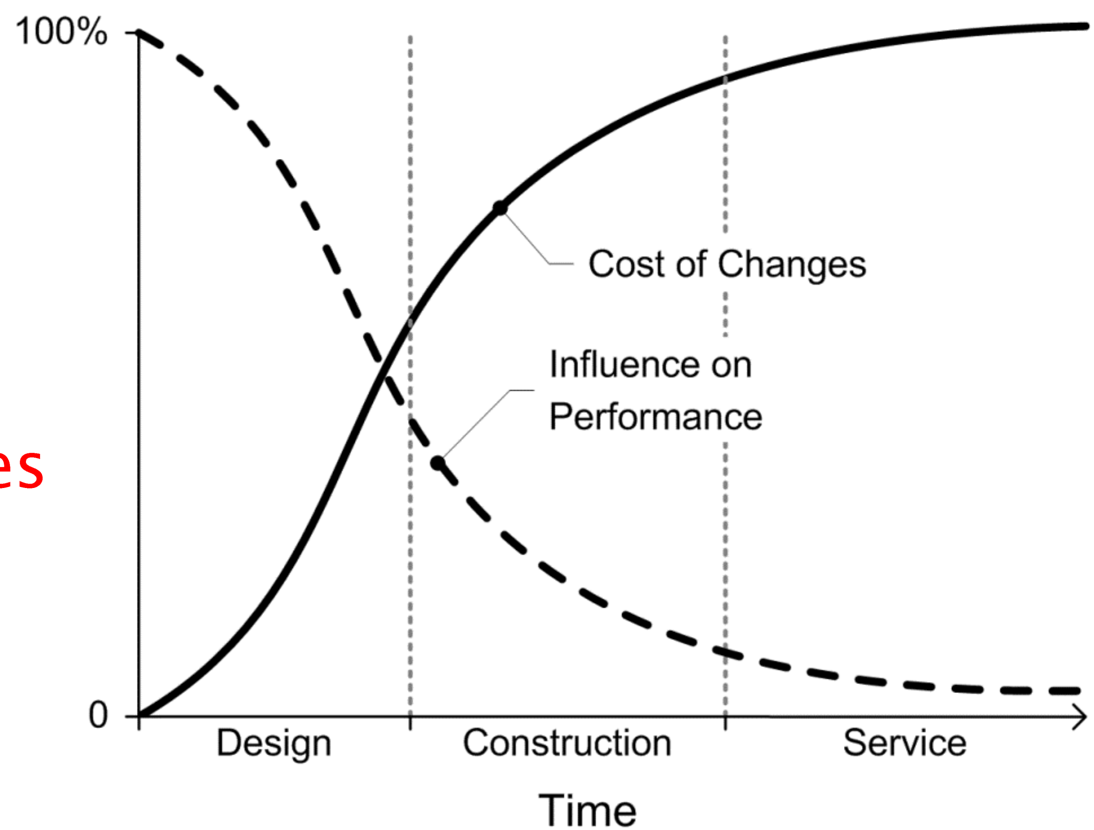
→ Structural Systems

→ Window Area

→ Enclosure attributes

→ HVAC… later

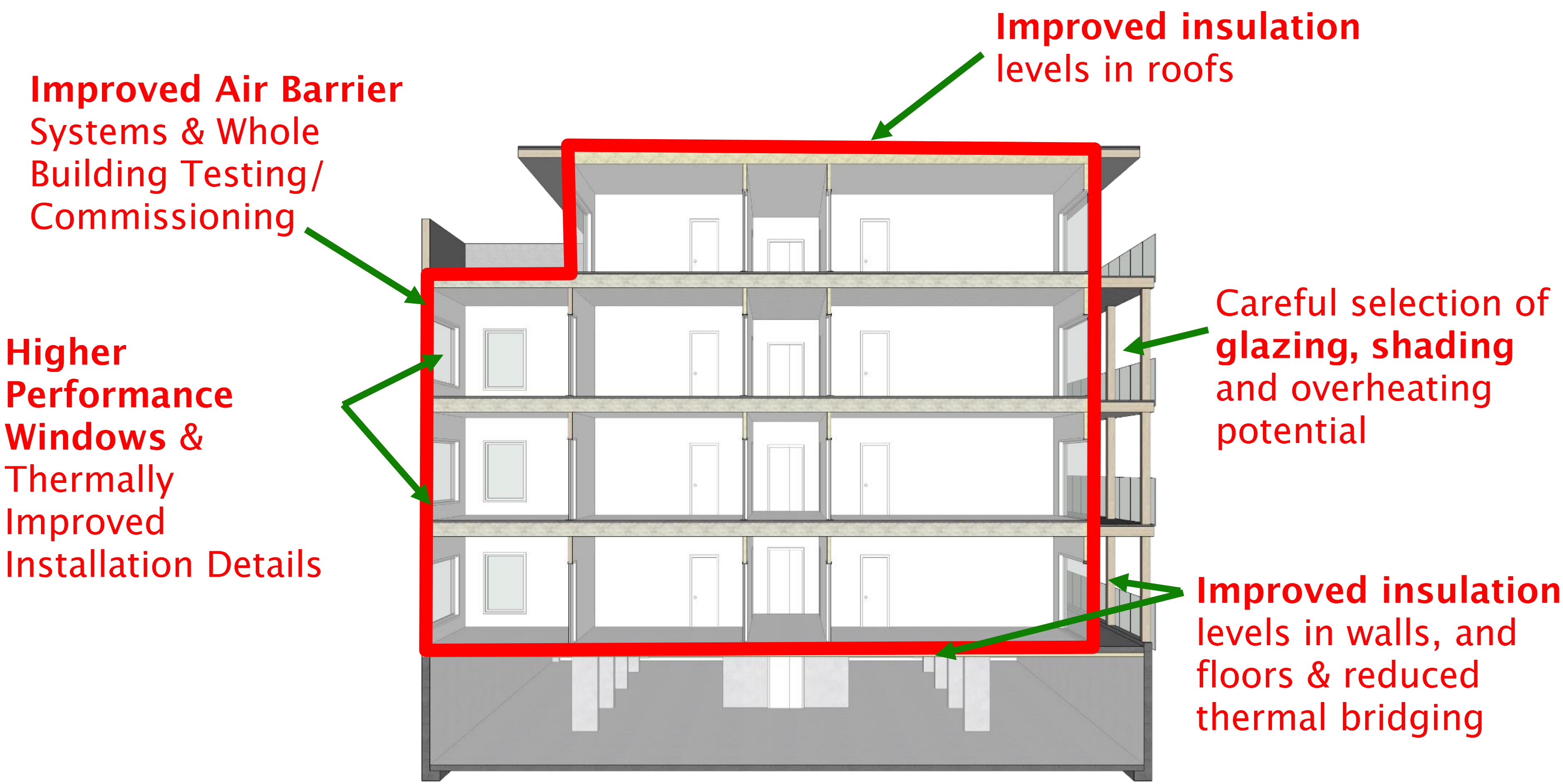
→ Details .. later



Low Energy: Enclosure First

- → Low-energy buildings focus on high-performance enclosures first
- → Allows more affordable, often more efficient and simpler HVAC
- → Design to lower:
  - → Heat loss (UA + air leakage)
  - → Heat Gain (Window area time SHGC)

Enclosure Focus Areas for Low Energy



The Road to *Net Zero* Performance Housing

	Vintage <1980 **ERS 50…**	2017 **ERS 80**	R-2000/NZER **ERS 86-89**	Net Zero **ERS 100**
Attics	R-12 to R-20	R-40 to R-50	R-60 to R-80	R-60 to R-80
Walls Above Grade	R-12 to R-19	R-19/R22+R5 ci	**R-24 + R10/R15 ci**	**R-24 + R10/R15 ci**
Foundation Walls	R-8 to R-12	R-12 to R-20	R-30 to R-40	R-30 to R-40
Slab	R-0	R-0	R-10 to R-15	R-10 to R-15
Airtightness:	AVG 5 ACH	<3.5 ACH	<1.5 ACH	<1 ACH

Role of Factors on Energy use

- → Window area is the largest practical factor
  - → Less window area reduces energy use, improves thermal comfort, and costs less
- → Shape and orientation are less important, but can be useful to reduce cost and save energy
- → HVAC and details can be chosen later in process

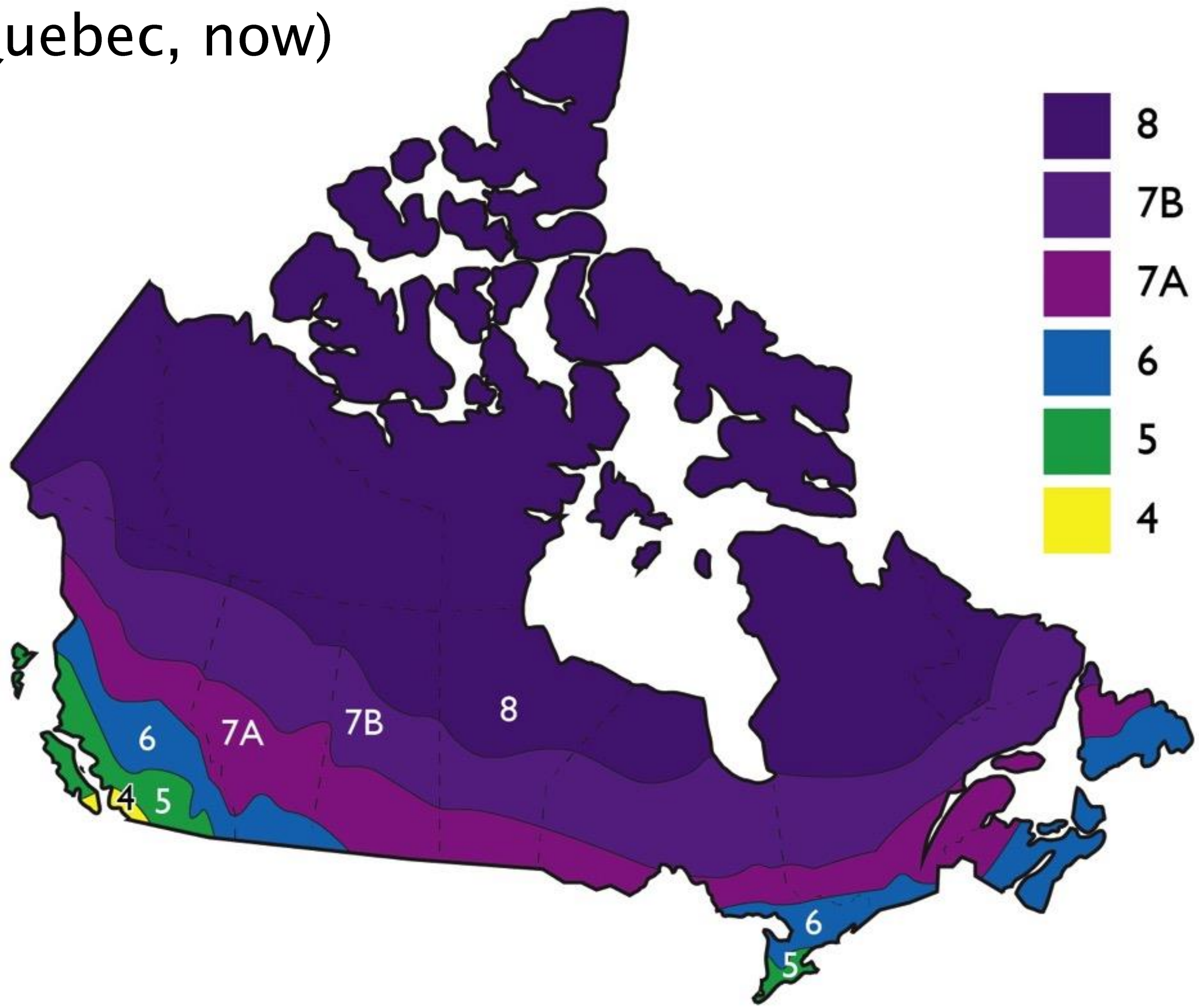
Codes

Common Codes in Canada

- → ASHRAE 90.1-20xx
- → **NECB 20xx**
- → Provincial
  - → Quebec
    "*Regulation Respecting Energy Conservation in New Buildings Act.*\
  - → Ontario SB-10
- → Enhanced
  - → Net Zero Energy
  - → Passive House, Energy St
  - → Living Building Challenge

Climate Zone obviously matters

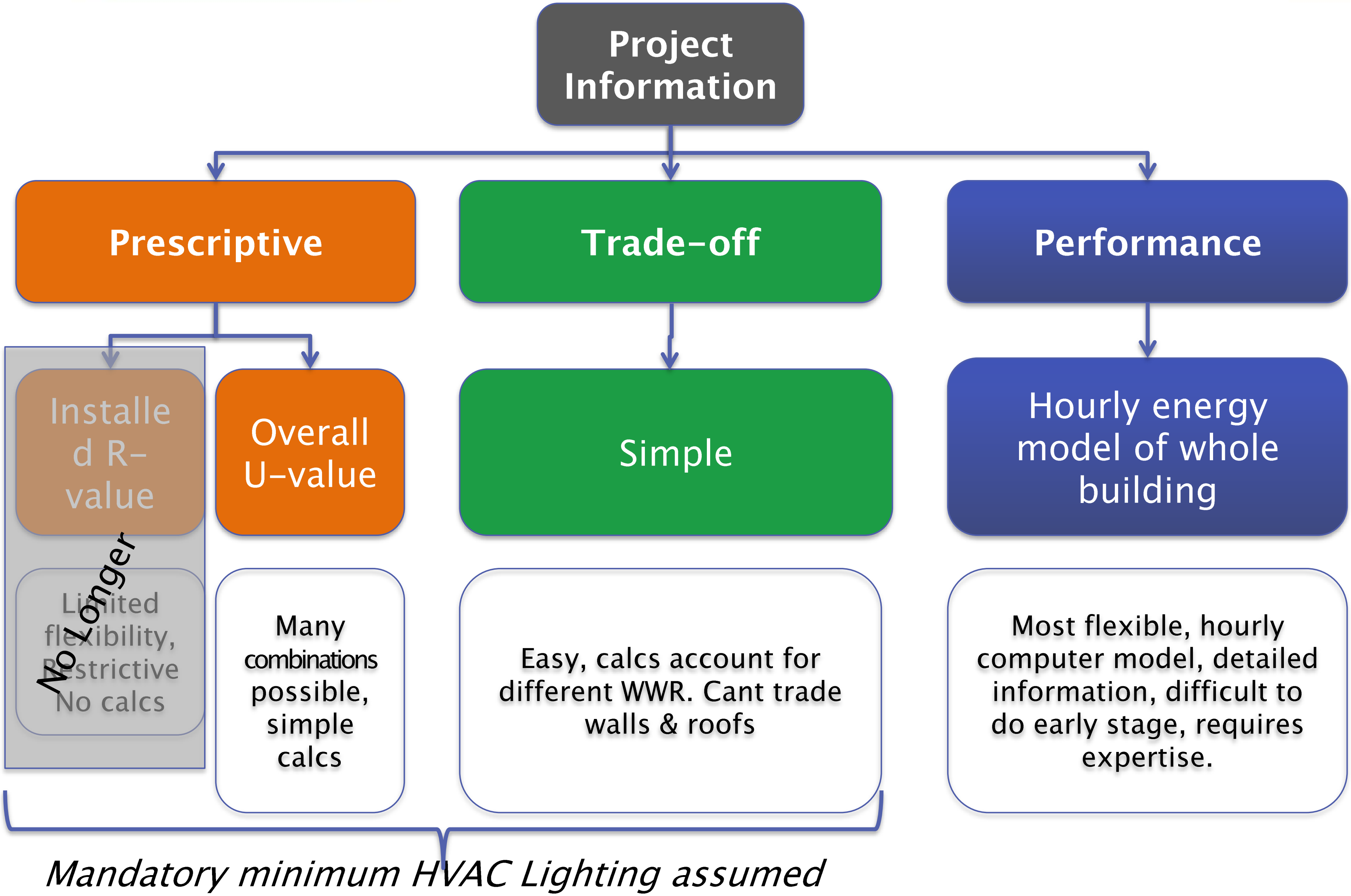
→ Most codes use some version of this map (not Quebec, now)



How Codes Work

- → There is no "code R-value your wall must meet"
- → Code official ("Authority Having Jurisdiction") ask designers to "demonstrate compliance" to code
- → Designers must know the thermal performance of their enclosures to:
  - → compare to tabulated values
  - → provide information to energy modelers
- → Level of detail in "calculations" depend on code and AHJ

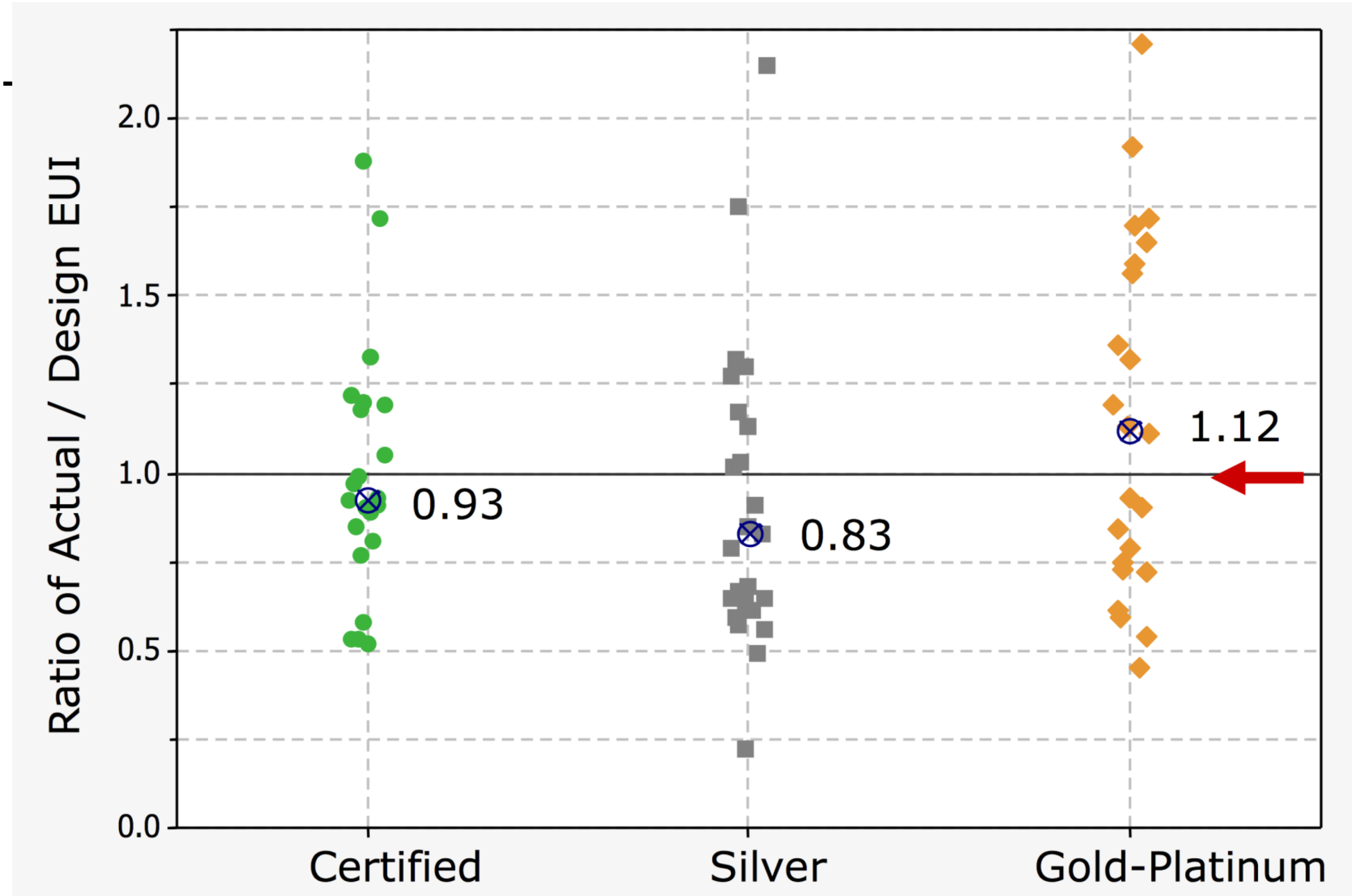
Code Compliance Paths



Energy Modeling

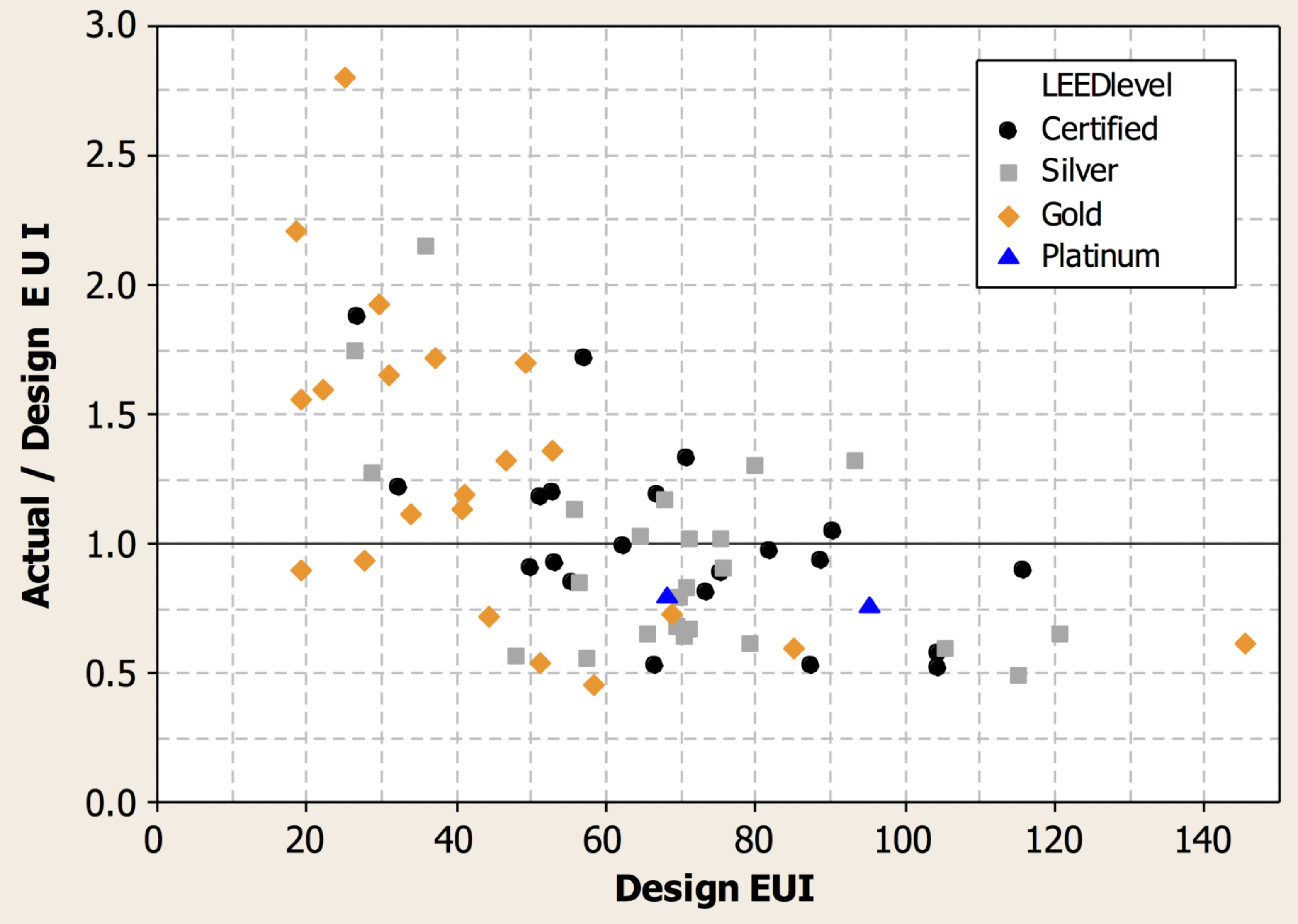
- → Allows for great flexibility
- → Model code minimum building, including all HVAC, lighting, DHW, etc. (“Reference Building”)
- → Demonstrate Design Building is same or lower energy use
- → Often require too much information at early stage.
- → Can’t wait for modeling to make important design decisions
- → Black box models often cloud understanding

Energy Models: not very accurate



Ref:Owens, Frankel, Turner. *Energy Performance of LEED Buildings*.

Low-energy Buildings are harder



Ref:Owens, Frankel, Turner. *Energy Performance of LEED Buildings*.

Section 2: Net Zero Building Enclosures

Building Enclosures

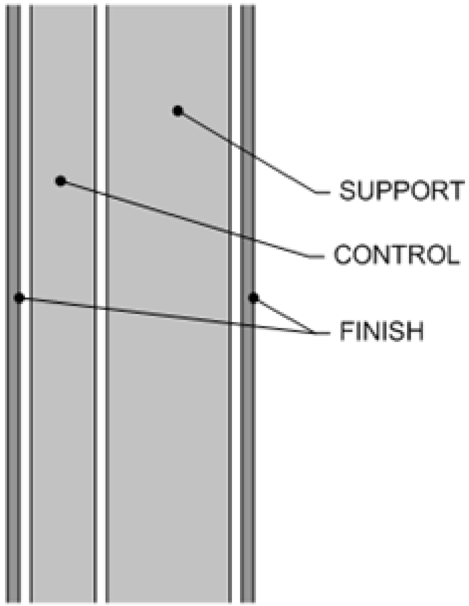
- Enclosure seperates indoors from outdoors
- Important component
  - Appearance
  - Comfort
  - Durability / maintenance
  - Energy!
- Common source of problems
  - Leaks, comfort, mold, cladding failure, etc
- Critical for low-energy buildings

Basic Functions of the Enclosure

- → 1. Support
  - → Resist and transfer physical forces from inside and out
- → 2. Control
  - → Control mass and energy flows
- → 3. Finish
  - → Interior and exterior surfaces for people

- → Distribution – a building function

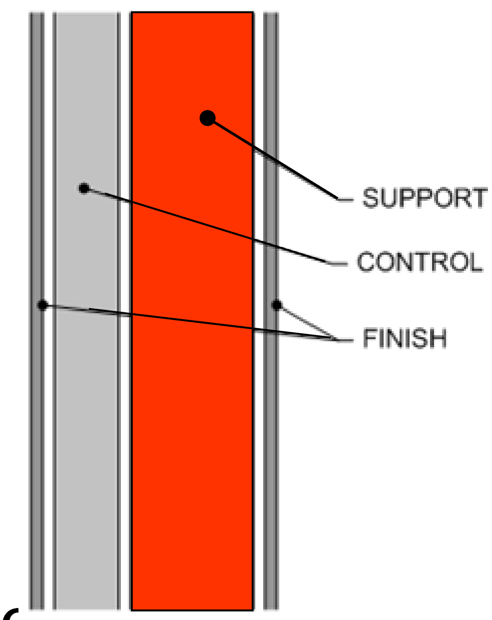
Functional Layers



Basic Enclosure Functions

- → **Support**
  - → **Resist & transfer physical forces from inside and out**
    - › Lateral (wind, earthquake)
    - › Gravity (snow, dead, use)
    - › Rheological (shrink, swell)
    - › Impact, wear, abrasion
- → Control
  - → Control mass and energy flows
- → Finish
  - → Interior and exterior surfaces for peo

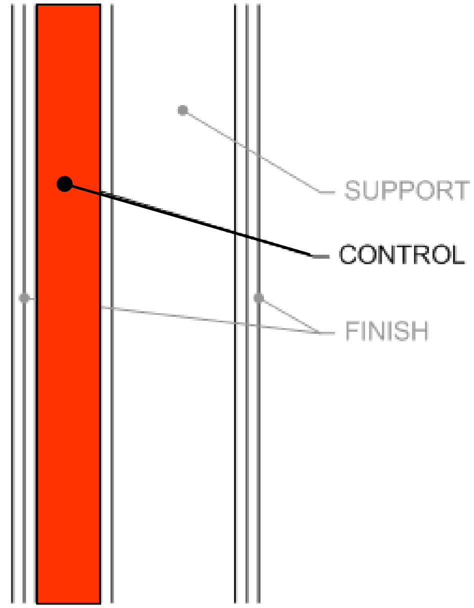
Functional Layers



Basic Enclosure Functions

- → Support
  - → Resist & transfer physical forces from inside and out
- → **Control**
  - → **Control mass and energy flows**
    - › **Rain** (and soil moisture)
      - – Drainage plane, capillary break, etc.
    - › **Air**
      - – Continuous air barrier
    - › **Heat**
      - – Continuous layer of insulation
    - › **Vapor**
      - – Balance of wetting/drying
- → Finish
  - → Interior and exterior surfaces for peo

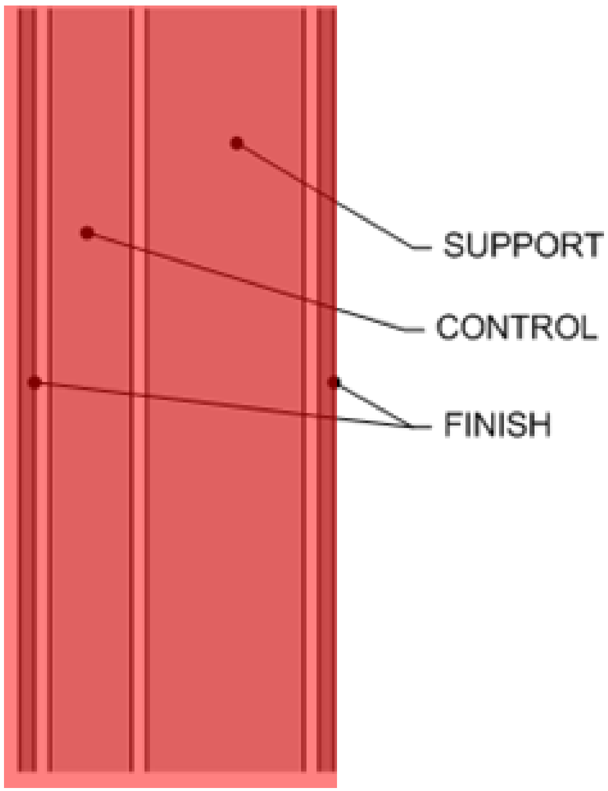
Functional Layers



Other Control . . .

- Support
- **Control**
  - **Fire**
    - **Penetration**
    - **Propagation**
  - **Sound**
    - **Penetration**
    - **Reflection**
  - **Light**
    - **Diffuse/glare**
    - **View**
- Finish

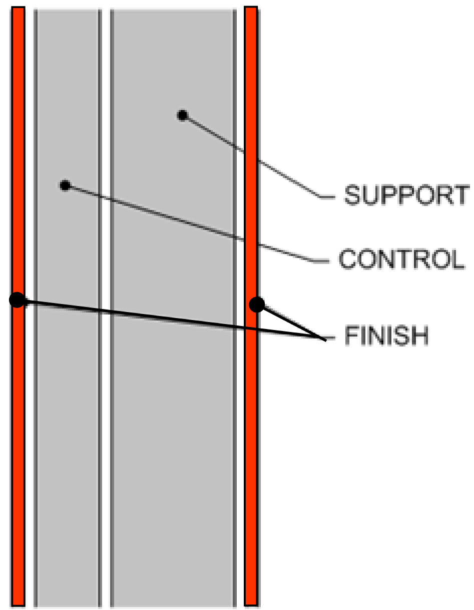
Functional Layers



Basic Enclosure Functions

- → Support
  - → Resist & transfer physical forces from inside and out
- → Control
  - → Control mass and energy flows
- → **Finish**
  - → **Interior & exterior surfaces for people**
    - › Color, speculance
    - › Pattern, texture

Functional Layers



History of

→ Older Buildings

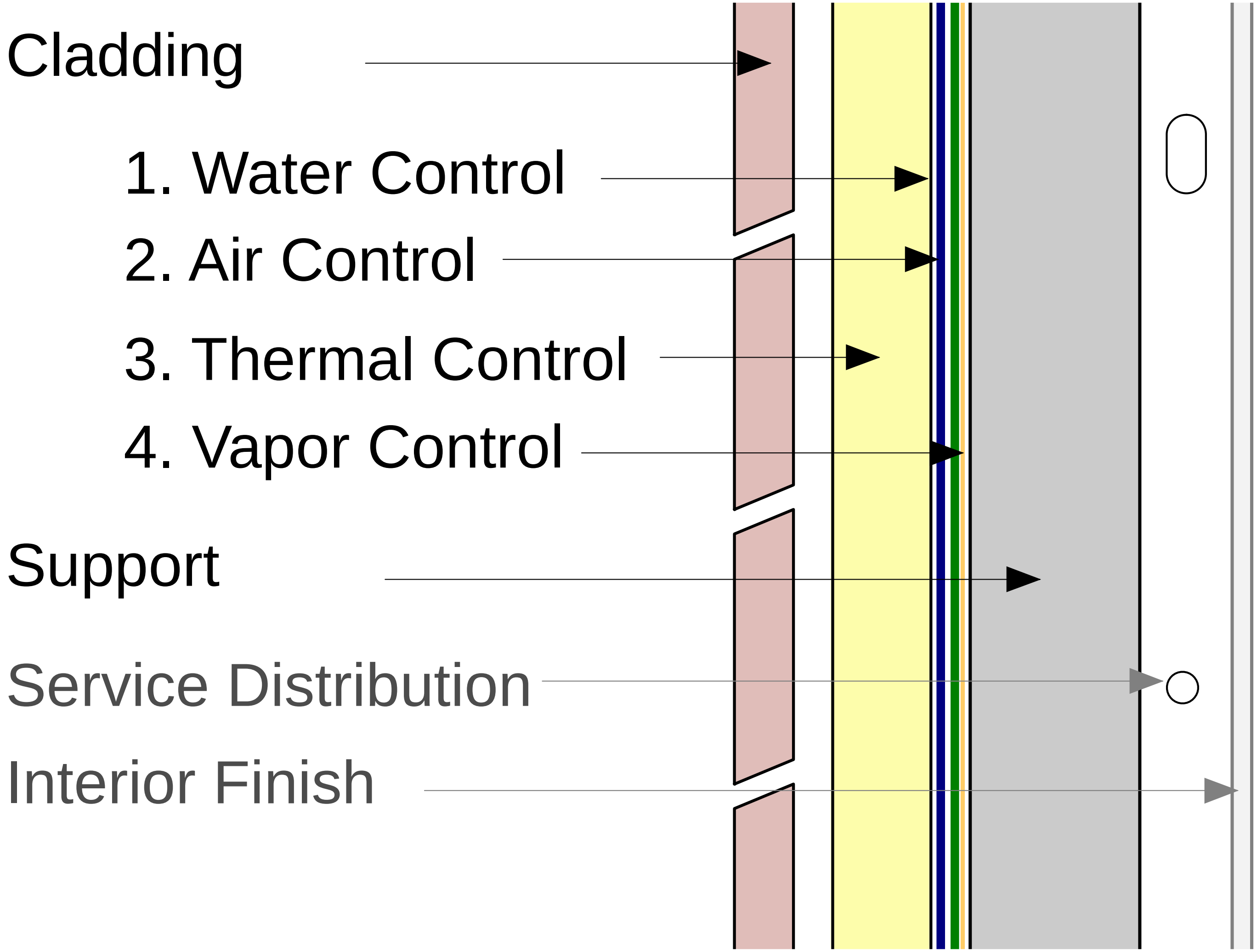
  → One layer does everything

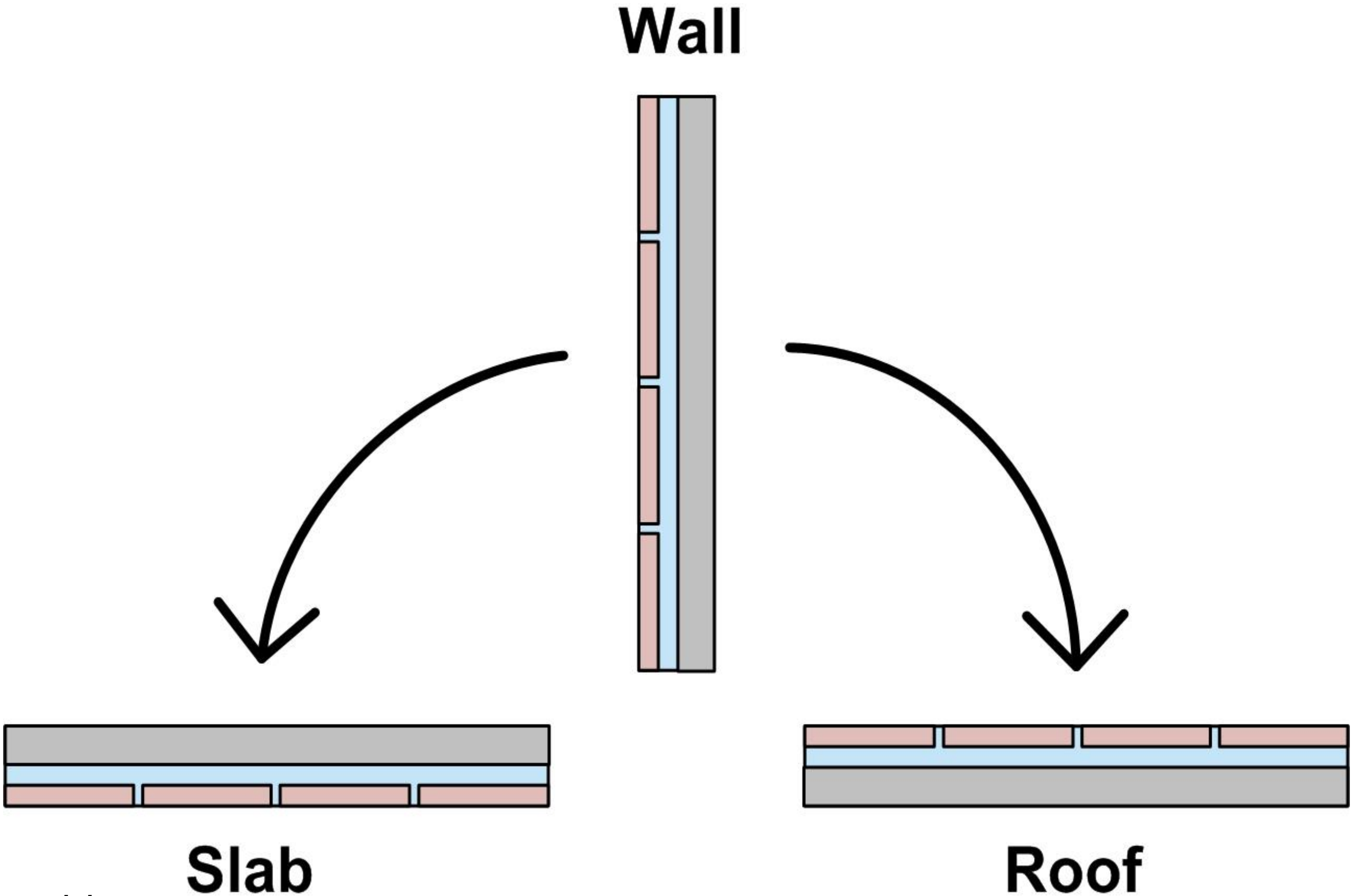
→ Newer Building

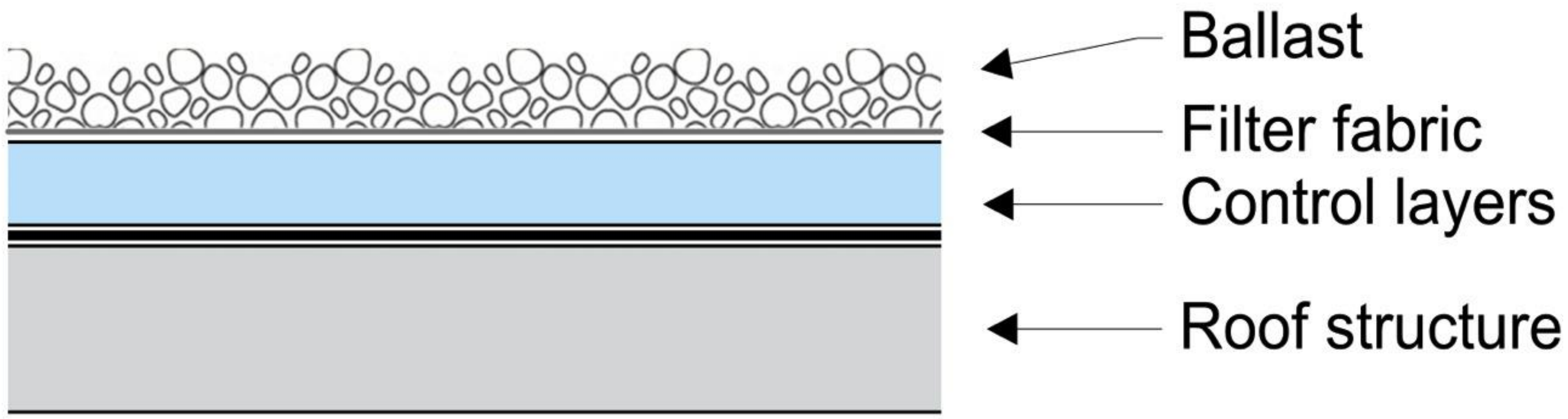
  → Separate layers,

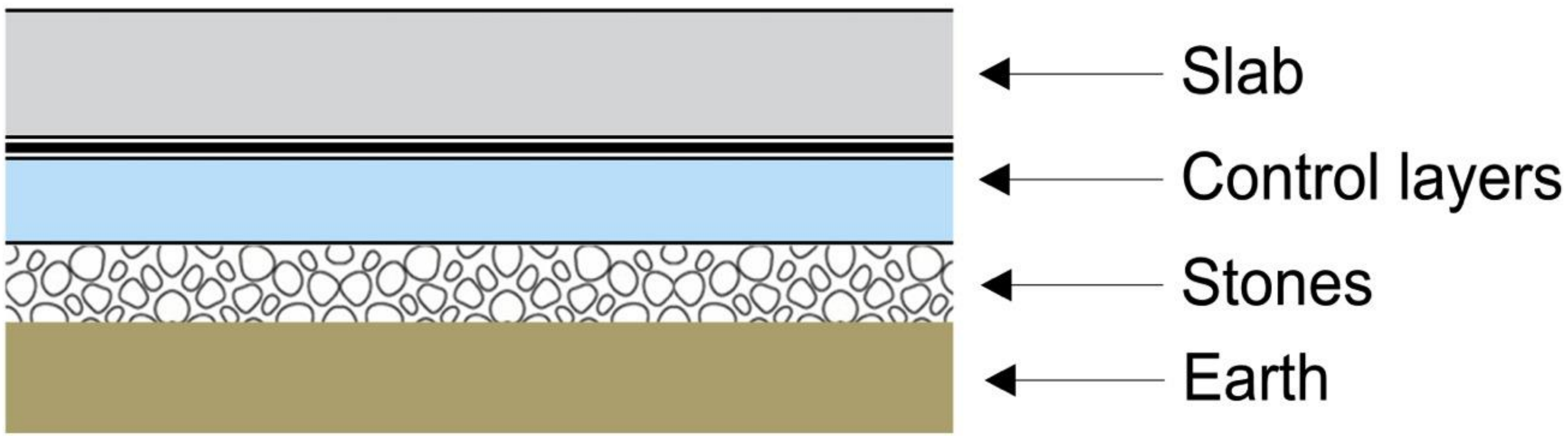
  . . . separate functions

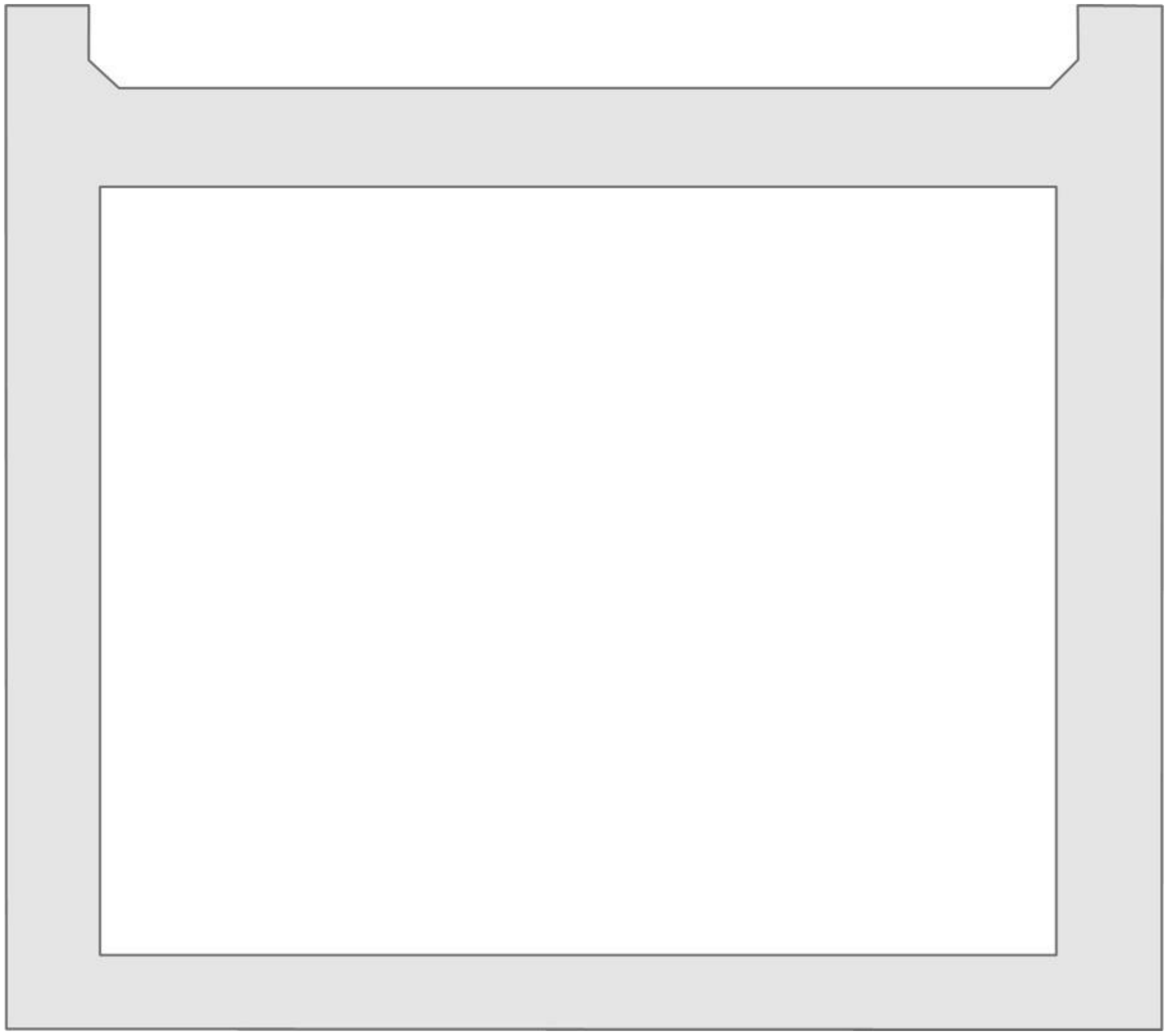
Ideal Enclosure / Perfect Wall



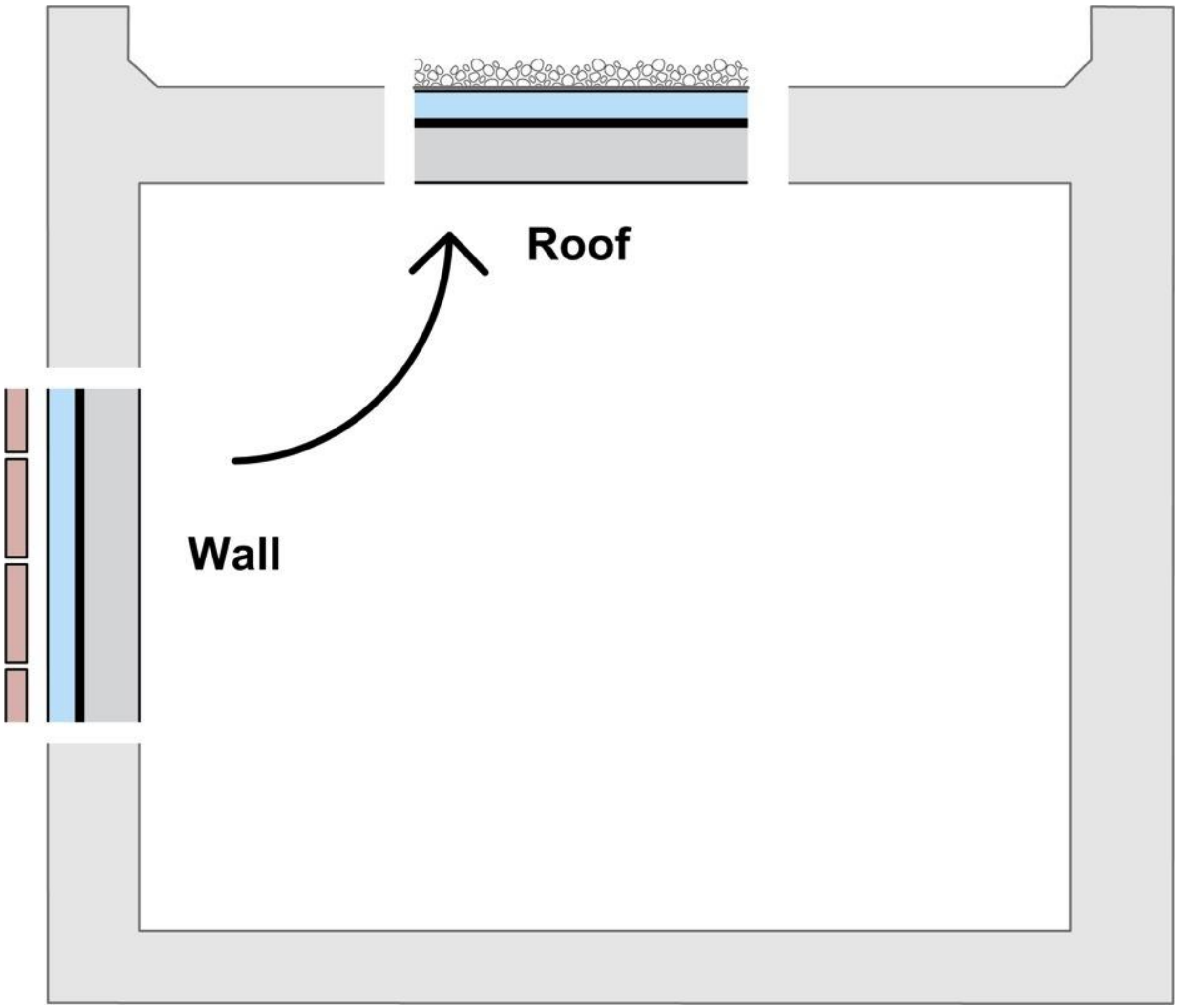

Wall
Slab
Roof

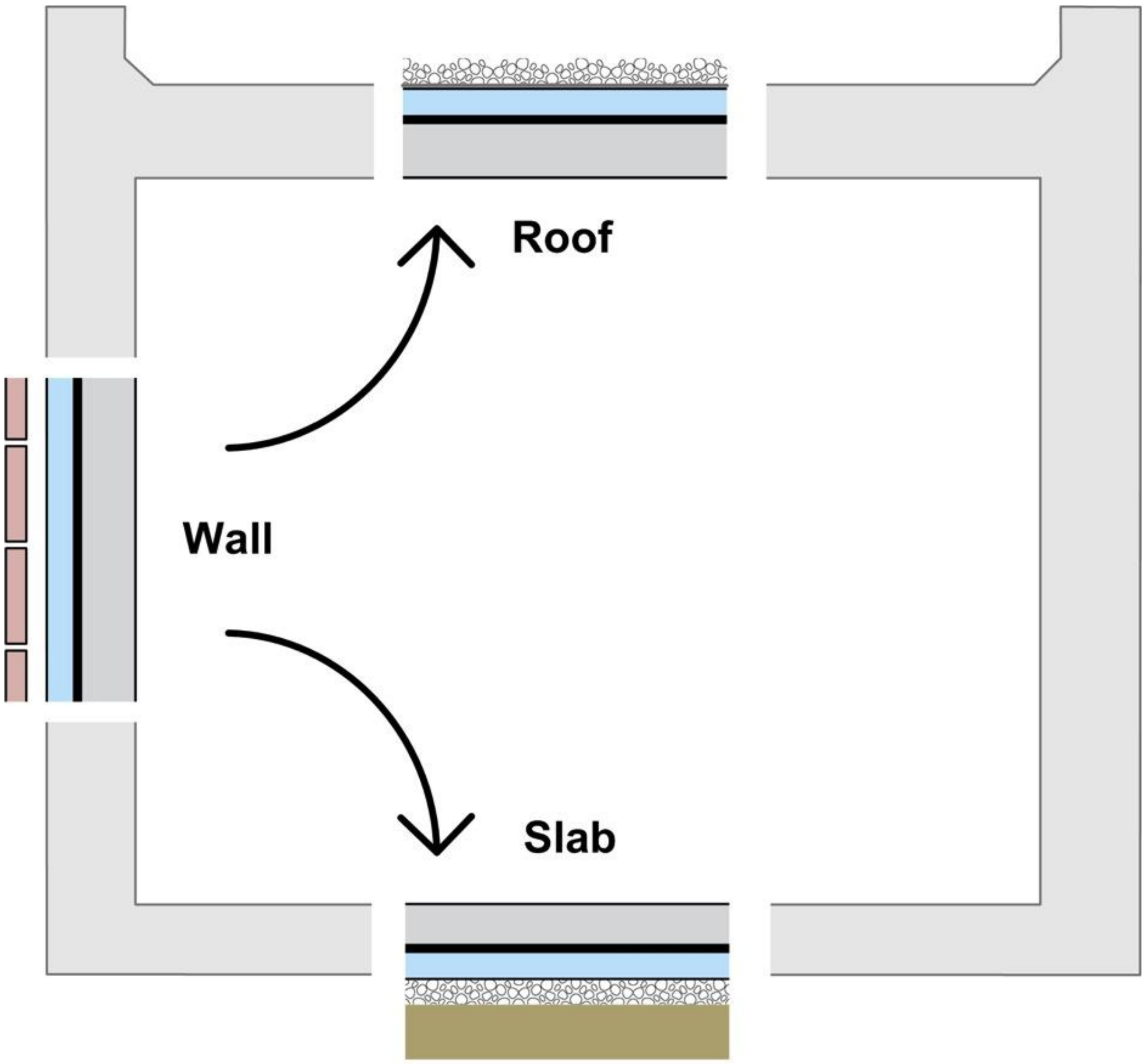

Ballast
Filter fabric
Control layers
Roof structure

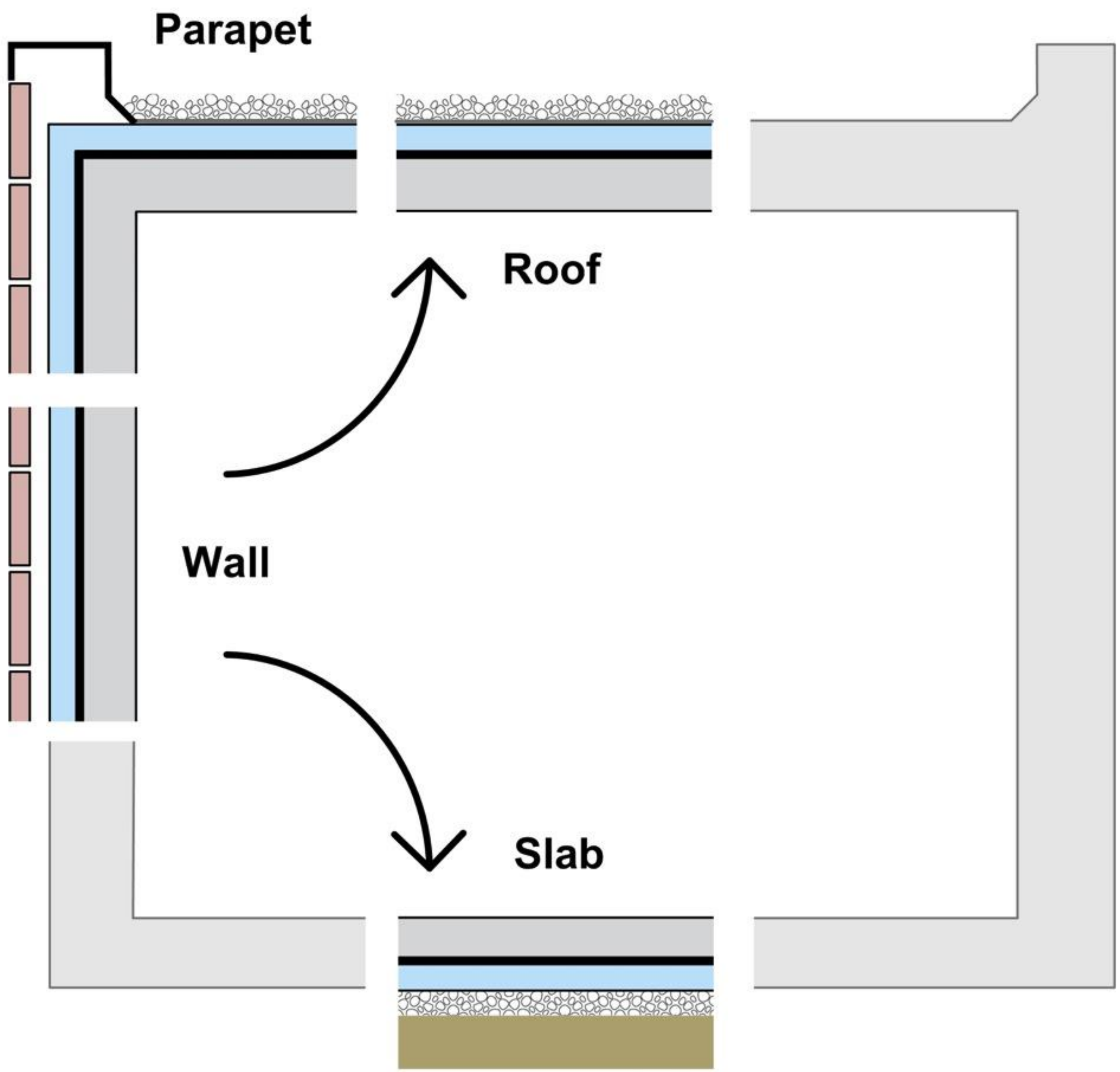

Slab
Control layers
Stones
Earth

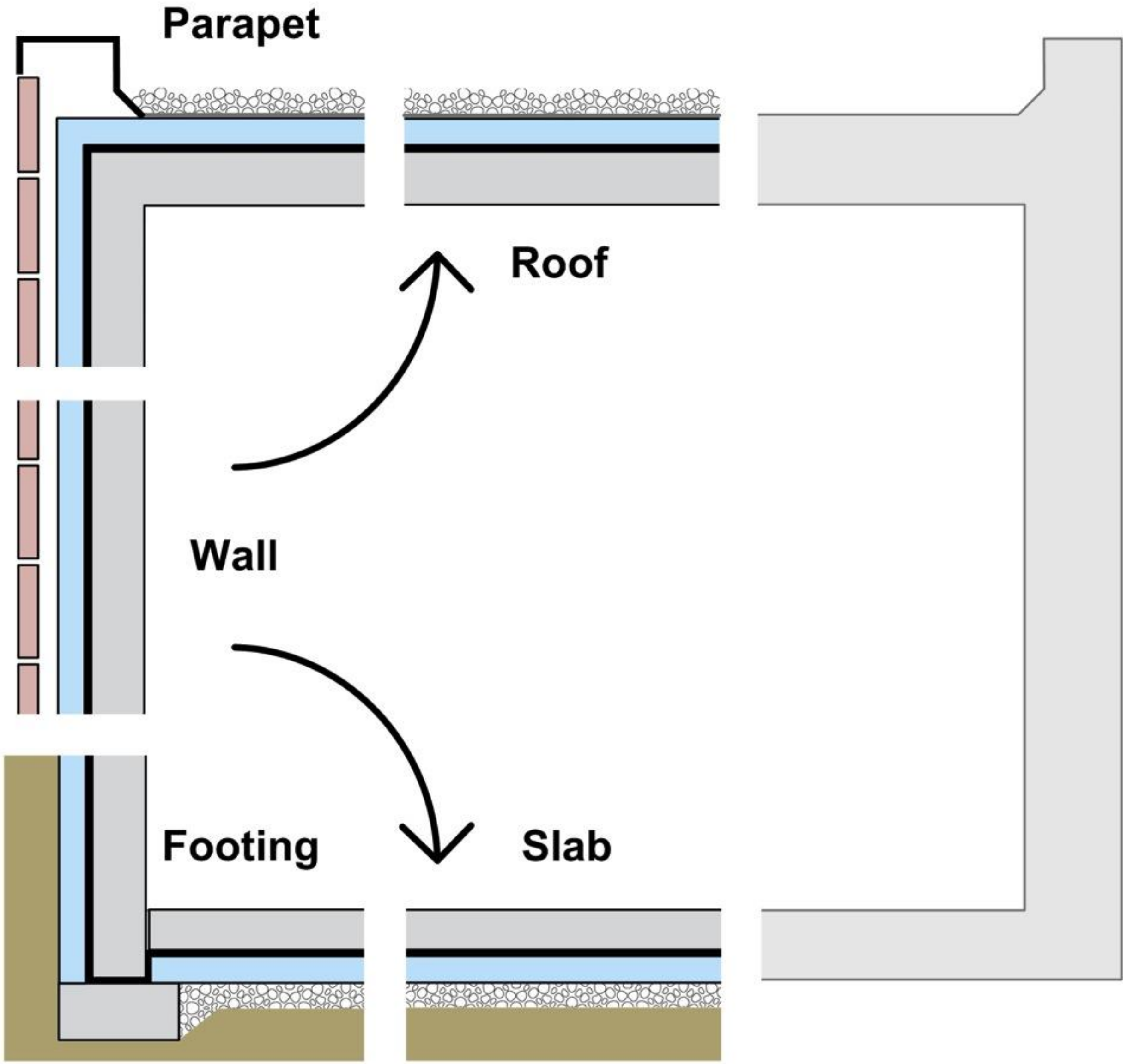


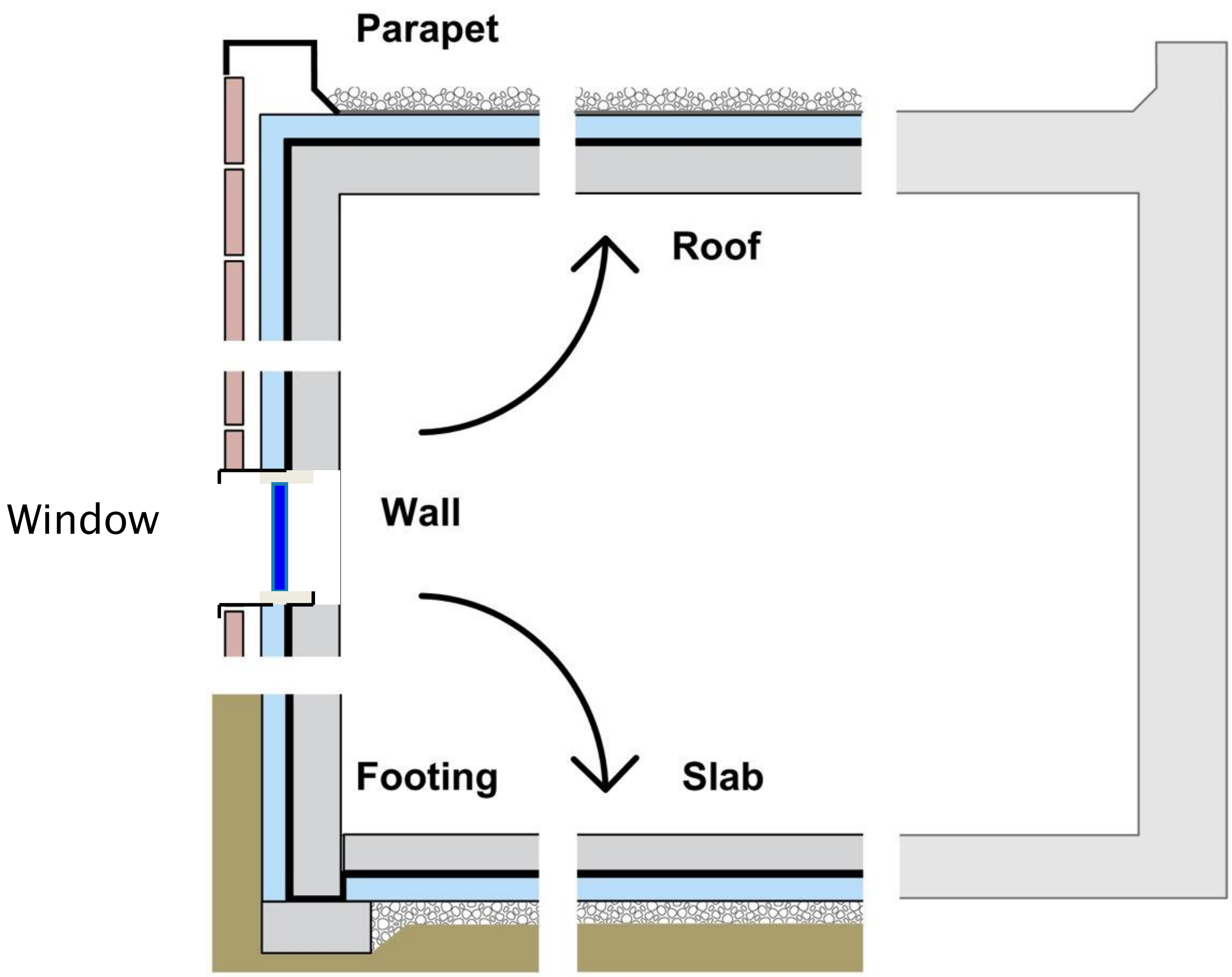

Wall


Roof
Wall


Roof
Wall
Slab


Parapet
Roof
Wall
Slab


Parapet
Roof
Wall
Footing
Slab


Parapet
Roof
Window
Wall
Footing
Slab

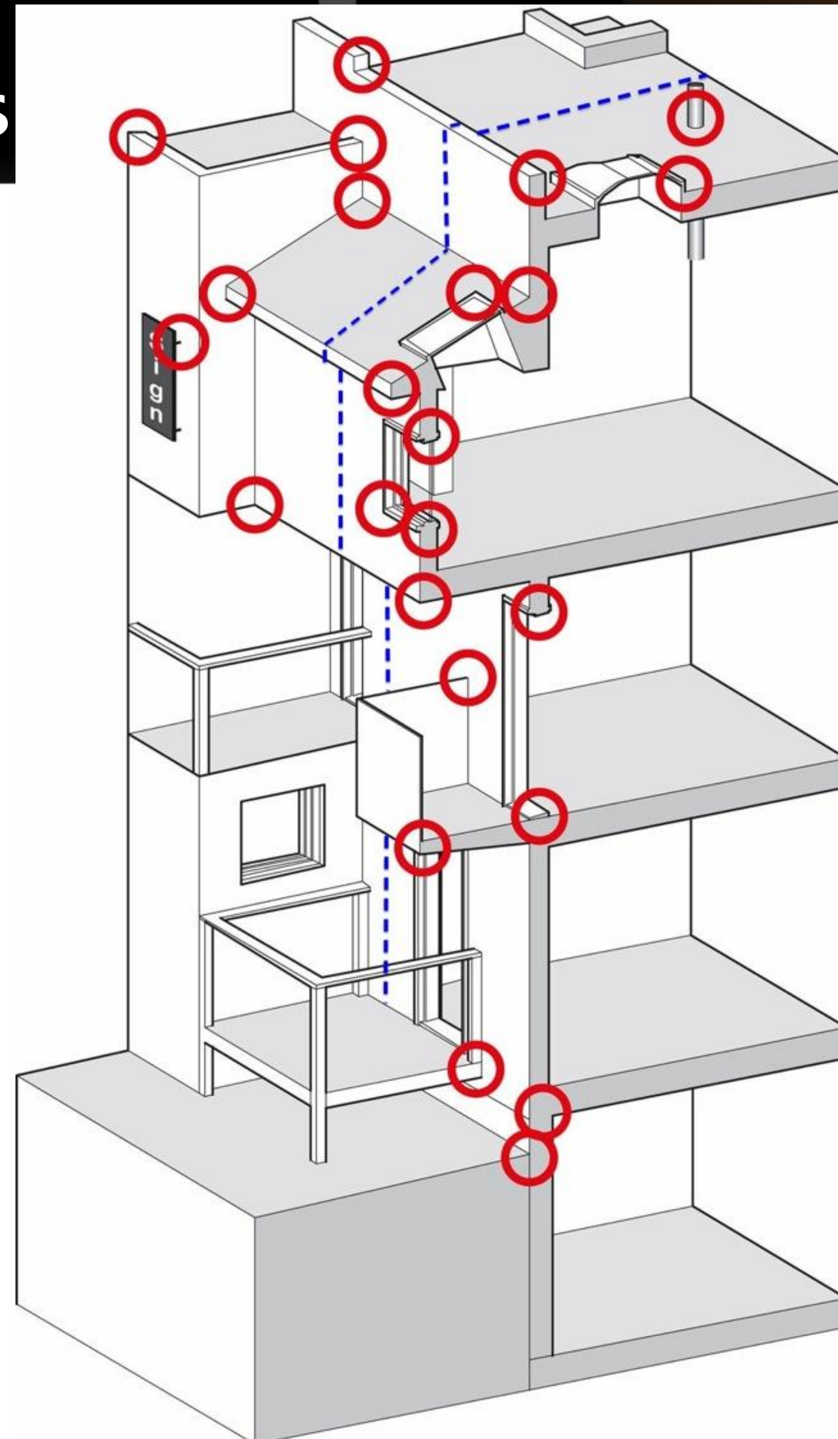
Complexity increases detailing effort, risk of failu
and reduces performance

Enclosure Design: Details

- Details demand the same approach as the enclosure.

- Scaled drawings required at ○

  - change in plane
  - change in material
  - change in trade



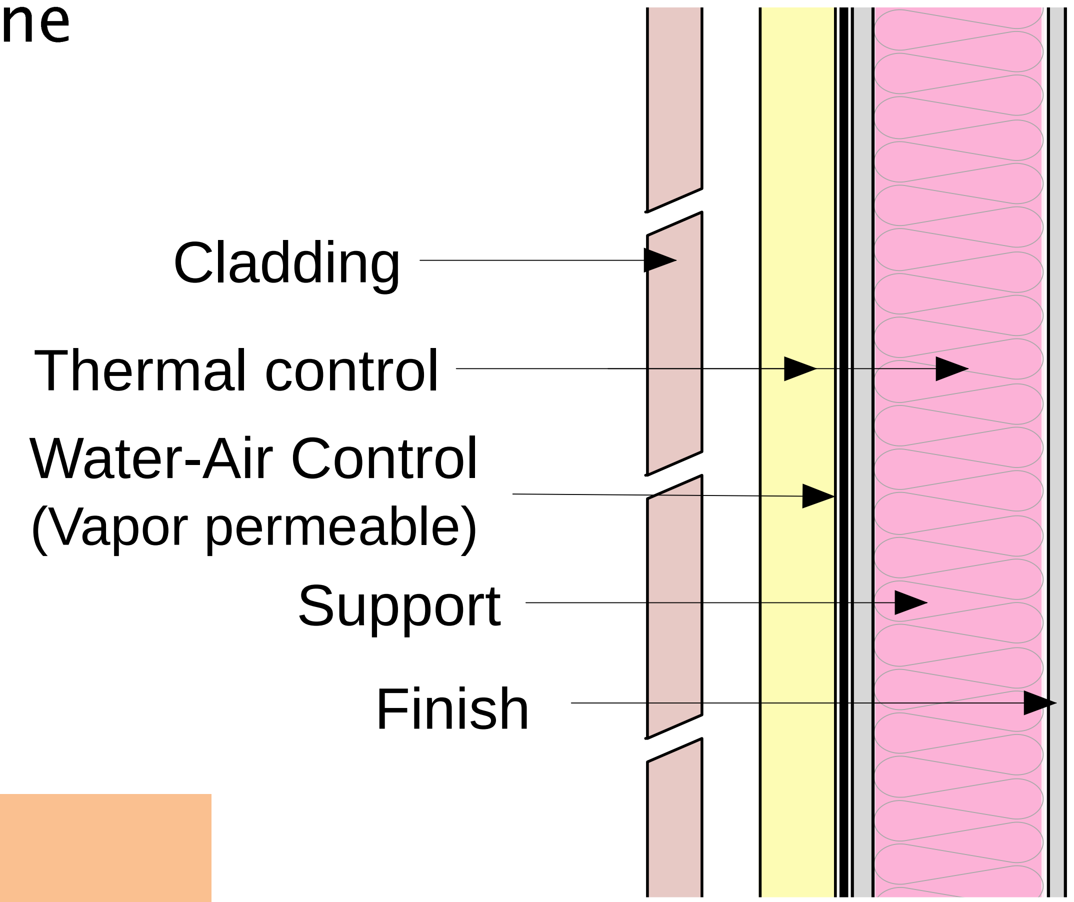
What is a high performance enclosure?

- → High levels of control (heat, air, rain)
- → **But**, poor continuity limits performance
- → **&** Poor continuity causes most problems too:
  - → E.g. air leakage condensation
  - → Rain leakage
  - → Surface condensation
  - → Cold windows
- → Thus: *continuity + high levels of control*


FIBREX

Insulation in stud cavity

- → Need vapor permeable air-water membrane
- → Wood studs usually have cavity insulation



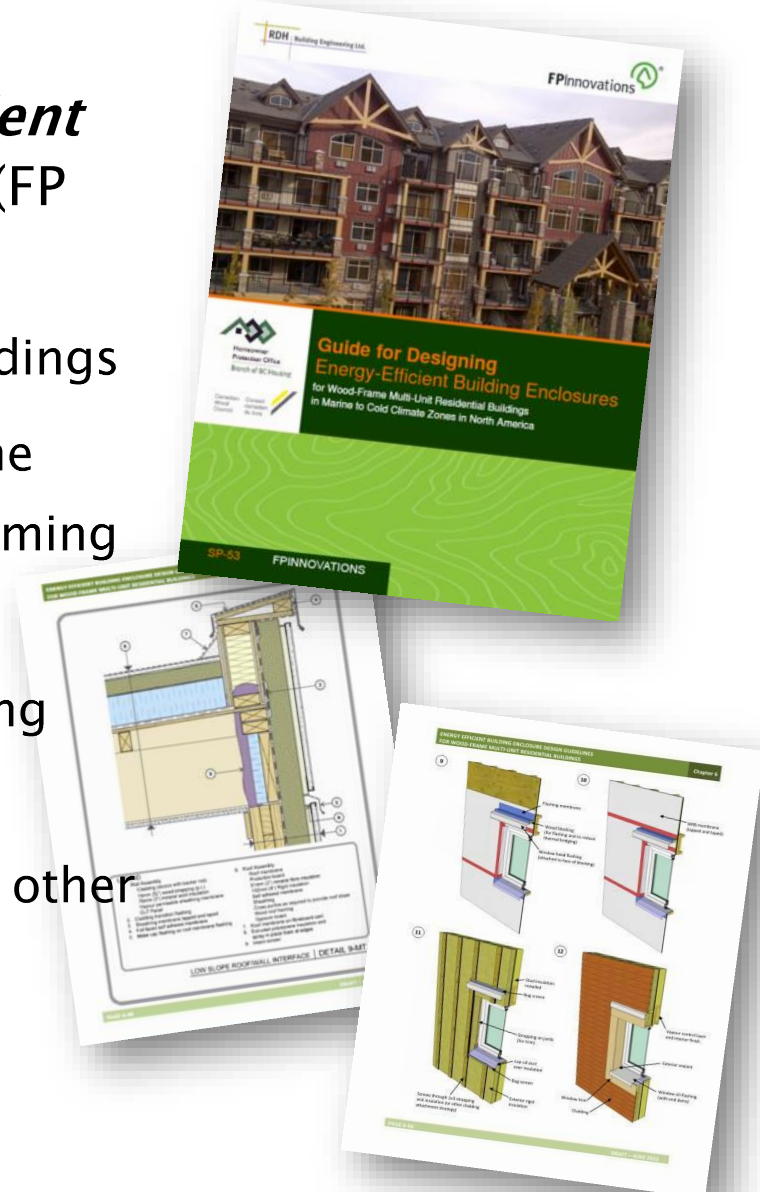
- Higher R-values
- Can use lower cost fiber insulation
- Reduces wall thickness

Exterior Insulation

→ Wood frame, split-insulated. With batt inside frames

Resource: Low-Energy Design Guide

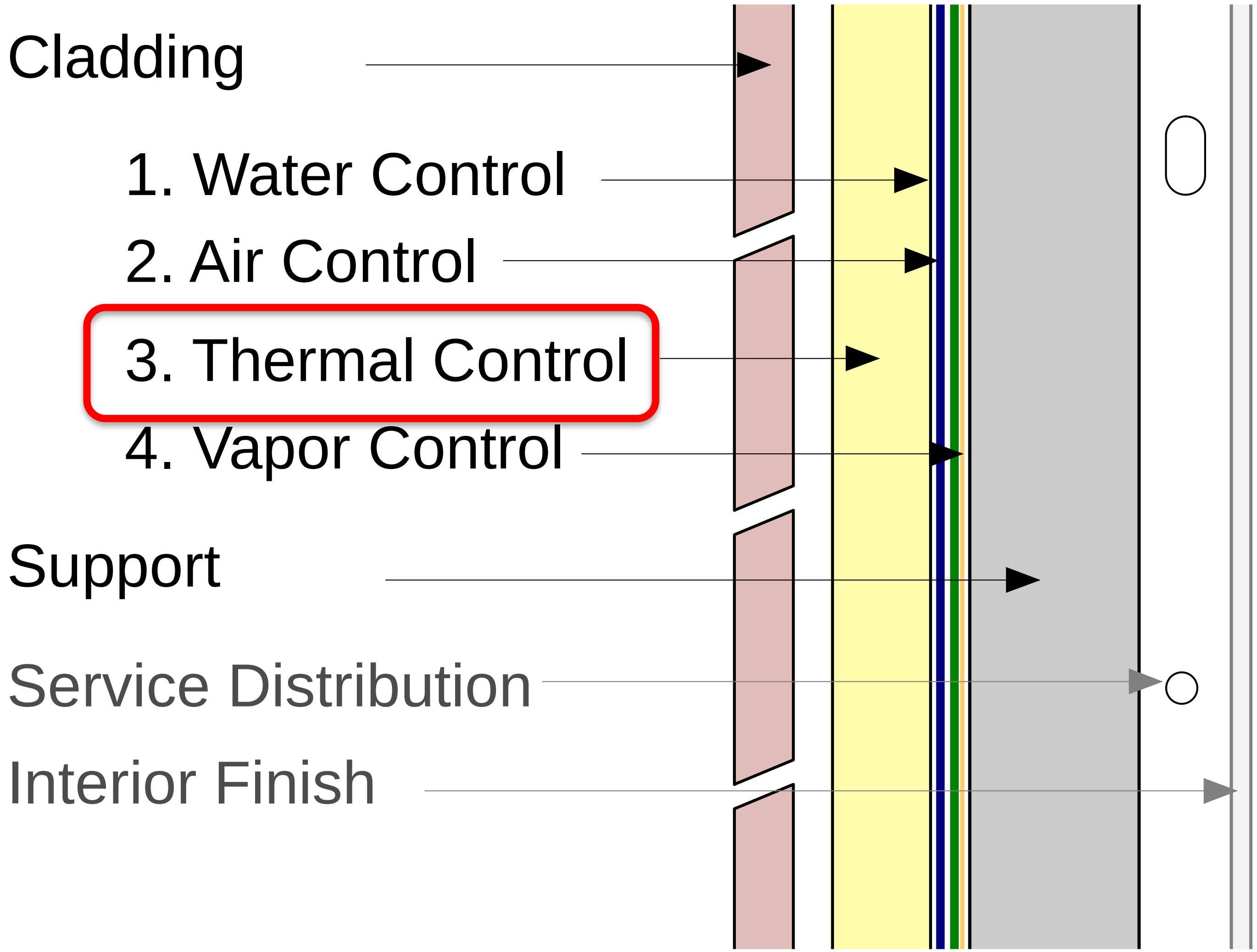
- ***Guide for Designing Energy-Efficient Wood-Frame Building Enclosures*** (FP Innovations, 2013)
  - For up to 6-storey **Wood-frame** Buildings
  - Focus on highly insulated wood-frame assemblies to meet current and upcoming energy codes
  - Strategies, assemblies & many building enclosure details provided
  - Sequential detailing for windows and other complicated details



Thermal Control

- Insulation
- Thermal bridging

The Ideal Enclosure / Perfect Wall



Thermal Control

- → Critical part of low-energy buildings in Canada
- → Significant quantities of insulation ….
  - → Key is to get it continuous – avoid metal and concrete thermal bridges!
  - → Airtight – don't bypass insulation with air!

- → Many choices for insulation products

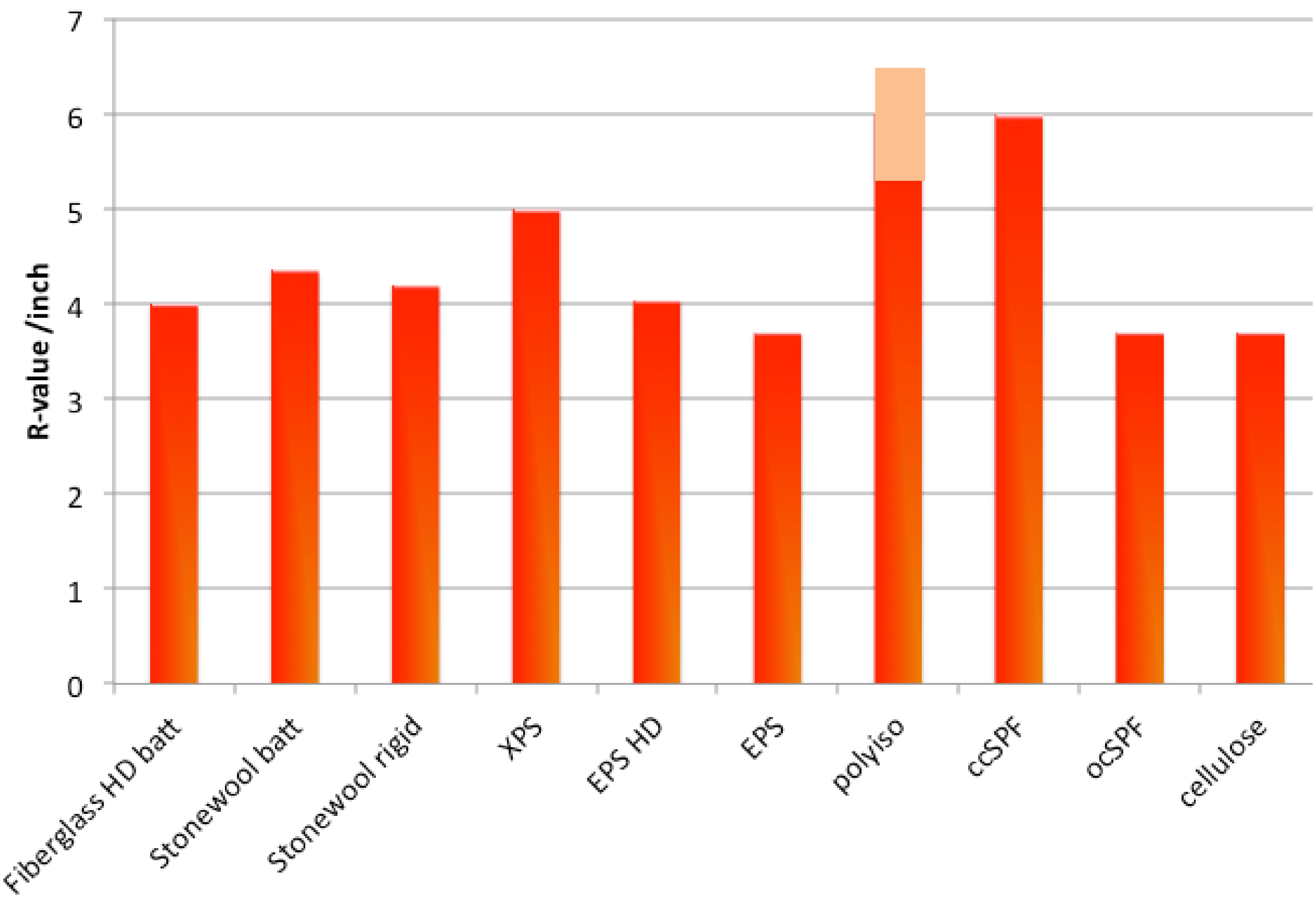
Choices: Insulation *Materials*

Materials	Examples	Moisture	Fire	Vapor Permeance	Air Permeance
Mineral fiber	Fiberglass, stone, slag	Tolerant	Non-combustible	high	high
Organic Fiber	Cellulose, cotton, wool, straw	Sensitive	Combustible	high	high
Plastic foam	Polystyrene, polyurethane, polyisocyanurate	Tolerant	Combustible	Low-medium	low
Mineral foam	Foamglass, pumice, airkrete, aerogel	Tolerant	Non-combustible	low	low

Choices: *Form* of Insulation

Form	Installation	Limits to use
Loose	poured or blown	may settle, easily compressed
Batt	friction fit	held in place by friction, easily compressed
Roll	friction fit / mechanically attached	as for batts
Board	mechanically, adhesively attached	resistant to mechanical pressure
Spray	spray in place	sticks to adjoining surfaces, resilient

Insulations: R/inch compared



Making Choices

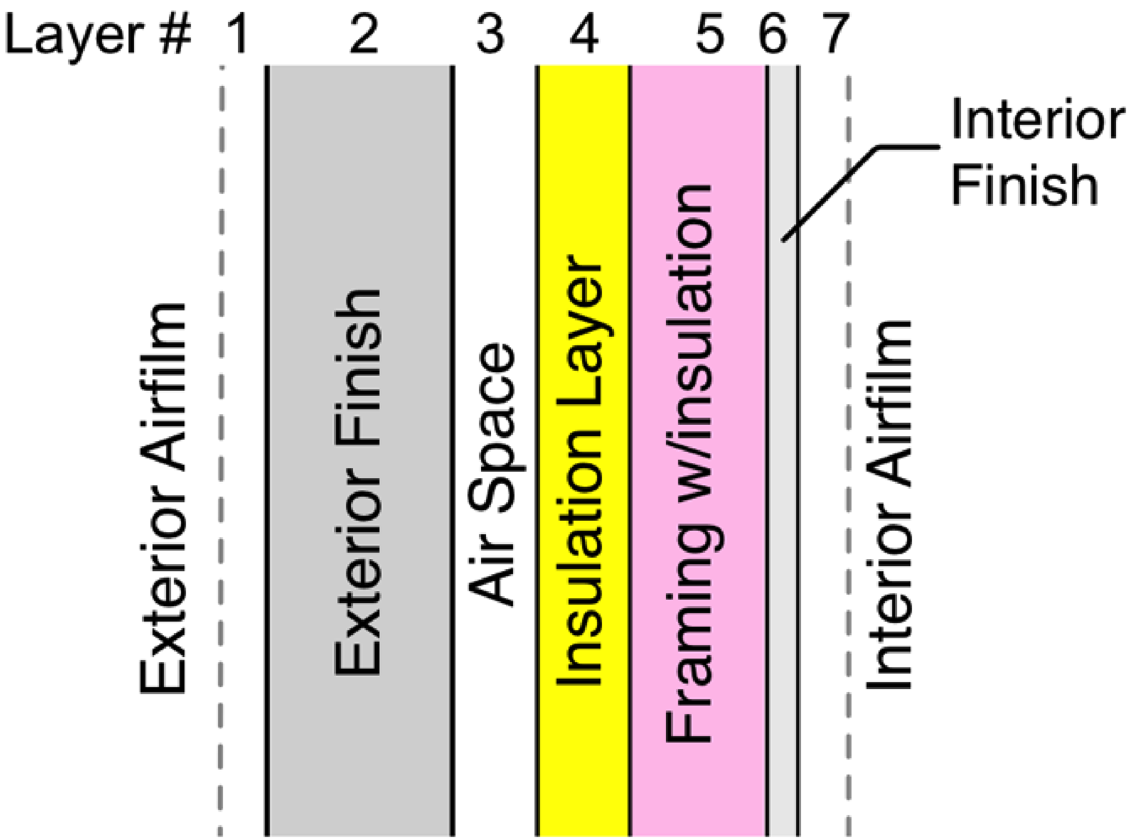
- Factors *other than R-value* are usually most important
  - Fire resistance
  - Moisture tolerance
  - Physical strength
  - Vapor permeance
  - Air permeance
- Most insulation products are very inexpensive relative to other building products

Thermal Bridging

- Manage to get effective R-value
- Increasing code restrictions

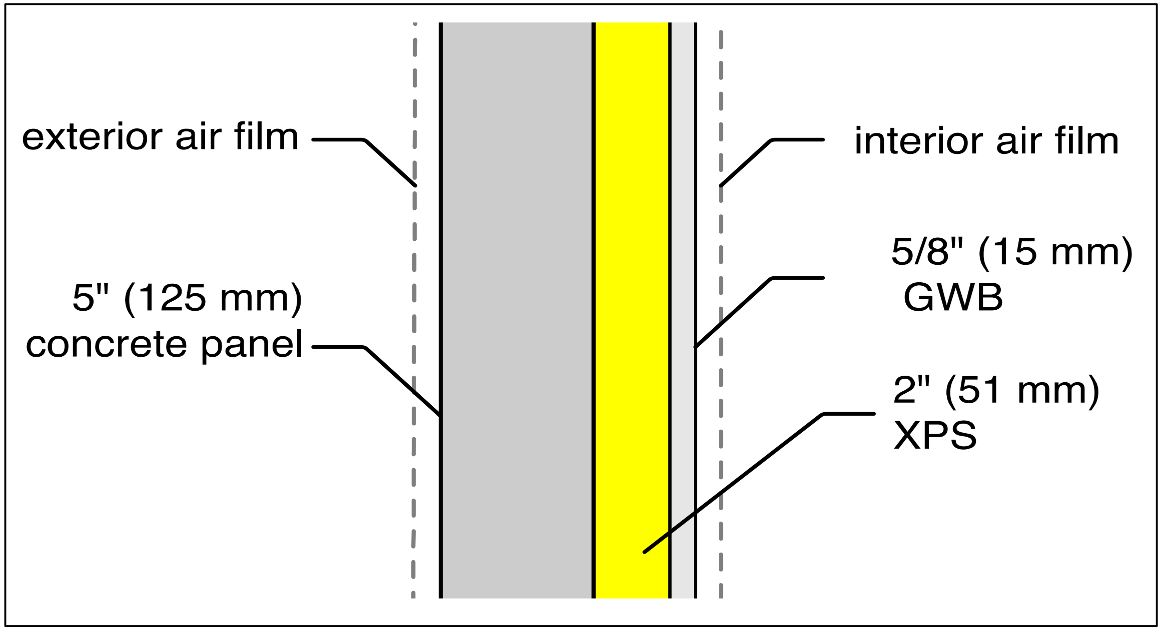
Calculating R-value: the good old days

→ Just add the layer *R-values*.



$$R_{total} = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7$$

Example Assembly R-value



Layer	R-value
Exterior air film	0.16
5” (125 mm) concrete	0.30
2” (51 mm) XPS insulation	10.0
5/8” (15 mm) GWB	0.10
Interior air film	0.68
Total	**11.2**

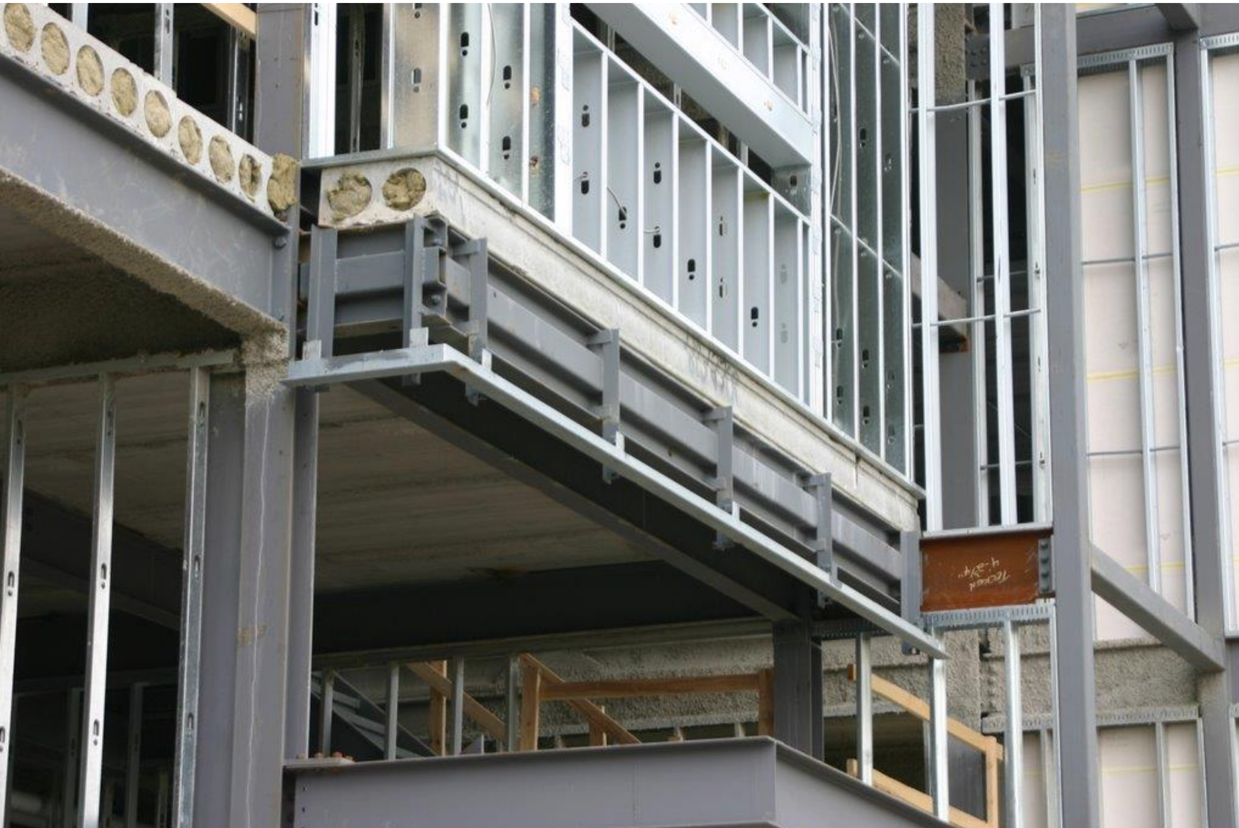
Values from tables

e.g. 2” x R-5/inch

$U = 1/R_{total}$

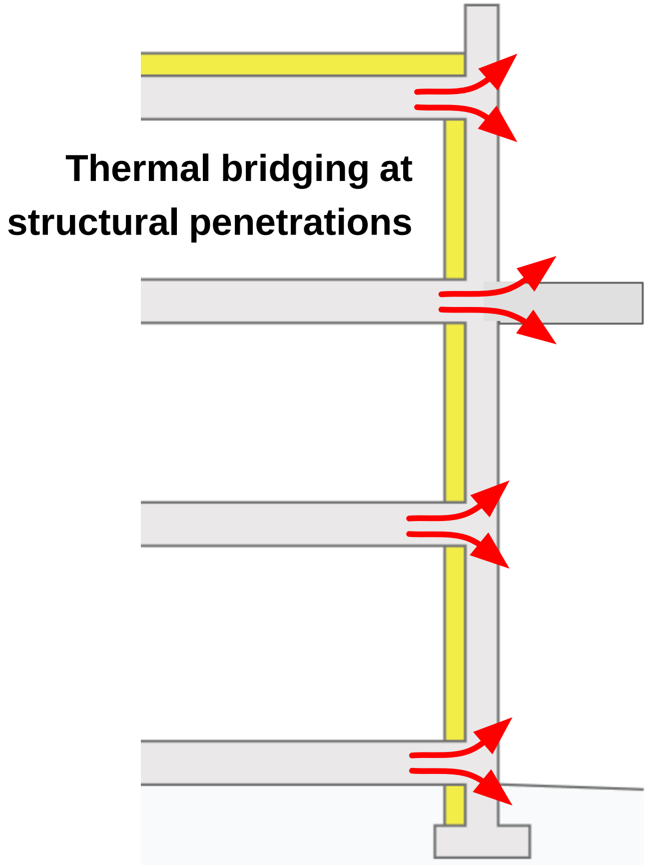
$U = 1/11.2 = 0.089$

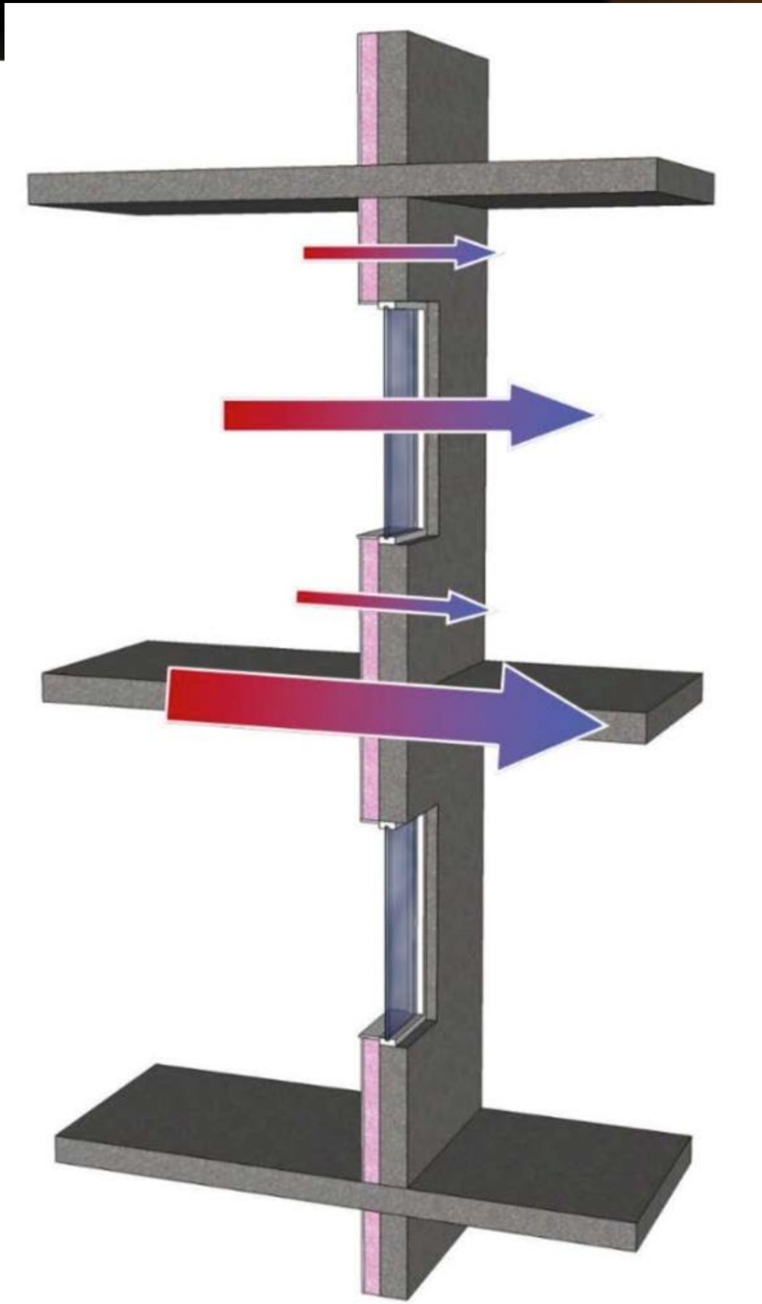
Real walls are often not simple layers



Thermal Bridging

- A local area of the enclosure that has higher heat loss
-

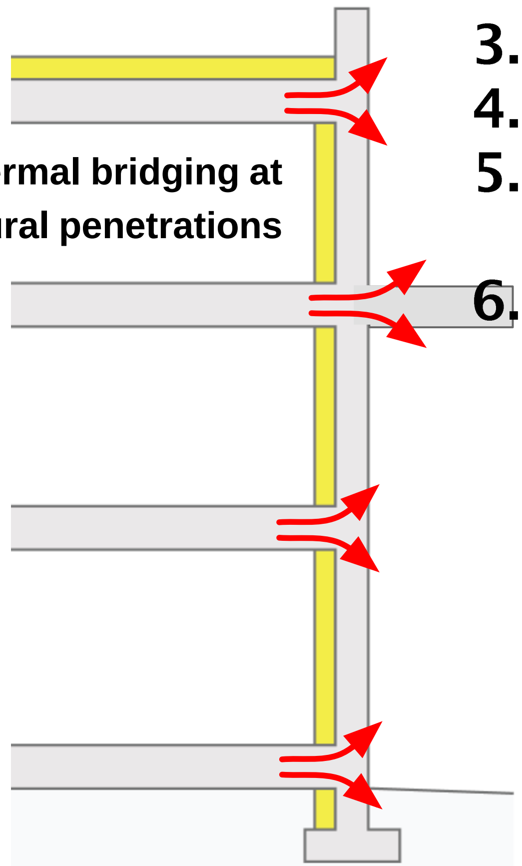




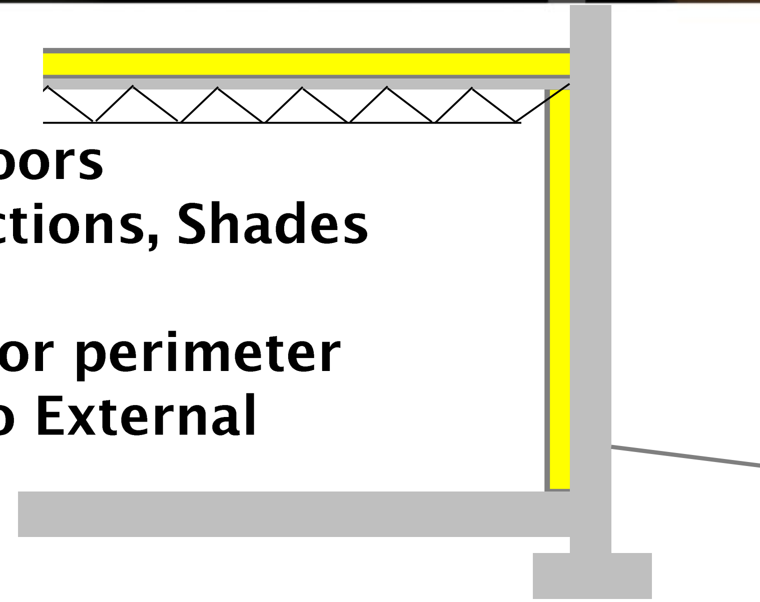
Interior Insulation

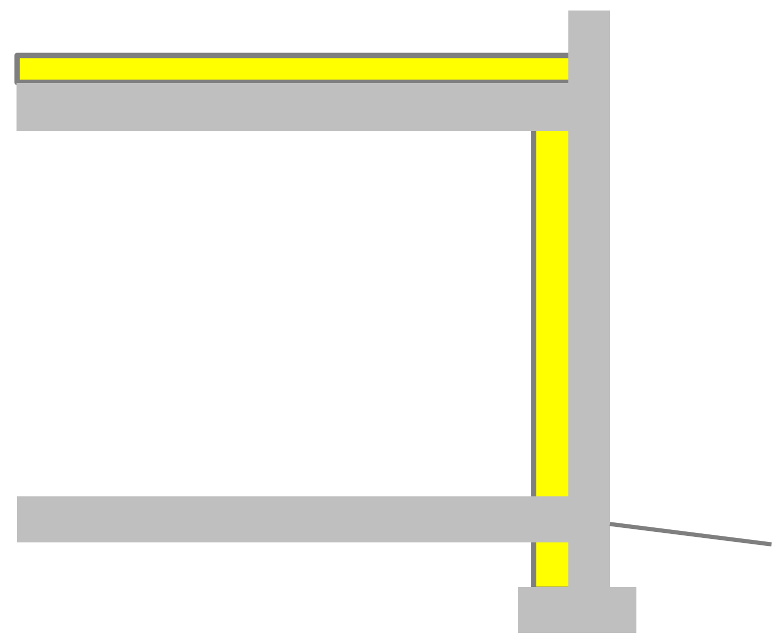
Hard / impossible to get continuous

1. Intermediate Floors
2. Baconies, Projections, Shades
3. Parapets
4. Window and Door perimeter
5. Internal Walls to External Walls
6. At Grade



Thermal bridging at structural penetrations

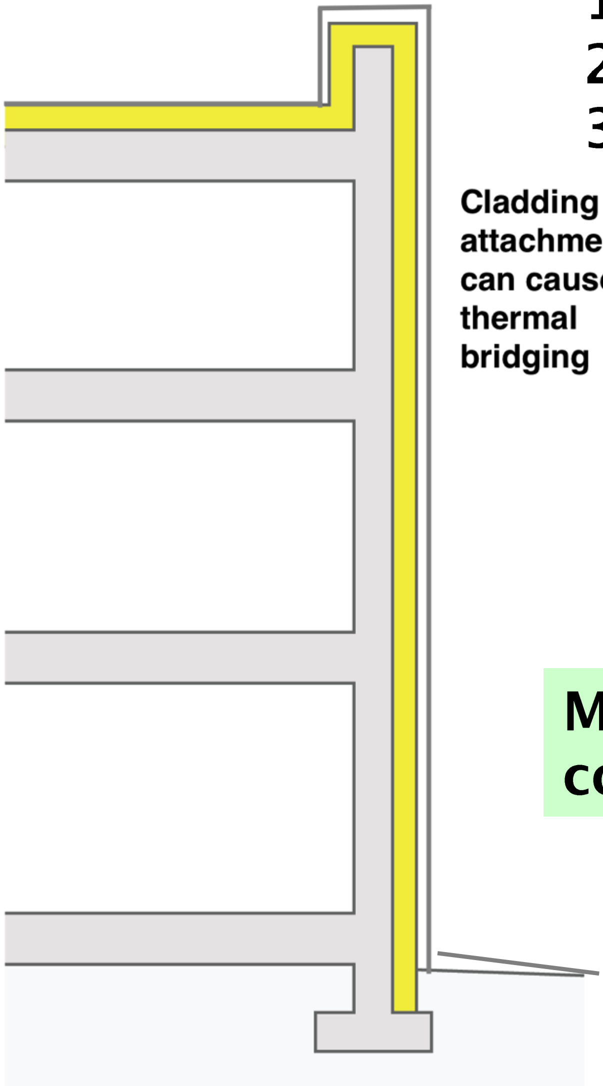




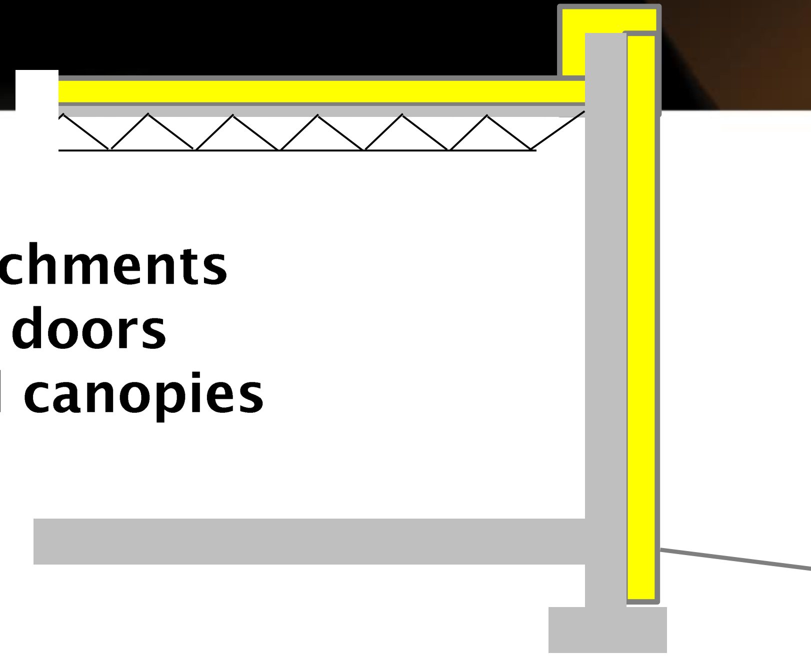
Floors, roofs, slabs cause penetrations

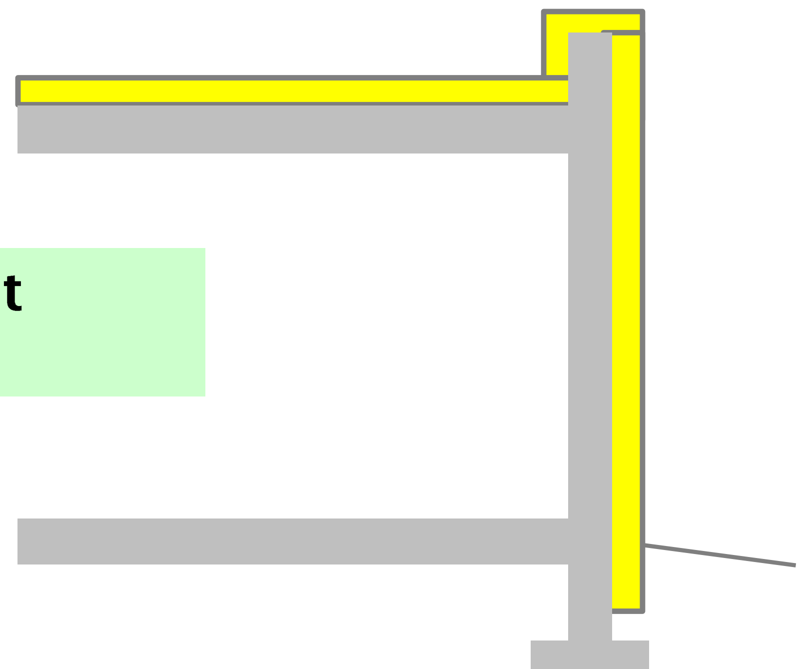
Exterior Insulation

1. Cladding attachments
2. Windows and doors
3. Balconies and canopies



Cladding attachment can cause thermal bridging

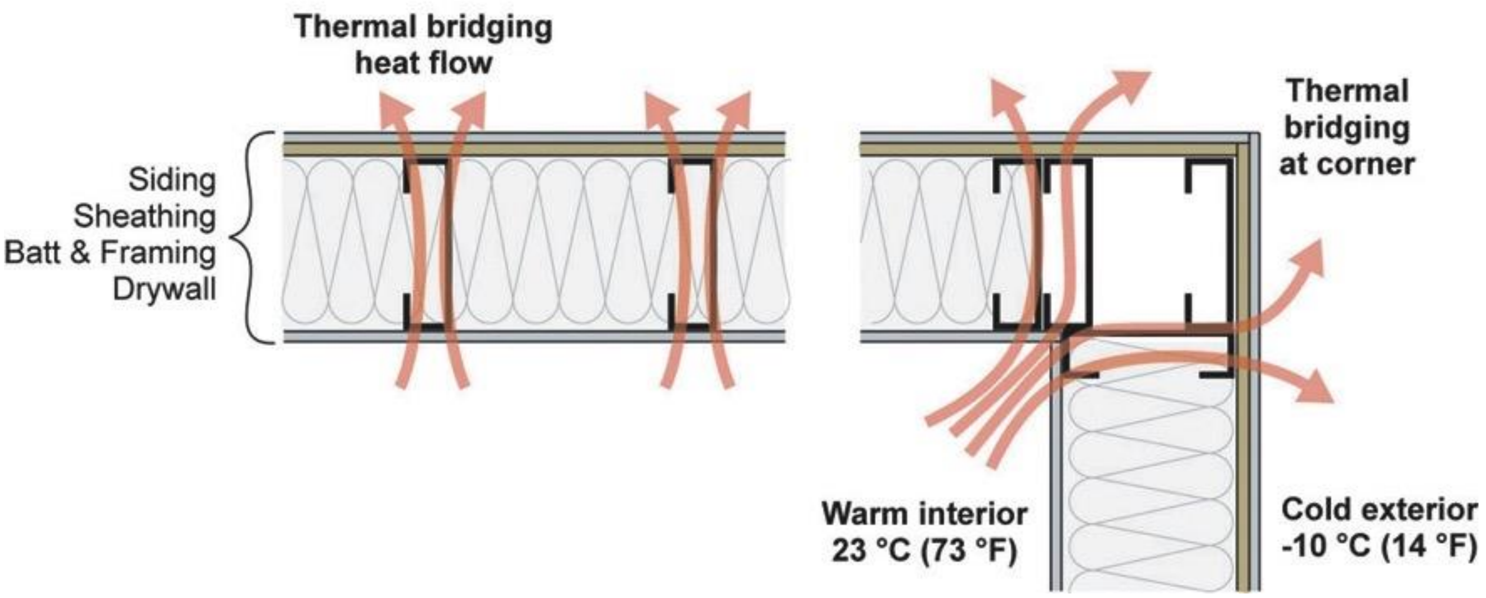




Much easier to get continuous

Thermal bridging of framing

- → Codes NECB / ASHRAE 90.1... requires thermal bridging of framing studs be accounted for
- → Typically, ⅔ to ¾ of batt insulation R-value is lost by placing between *steel* studs



Find the thermal bridge

Accounting for framing

- → We can convert 3-D frames into **a layer**
- → Note the poor performance of steel stud framing with batt insulation

Cavity Depth		Rated Cavity R-value	Layer R_{cw}-value @ 16 inch centres	Layer RSI_{cw} @ 405 mm centres	
In	mm				
2.5	64	Empty	0.75	0.13	$
3.5	89	Empty	0.79	0.14	$
		R-13	6.0	1.06	$$
		R-15	6.4	1.13	$$$
6.0	152	Empty	0.84	0.15	$
		R-19	7.1	1.25	$$
		R-21	7.4	1.31	$$$
		R-24 (4" ccSPF)	7.6	1.34	$$$$$

This assumes 16" o.c. studs… in reality, many more studs used and R-value drops

Note: "ccSPF" is closed cell Sprayed Polyurethane Foam insulation

Then add GWB, sheathing, cladding and airfilms

Exterior insulation ci R-value can be added to other layers R-values

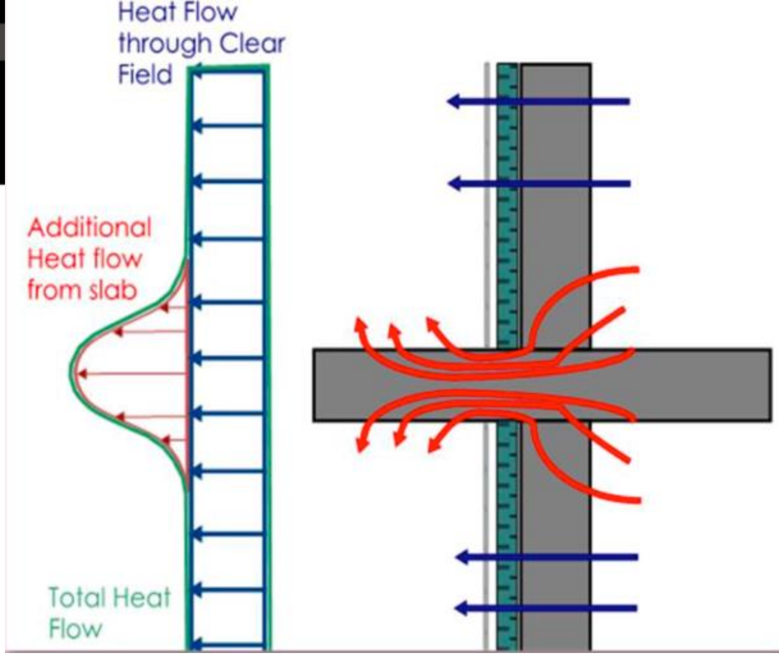
Continuous Insulation (ci)

- → Example:
  - → steel-studs with R-19 batt have a value of about R-7.1 (see table)
  - → Addition of 2” of stonewool means R-value = 7.1* 2X R-4/inch = R-15.1
  - → Addition of 2.5 of XPS provides R-value = 7.1* 2.5 X R-5/inch = R-19.6

- → But, cladding attachment, balconies, etc have an impact

Calculating Thermal Bridging

→ Chi-factor



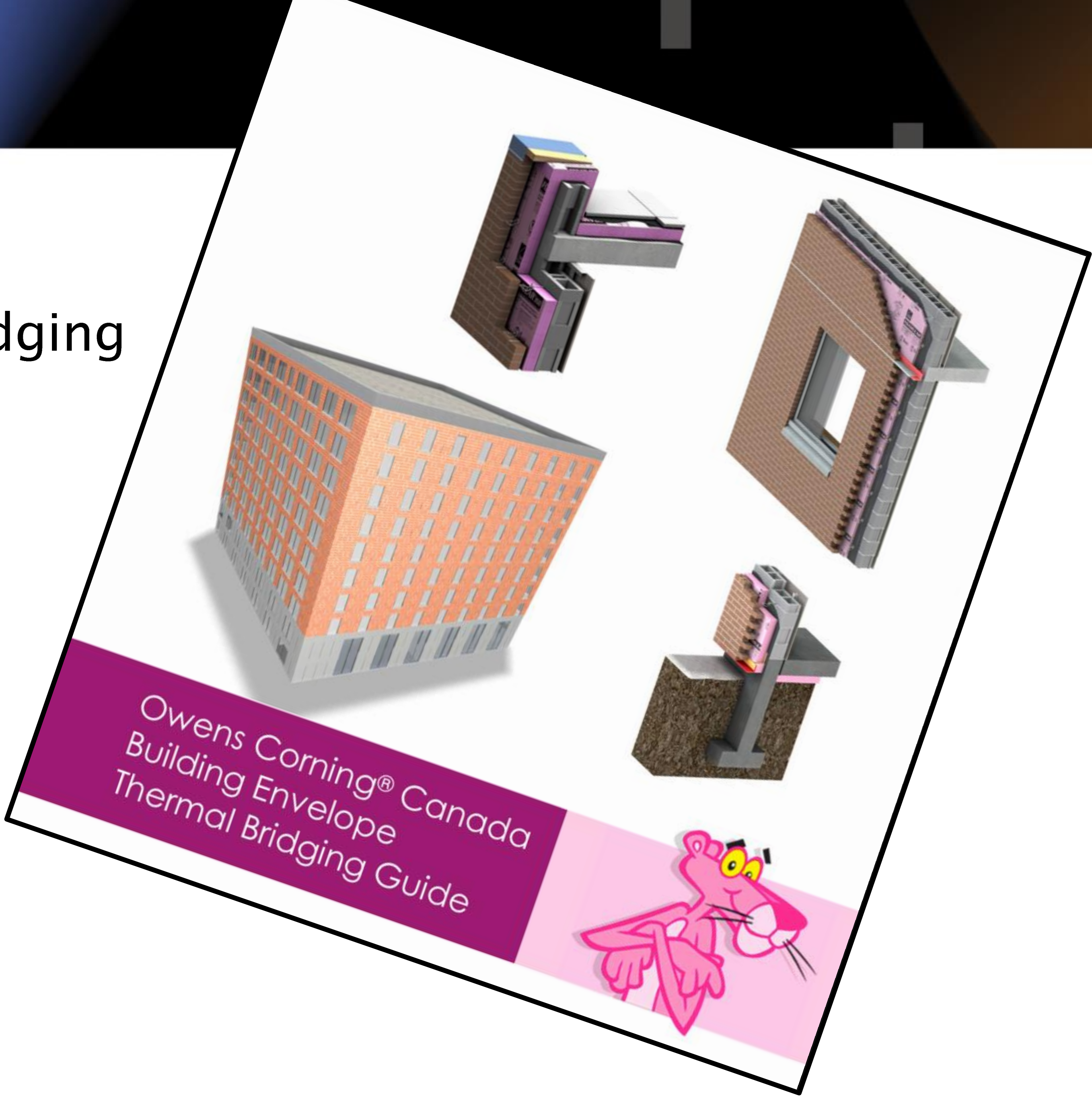
→ ISO 14683:2017. *Thermal bridges in building construction -- Linear thermal transmittance -- Simplified methods and default values*. International Organization for Standardization, Geneva, 2017.

Heat flow with floor and balcony intersection

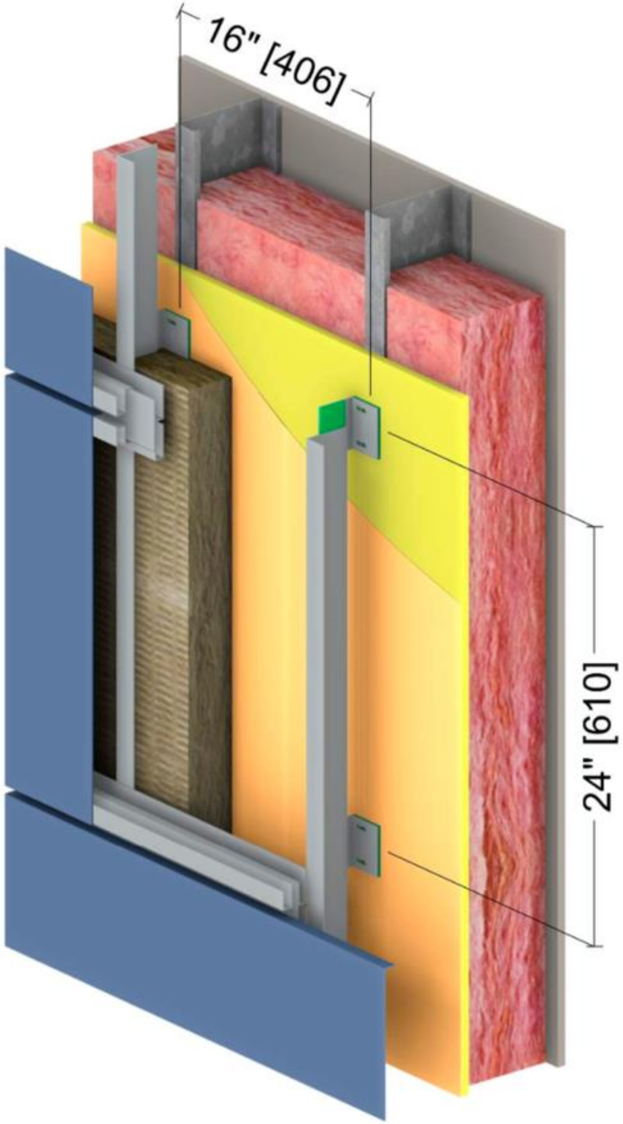
Clear Field heat flow

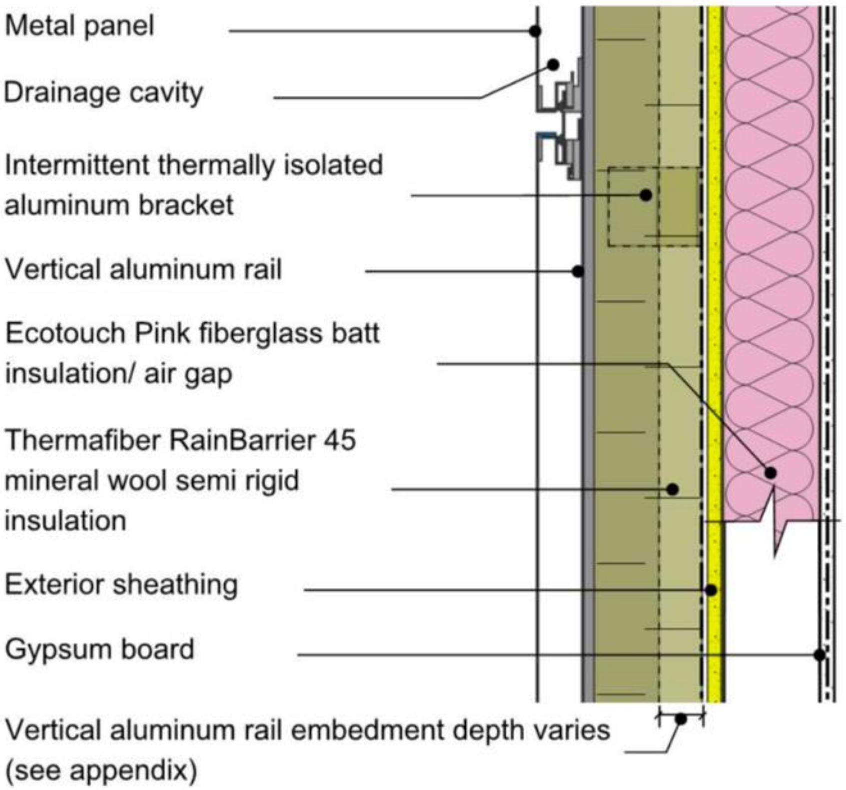
Additional heat flow due to thermal bridging at floor and balcony intersection

→ Resources: thermal bridging guides



Example


16" [406]
24" [610]


Metal panel
Drainage cavity
Intermittent thermally isolated aluminum bracket
Vertical aluminum rail
Ecotouch Pink fiberglass batt insulation/ air gap
Thermafiber RainBarrier 45 mineral wool semi rigid insulation
Exterior sheathing
Gypsum board
Vertical aluminum rail embedment depth varies (see appendix)

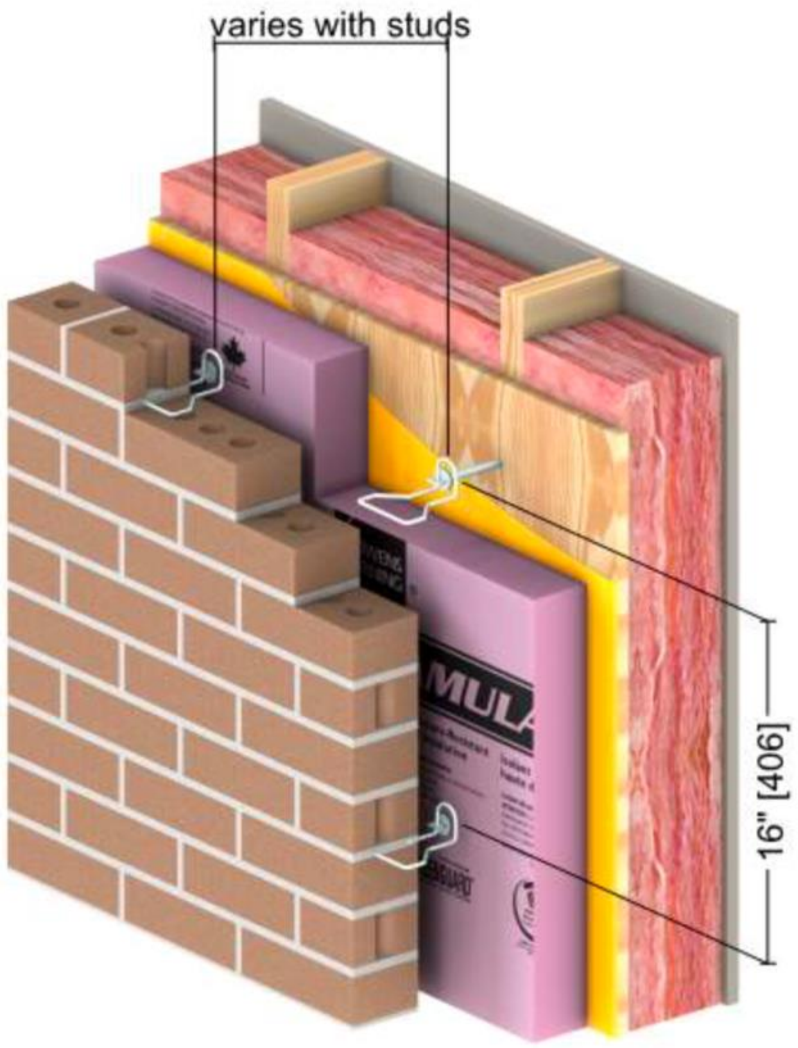
Performance including clips

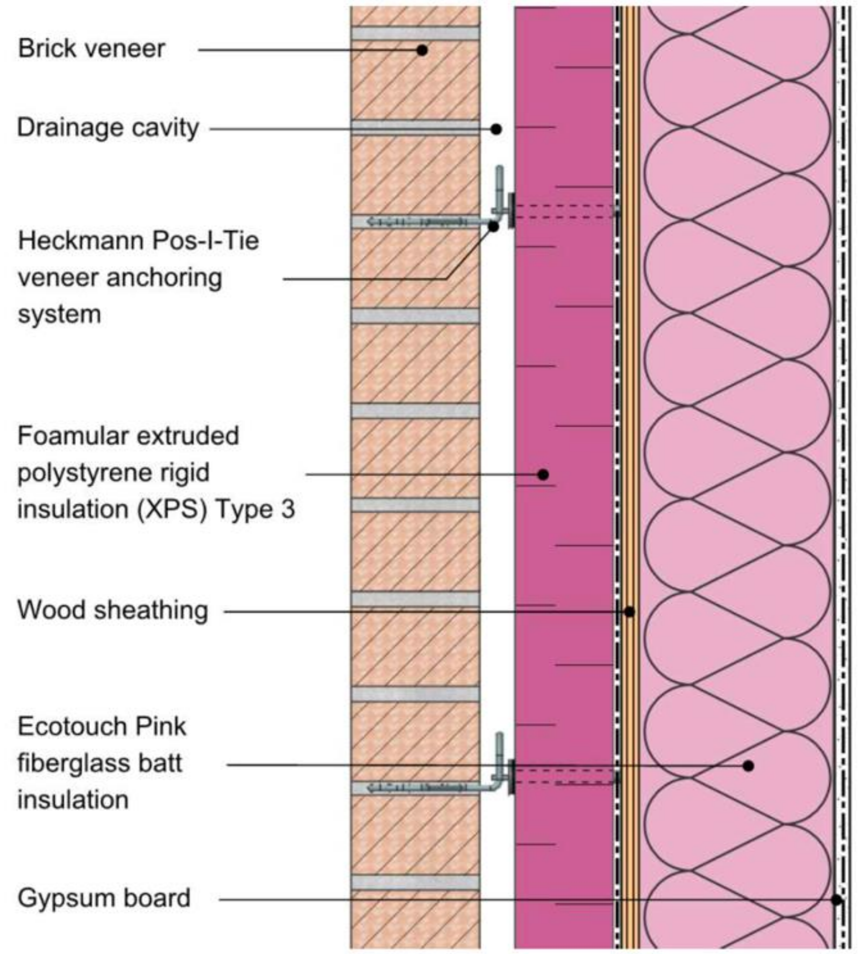
→

Buy R-5
get R1.2

Scenario	Exterior Insulation Thickness Inches (mm)	Exterior Insulation Nominal R-value hr·ft²·°F/Btu (m²K/W)	Assembly		Highest Applicable Climate Zone per NECB 2015[1]
			R-value hr·ft²·°F/Btu (m²K/W)	U-value Btu/hr·ft²·°F (W/m²K)	
Air in Stud Cavity	2" (50.8) 5" (127)	R-8.6 (1.51) R-21.5 (3.79)	R-10.2 (1.80) R-18.0 (3.16)	0.098 (0.557) 0.056 (0.316)	None None
R-19 (3.35 RSI) Batt Insulation in Stud Cavity	1.5" (38.1) 2" (50.8) 3" (76.2) 4" (101.6) 5" (127)	R-6.5 (1.14) R-8.6 (1.51) R-12.9 (2.27) R-17.2 (3.03) R-21.5 (3.79)	R-17.1 (3.01) R-18.2 (3.20) R-20.5 (3.60) R-23.2 (4.09) R-25.8 (4.54)	0.059 (0.333) 0.055 (0.313) 0.049 (0.278) 0.043 (0.245) 0.039 (0.220)	None 4 5 6 6
R-20 (3.52 RSI) Batt Insulation in Stud Cavity	1.5" (38.1) 2" (50.8) 3" (76.2) 4" (101.6) 5" (127.0)	R-6.5 (1.14) R-8.6 (1.51) R-12.9 (2.27) R-17.2 (3.03) R-21.5 (3.79)	R-17.3 (3.05) R-18.4 (3.25) R-20.7 (3.65) R-23.5 (4.13) R-26.0 (4.59)	0.058 (0.327) 0.054 (0.308) 0.048 (0.274) 0.043 (0.242) 0.038 (0.218)	None 4 5 6 6
R-22 (3.87 RSI) Batt Insulation in Stud Cavity	1.5" (38.1) 2" (50.8) 3" (76.2) 4" (101.6) 5" (127.0)	R-6.5 (1.14) R-8.6 (1.51) R-12.9 (2.27) R-17.2 (3.03) R-21.5 (3.79)	R-17.9 (3.15) R-18.9 (3.34) R-21.2 (3.73) R-24.0 (4.23) R-26.6 (4.68)	0.056 (0.318) 0.053 (0.300) 0.047 (0.268) 0.042 (0.237) 0.038 (0.214)	None 4 5 6 6
R-24 (4.23 RSI) Batt Insulation in Stud Cavity	1.5" (38.1) 2" (50.8) 3" (76.2) 4" (101.6) 5" (127)	R-6.5 (1.14) R-8.6 (1.51) R-12.9 (2.27) R-17.2 (3.03) R-21.5 (3.79)	R-18.4 (3.23) R-19.4 (3.42) R-21.7 (3.81) R-24.4 (4.30) R-27.0 (4.76)	0.054 (0.309) 0.051 (0.292) 0.046 (0.262) 0.041 (0.233) 0.037 (0.210)	4 4 5 6 7

Wood studs.. Better performance



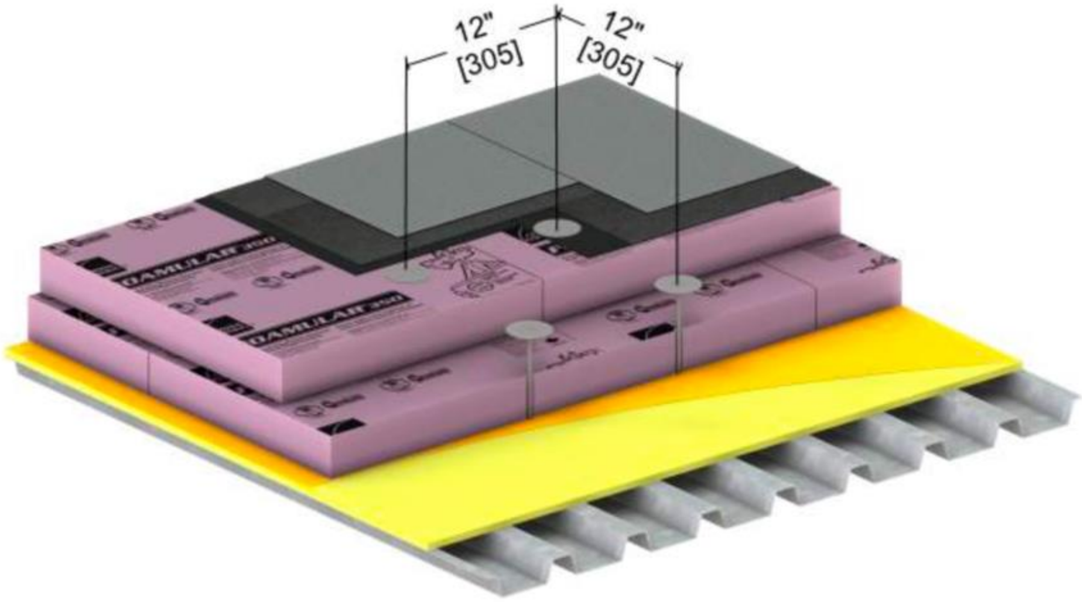


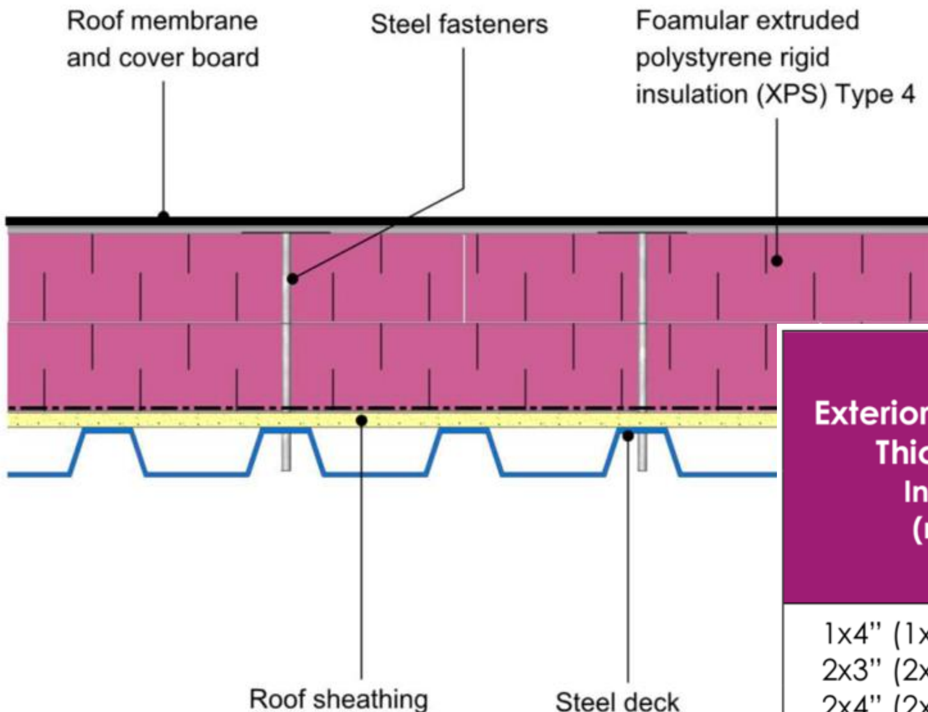
High R-values w/only R-10 ci

Scenario	Exterior Insulation Thickness Inches (mm)	Exterior Insulation Nominal R-value hr·ft²·°F/Btu (m²K/W)	Assembly		Highest Applicable Climate Zone per NECB 2015[1]
			R-value hr·ft²·°F/Btu (m²K/W)	U-value Btu/hr·ft²·°F (W/m²K)	
R-19 (3.35 RSI) Batt[2] Insulation in Stud Cavity Studs @ 16" o.c.	2" (50.8) 3" (76.2) 4" (101.6)	R-10 (1.76) R-15 (2.64) R-20 (3.52)	R-29.6 (5.21) R-33.6 (5.92) R-37.4 (6.59)	0.034 (0.192) 0.030 (0.169) 0.027 (0.152)	7 8 8
R-19 (3.35 RSI) Batt[2] Insulation in Stud Cavity Studs @ 24" o.c.	2" (50.8) 3" (76.2) 4" (101.6)	R-10 (1.76) R-15 (2.64) R-20 (3.52)	R-30.6 (5.39) R-35.0 (6.16) R-39.1 (6.89)	0.033 (0.185) 0.029 (0.162) 0.026 (0.145)	7 8 8
R-22 (3.87 RSI) Batt[2] Insulation in Stud Cavity Studs @ 16" o.c.	2" (50.8) 3" (76.2) 4" (101.6)	R-10 (1.76) R-15 (2.64) R-20 (3.52)	R-31.7 (5.58) R-35.8 (6.30) R-39.6 (6.97)	0.032 (0.179) 0.028 (0.159) 0.025 (0.144)	8 8 8
R-22 (3.87 RSI) Batt[2] Insulation in Stud Cavity Studs @ 24" o.c.	2" (50.8) 3" (76.2) 4" (101.6)	R-10 (1.76) R-15 (2.64) R-20 (3.52)	R-33.0 (5.82) R-37.3 (6.58) R-41.3 (7.28)	0.030 (0.172) 0.027 (0.152) 0.024 (0.137)	8 8 8
R-24 (4.23 RSI) Batt[2] Insulation in Stud Cavity Studs @ 16" o.c.	2" (50.8) 3" (76.2) 4" (101.6)	R-10 (1.76) R-15 (2.64) R-20 (3.52)	R-33.2 (5.84) R-37.1 (6.53) R-41.0 (7.21)	0.030 (0.171) 0.027 (0.153) 0.024 (0.139)	8 8 8
R-24 (4.23 RSI) Batt[2] Insulation in Stud Cavity Studs @ 24" o.c.	2" (50.8) 3" (76.2) 4" (101.6)	R-10 (1.76) R-15 (2.64) R-20 (3.52)	R-34.7 (6.11) R-39.0 (6.86) R-42.9 (7.56)	0.029 (0.164) 0.026 (0.146) 0.023 (0.132)	8 8 8

[1] Compared to above grade wall for maximum U-factor in Table 3.2.2.2

[2] Installed R-value. Rated R-20 Fiberglass Batt is compressed to R-19 when installed in a 5.5-inches wood studs cavity





Screws at 12" o.c. have almost no impact

Exterior Insulation Thickness Inches (mm)	Exterior Insulation Nominal R-value hr·ft²·°F/Btu (m²K/W)	Assembly	
		R-value hr·ft²·°F/Btu (m²K/W)	U-value Btu/hr·ft²·°F (W/m²K)
1x4" (1x101.6mm)	R-20 (3.52)	R-20.8 (3.67)	0.048 (0.272)
2x3" (2x76.2mm)	R-30 (5.28)	R-30.5 (5.36)	0.033 (0.186)
2x4" (2x101.6mm)	R-40 (7.04)	R-39.8 (7.02)	0.025 (0.142)

Fenestration

- Total Area (WWR)
- Thermal Quality

Windows & Glazing: Key Considerations

→ Window-to-Wall Ratio

Window Performance is Important

- → Code-approved windows have U_{SI} values of about 2.5 W/m^2K … this is R-2.3
- → Windows and curtainwalls with R-2.5 to R3.5 comprise most installed
- → To achieve higher R-values, different frames and triple-glazing needed

Average R-value

R-20.4 wall

65% of Area

+

R-2.6 window

35% of Area

=

Window U_{SI} =2.2 or R-2.6

Average R-value

R-20.4 wall

65% of Area

+

R-2.6 window

35% of Area

=

R-6.0

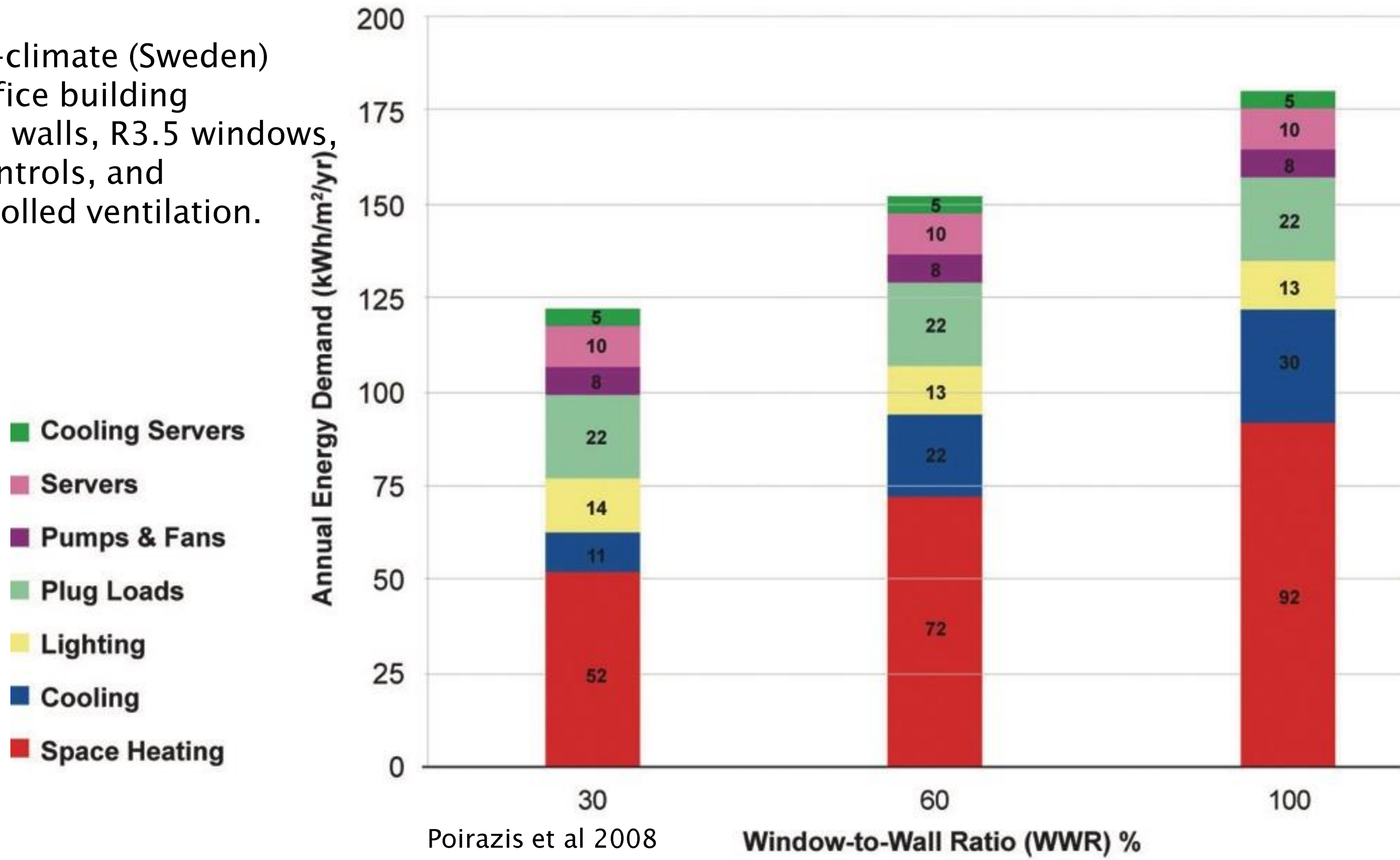
100% of Area

Window U_{SI} =2.2 or R-2.6

Example Low-energy Office Building

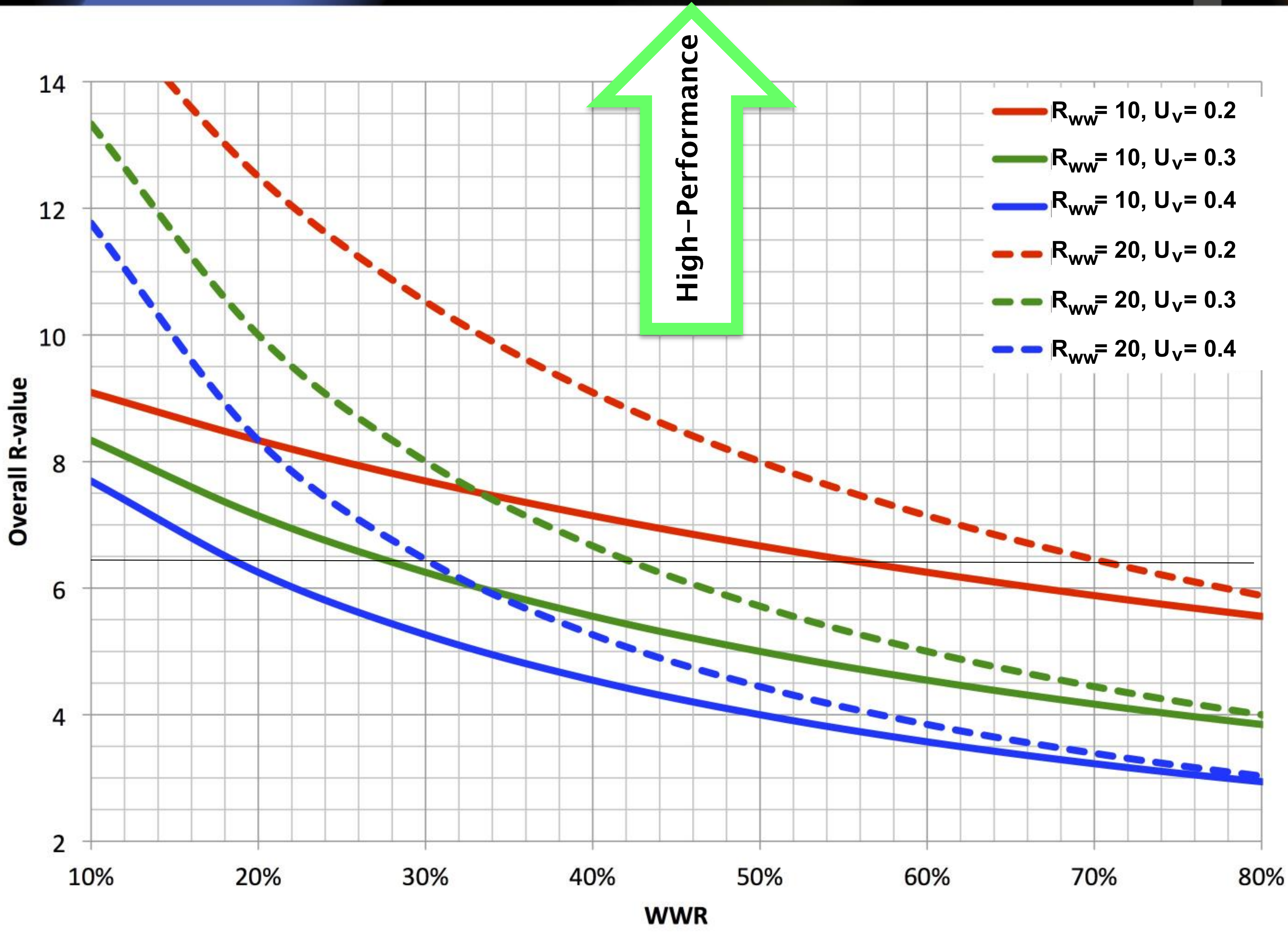
→ Adding window area = more energy for heating & cooling

Mid-size cold-climate (Sweden) low-energy office building
Note: true R20 walls, R3.5 windows, daylighting controls, and demand-controlled ventilation.

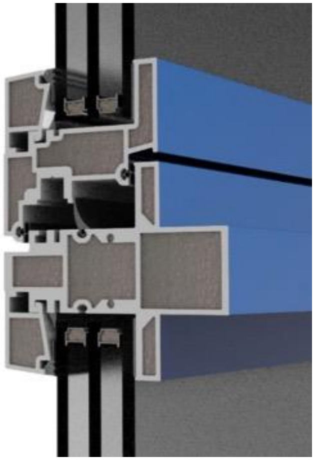


Poirazis et al 2008

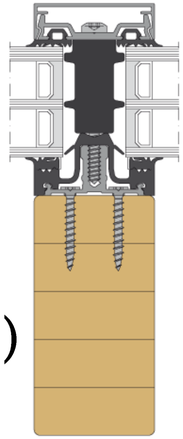
Window-to-Wall Ratios

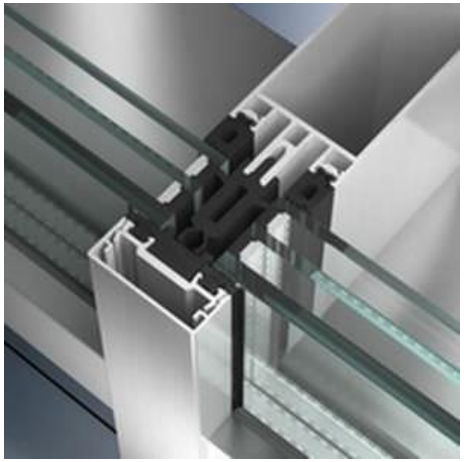


High Performance Windows & Glazing



- → Triple glazing with argon fill, war
  edge spacers and 2-3 low-e coati
  - → Possibly quad IGUs in far Nort
- → Punched window options (domestic & imported)
  - → Insulated fiberglass, insulated vinyl, vinyl/aluminum
- → Curtainwall options
  - → Imported thermally broken aluminum
  - → Options for wood veneer (aluminum glazing components) fiberglass/vinyl





Better Windows

R-20.4 Wall

65% of Area

+

R-4

35% of Area

=

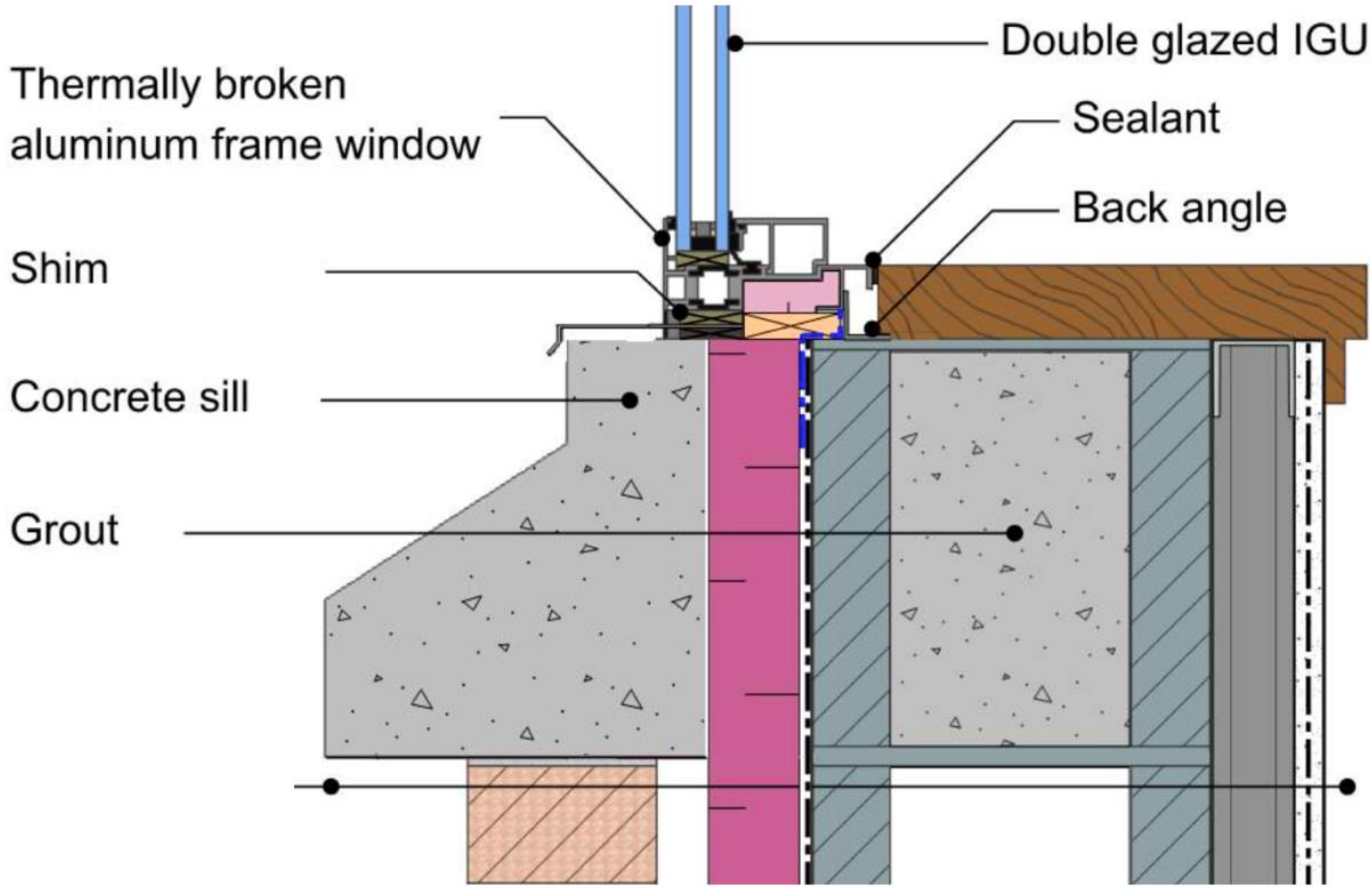
R-8.4

100% of Area

Better windows, and almost 30% reduction in heat loss

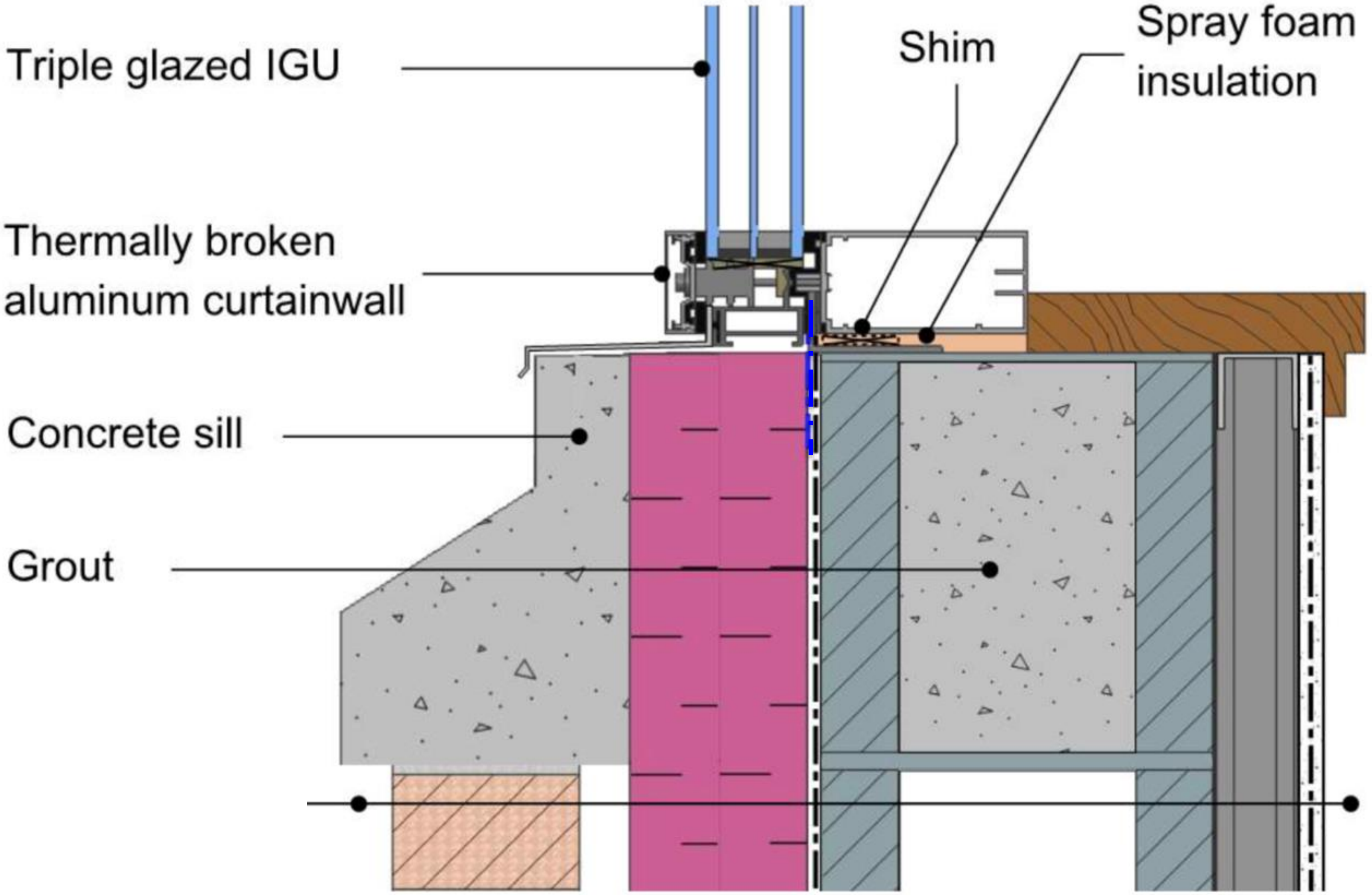
Window Installation

→ Ensure continuity of water, air, and thermal control

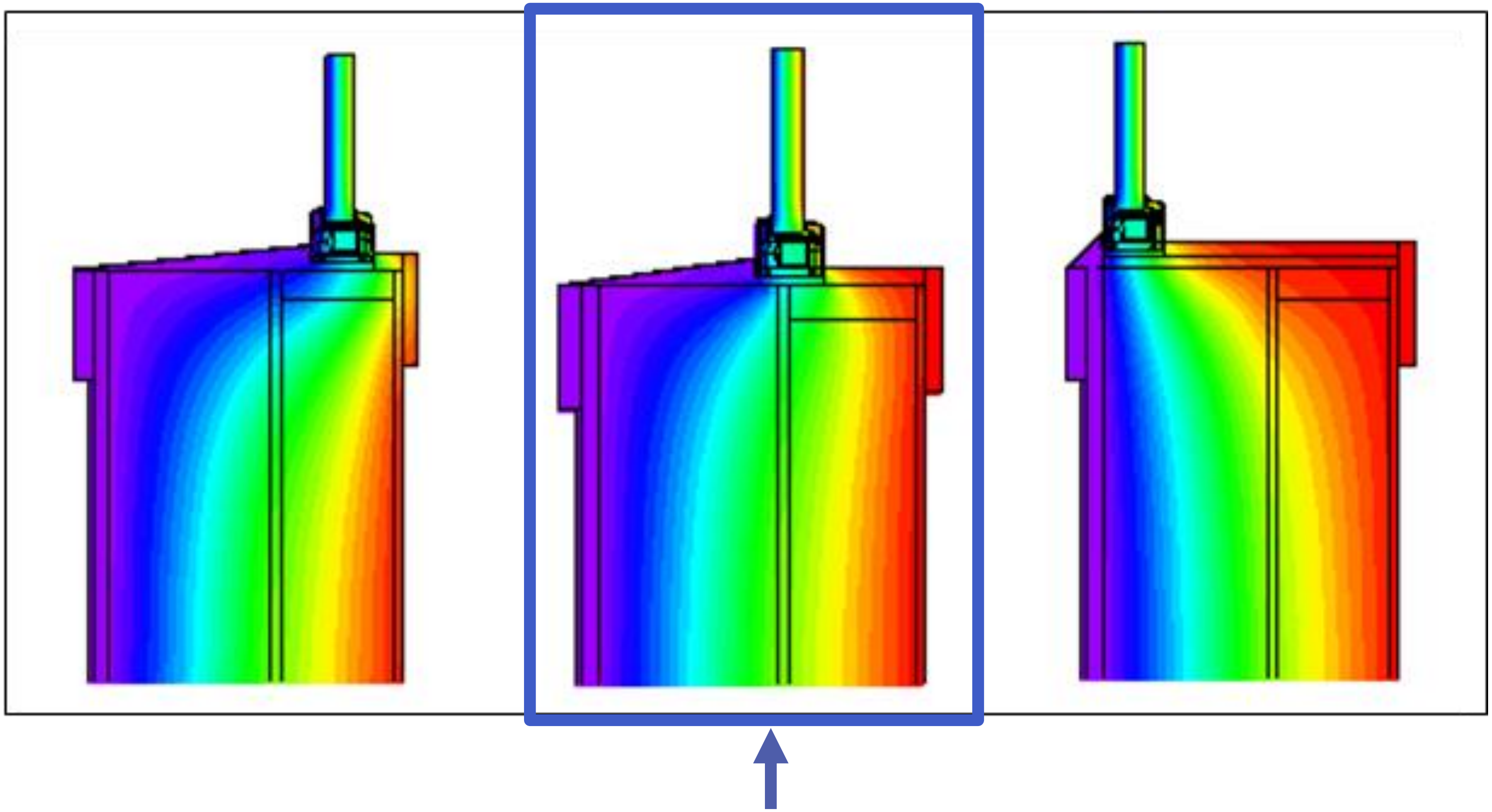


Curtainwall Installation

→ Note difference to window /storefront



Windows Placement in Rough Openings



Optimal placement aligns window with insulation

Path forward

→ Better insulated windows

→ Triple-glazed

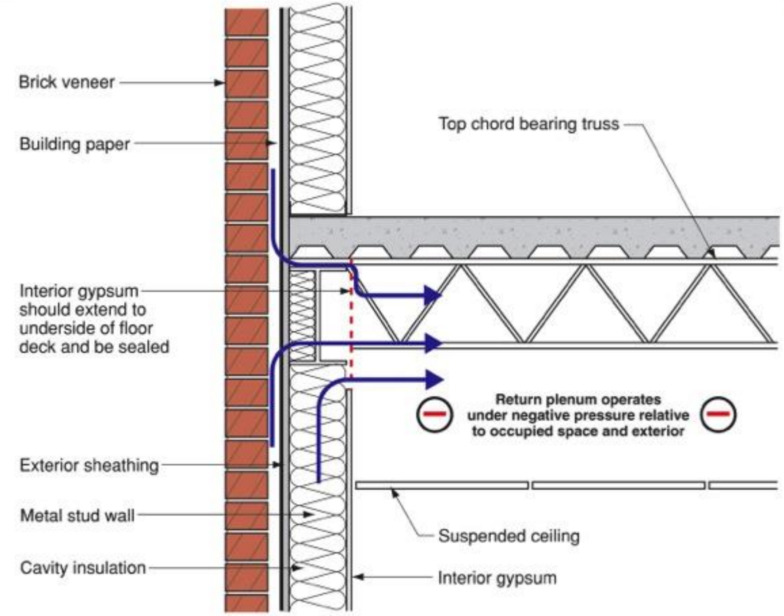
→ Carefully designed installation to avoid water, air, and thermal leaks

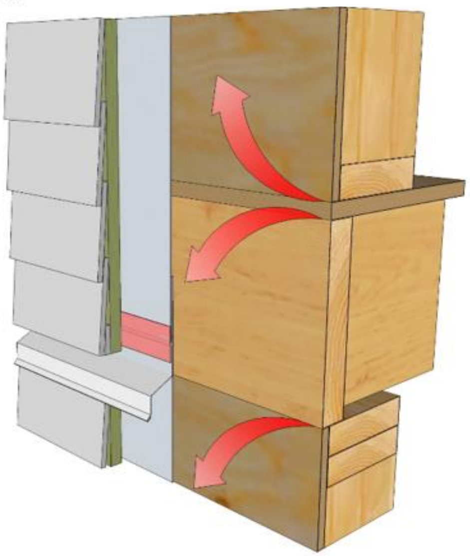
Airflow Control

- Air Barriers
- Convection and Windwashing

Air Barriers

- Air Barrier Systems must:
  - Be Continuous
  - Be Durable
  - Resist Structural Loads – Stiffness & Strength for Design Wind Load
  - Be Airtight
- May need to allow vapor diffusion drying and act as/with Water Control
- Wind loads on mid-rise buildings can be significant and approaches used for low-rise wood-frame may not be appropriate





Why is Air Leakage Control is Important – Preventing Building Enclosure Failures

Air Barriers Are Systems

Materials

Components

Accessories

Whole Building Airtightness

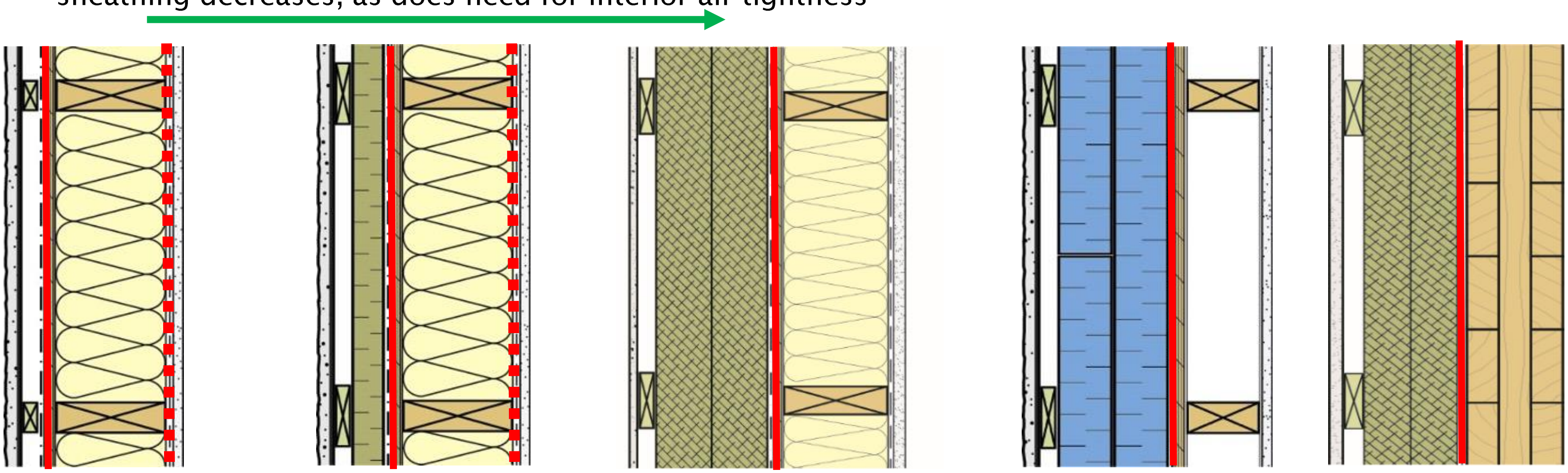
Water Barriers & Air Barriers

- → Often combine functions for same product
  - → E.g. liquid-applied and adhered sheets
- → Requirements of both functions required
  - → Water: Gravity lapped, connected to flashing
  - → Air: sealed, supported
- → Conflicts: connected to interior of window for air, but shed to the exterior flashing at window head

Shift to the Exterior Air Barrier

- → Industry shift from the use of interior air barrier approaches (poly, drywall) to exterior sheathing approaches as the primary air barrier element
- → BUT! still need to maintain a reasonable degree of airtightness at interior side of cavity insulation in cold climates (convection suppressor)
- → Vapor barrier/retarder at interior side depending on insulation ratio & type

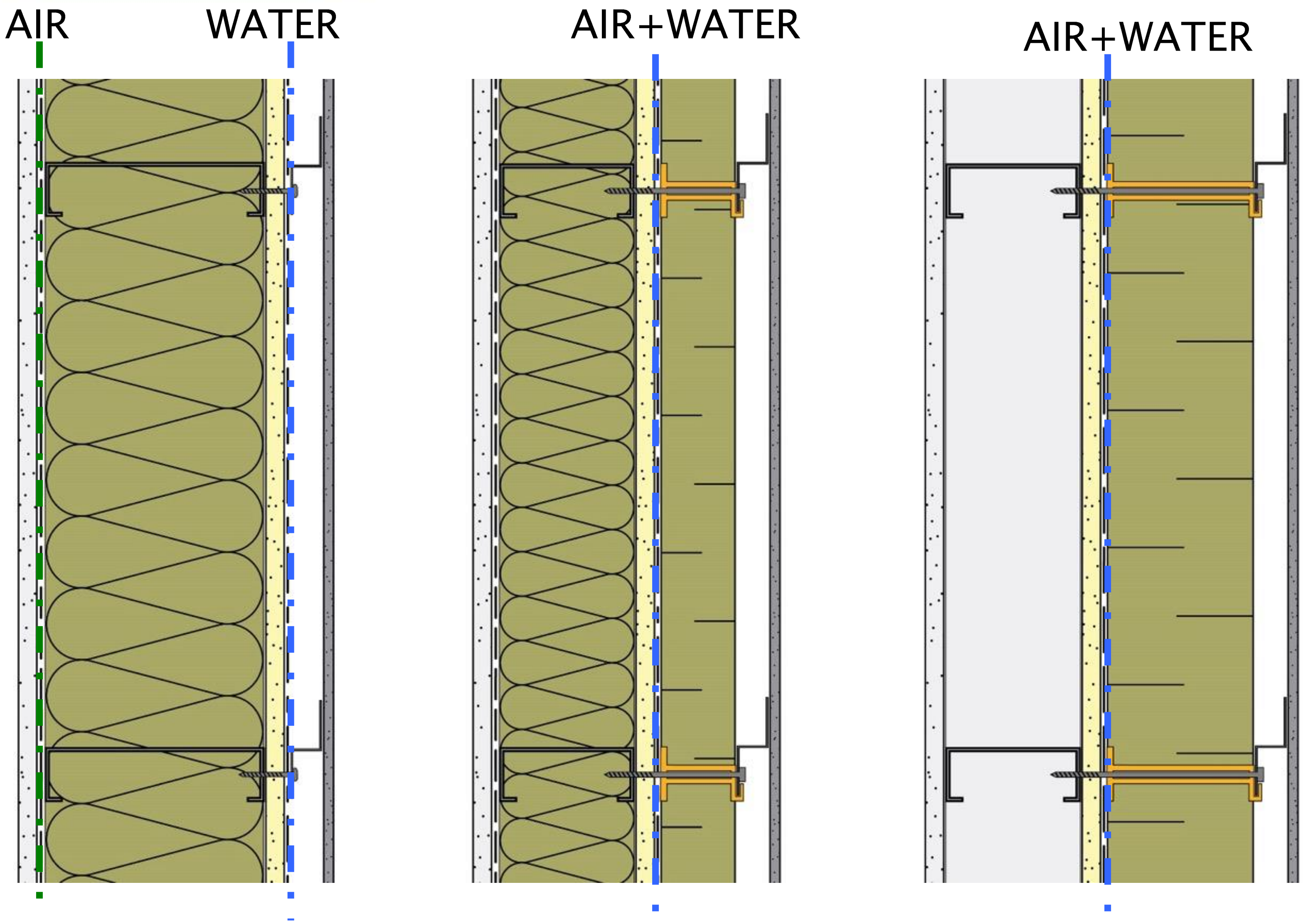
With enough exterior insulation – risk for condensation at sheathing decreases, as does need for interior air tightness



Primary Air Barrier System

Secondary Airtight element, maybe vapor retarder

Air Barrier/WRB Placement Considerations

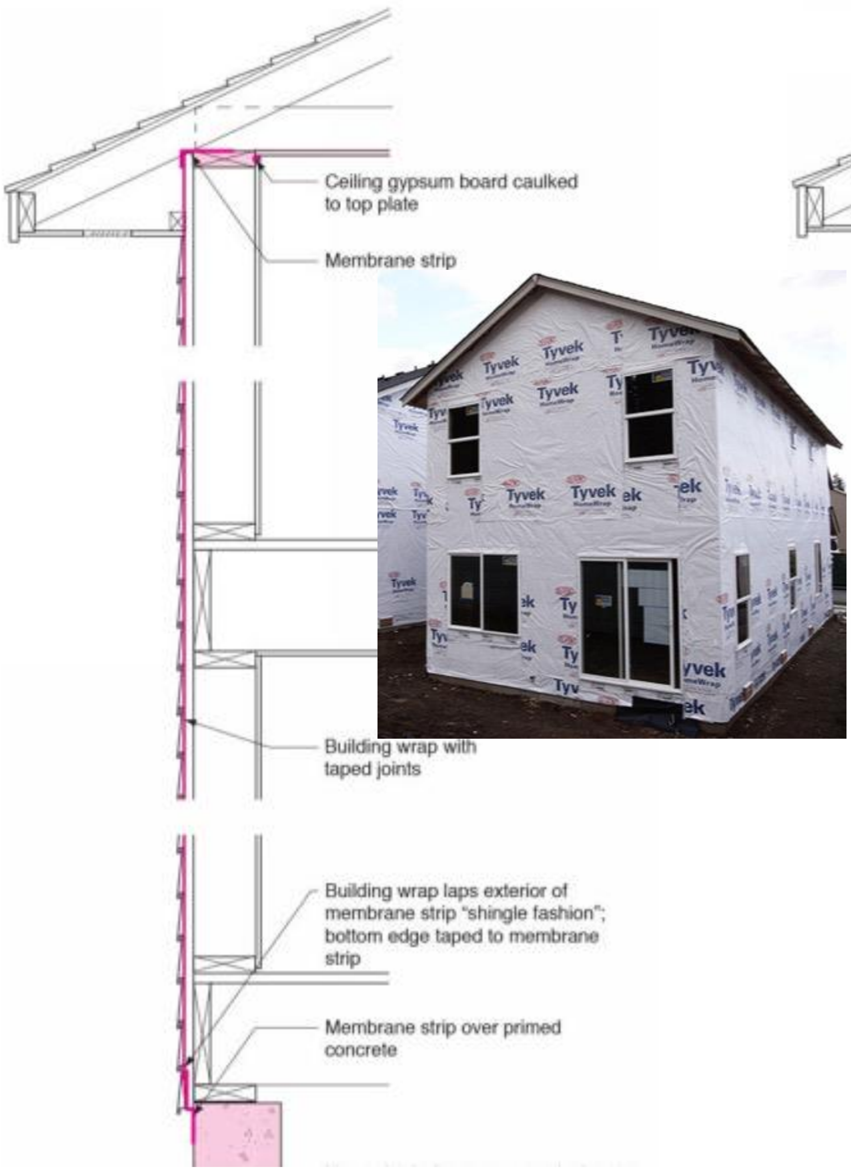


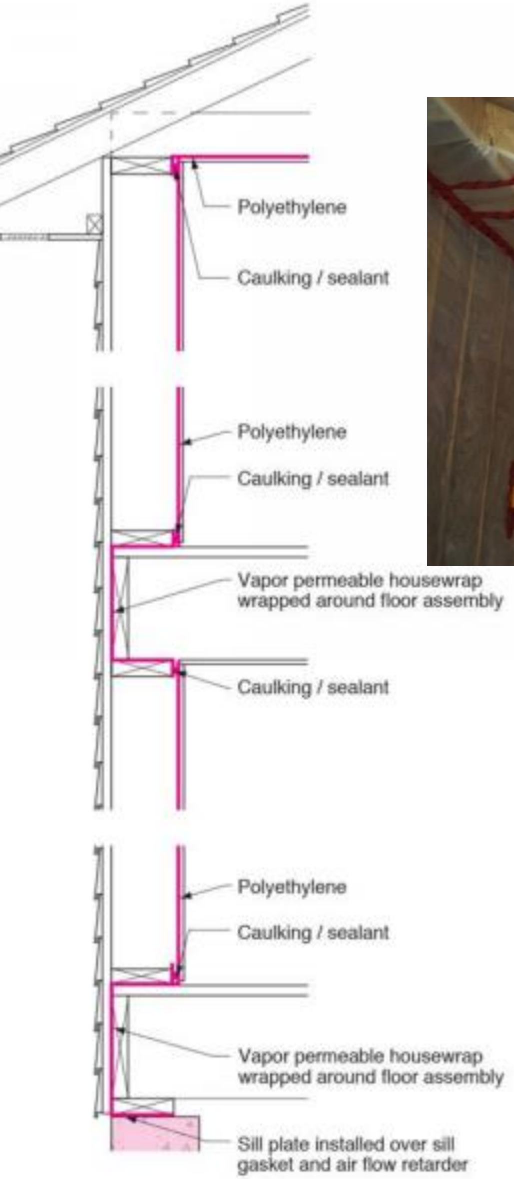
Interior (stud) insulated)

Split (exterior & stud) insulated

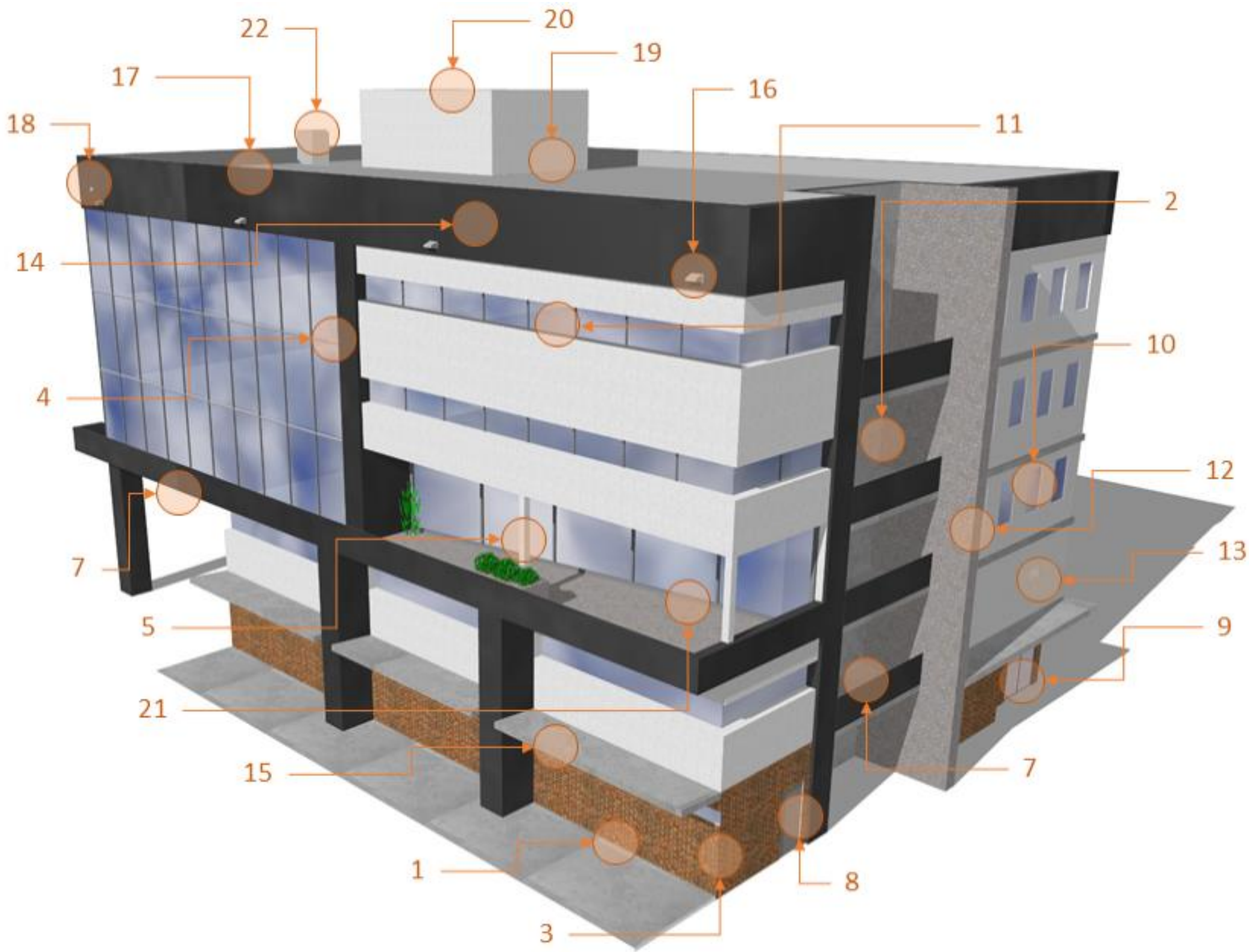
Exterior insulated

Why Exterior Air Barriers vs. Interior?



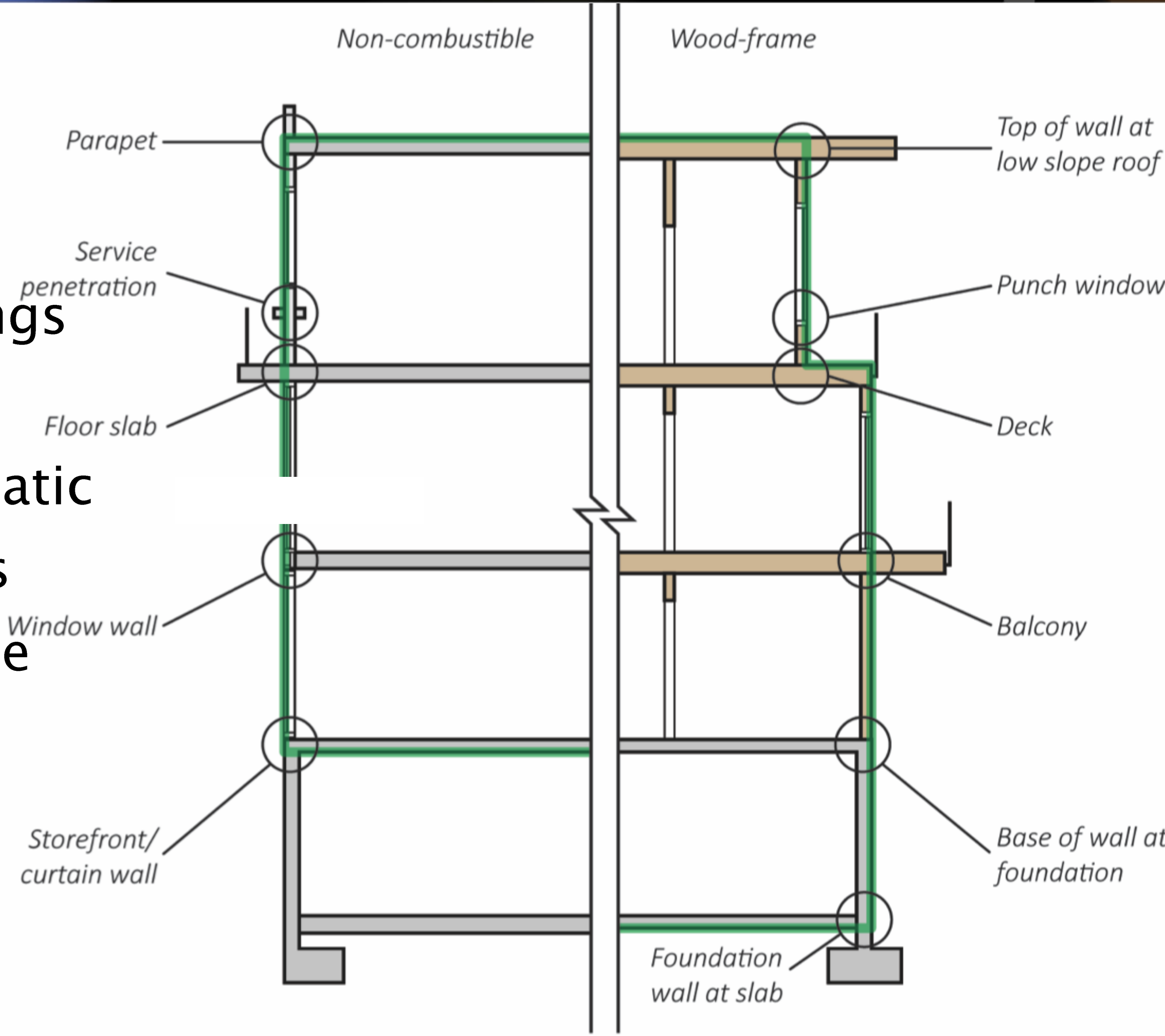


Air Barrier: As Good as Weakest Detail

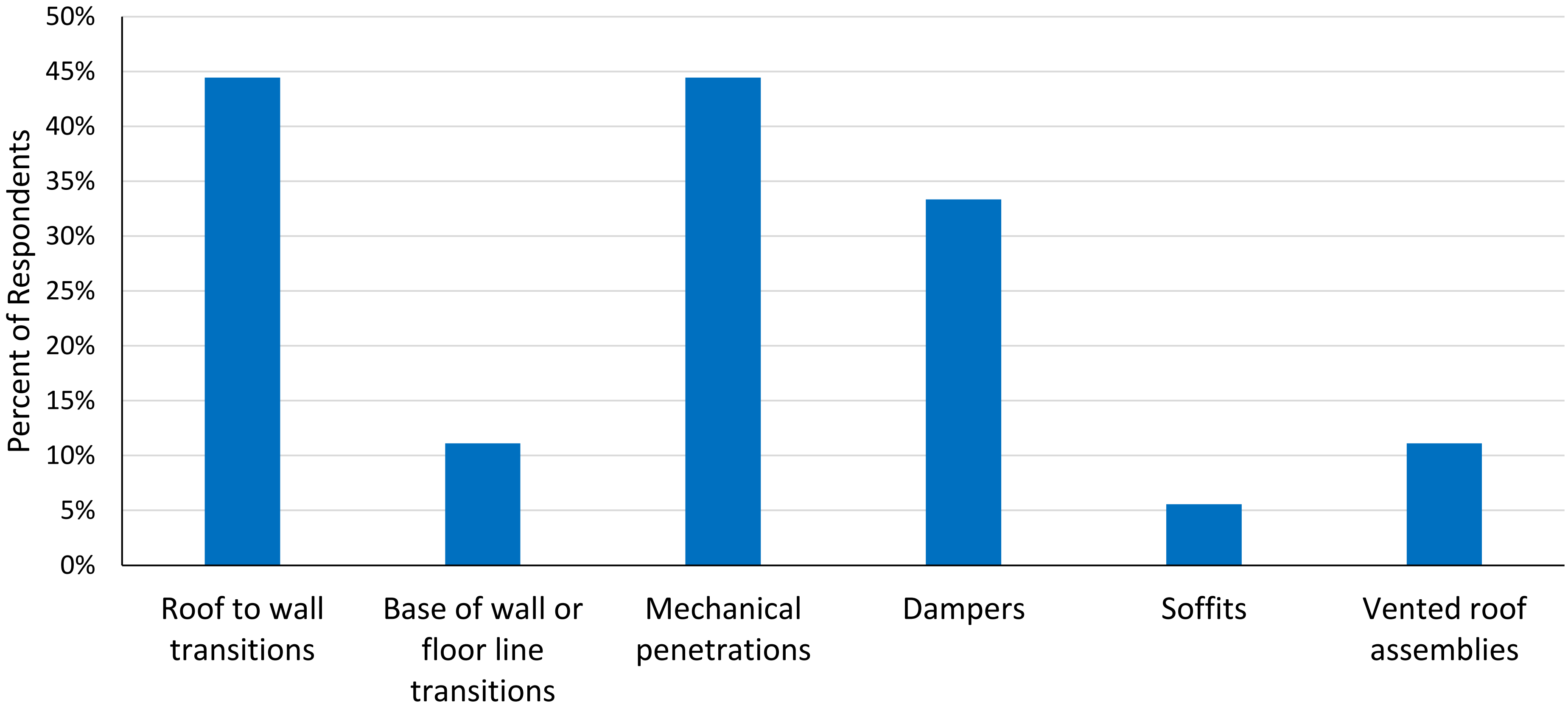


Continuity Detailing

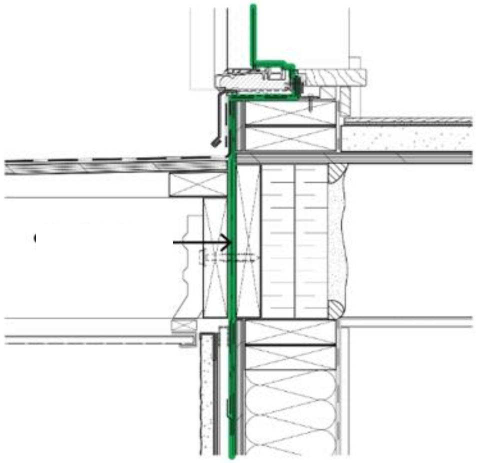
- → **Early**
  - → Plan
  - → Label drawings
- → **Often**
  - → Schematic
  - → Details
  - → On-site

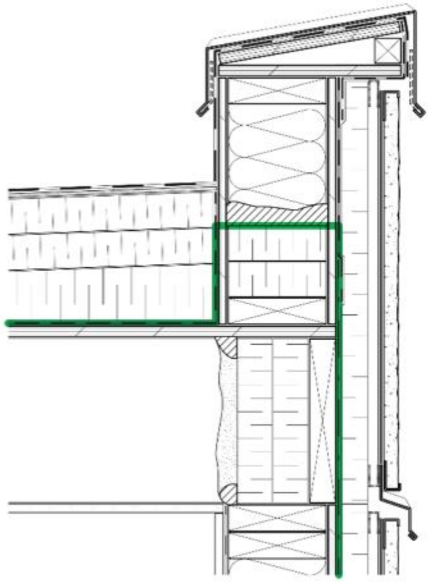


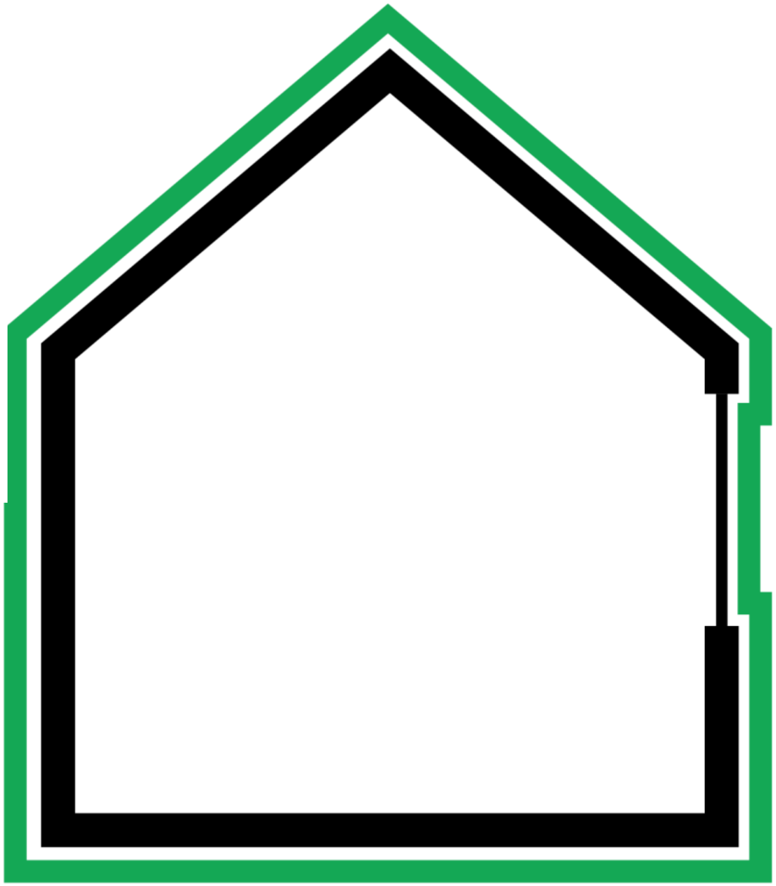
Air Leak Locations – Mid to High-rise

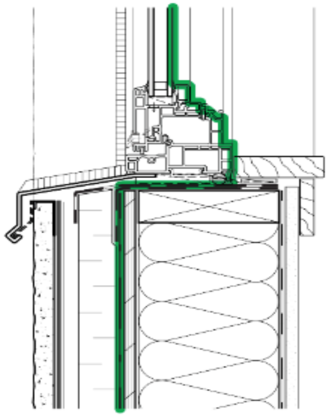


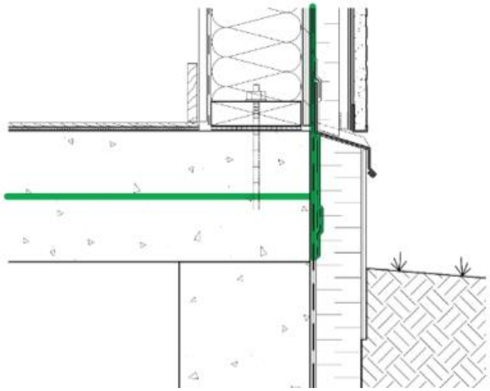
Continuity Detailing at EVERY Detail











Exterior Air Barrier Systems

- Exterior air barrier approaches (at sheathing plane) rely on rigidity of wood/gypsum sheathing
- **Sealed sheathing <u>membrane</u> approach**
  - Mechanically Attached Sheets (Taped & Sealed), $
  - Self-adhered Membranes, $$$
  - Liquid/Fluid Applied, $$$+
- **Sealed sheathing approach** (plywood/OSB/gypsum)
  - Sealed joints (good sealant or tapes), $$
- **Sealed foam insulation** $$

Mechanically Attached Air (&Water?) Barrier

→ Loose sheet mechanically attached to wall with cap staples/nails and sealed with tapes, self-adhered membrane and sealants

Challenges with Mechanically Attached Membranes & Wind During Construction

Fully-adhered vs mechanical attached

Fully-adhered vs mechanical attached

Fully-adhered vs mechanical attached

Fully-adhered vs mechanical attached

Exterior Insulation Sandwich Support for Mechanically Attached Air Barriers

Sprayfoam Air Barrier between studs

→ Careful with Application

Airseal required between all wood-wood joints

Trends in Air Barrier Systems

→ Exterior Sprayfoam

→ Air <u>and</u> Water Control

Trends in Air Barrier Systems

→ Sealed Exterior Foam Sheathing

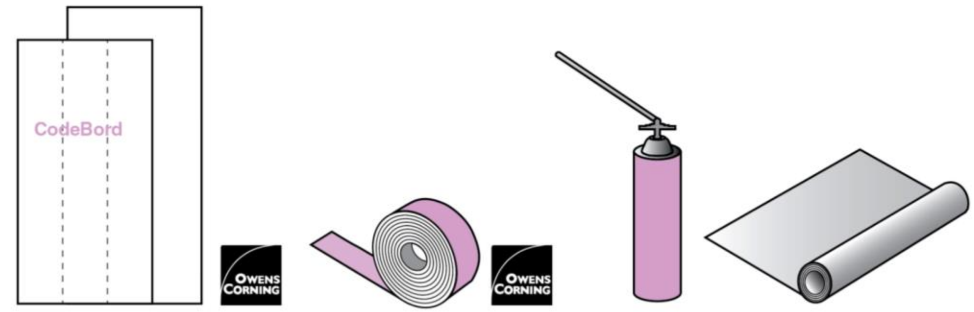
→ Air <u>and</u> Water Control

XPS *can* be air water barrier

→ Requires care at all details

Sealed Foam Sheathing: AB + WRB

→ **Systems** and compatible components are key

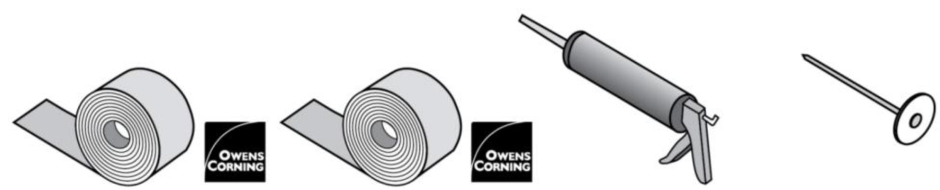


CodeBord® extruded polystyrene insulating sheathing (4' x 8' or 4' x 9') with ship lap or butt edges

FoamSealR™ polyethylene sealing gaskets (3-½" or 5-½")

Single-component foam sealant CCMC-evaluated

4-mil polyethylene vapour barrier (6-mil air/vapour barrier for ceiling applications)



JointSealR® foam joint tape

FlashSealR® foam flashing tape

Caulking sealant

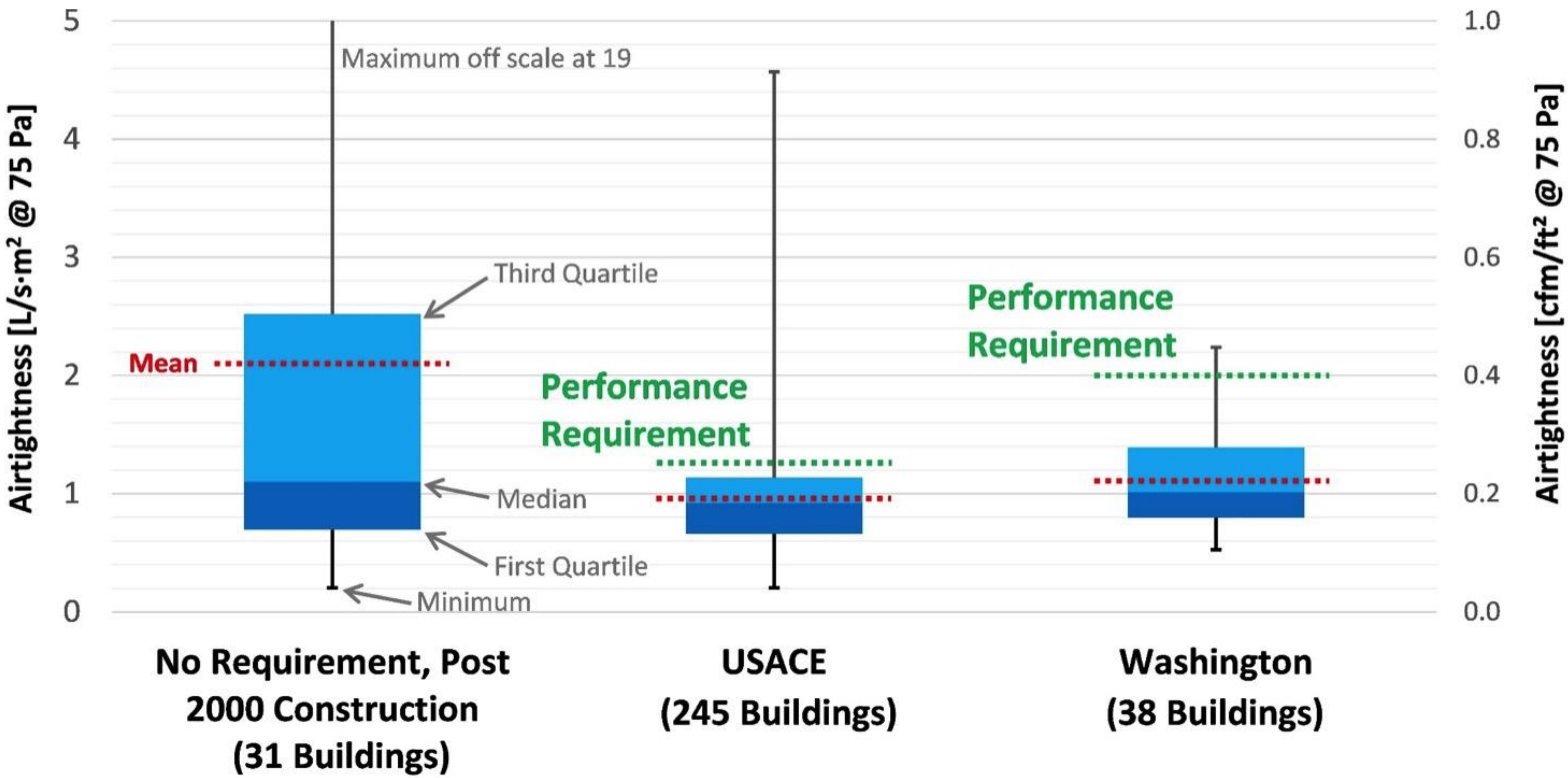
Nails with plastic or metal washers

Airtightness Does Not Happen By Accident

Multiple trades, multiple stages of construction require focus and commitment

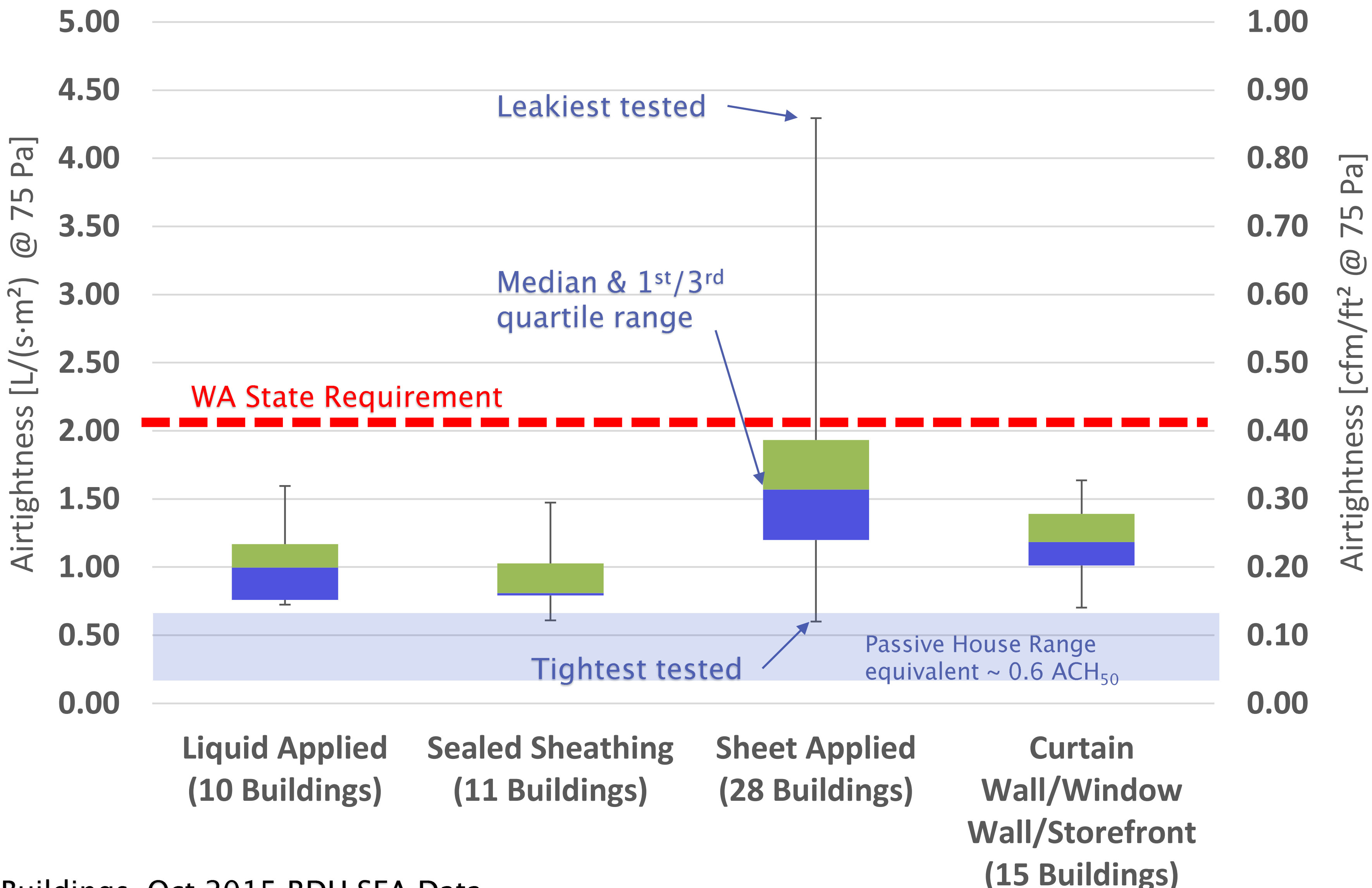
Experience with Large Buildings

→ Setting targets results in lower measured leakage



Based on RDH testing and research from the US

How Well Is the Industry Doing – WA State



54 Buildings, Oct 2015 RDH SEA Data

Path forawrd

- → Set targets (codes may impose)
- → Field Test
- → Repeat

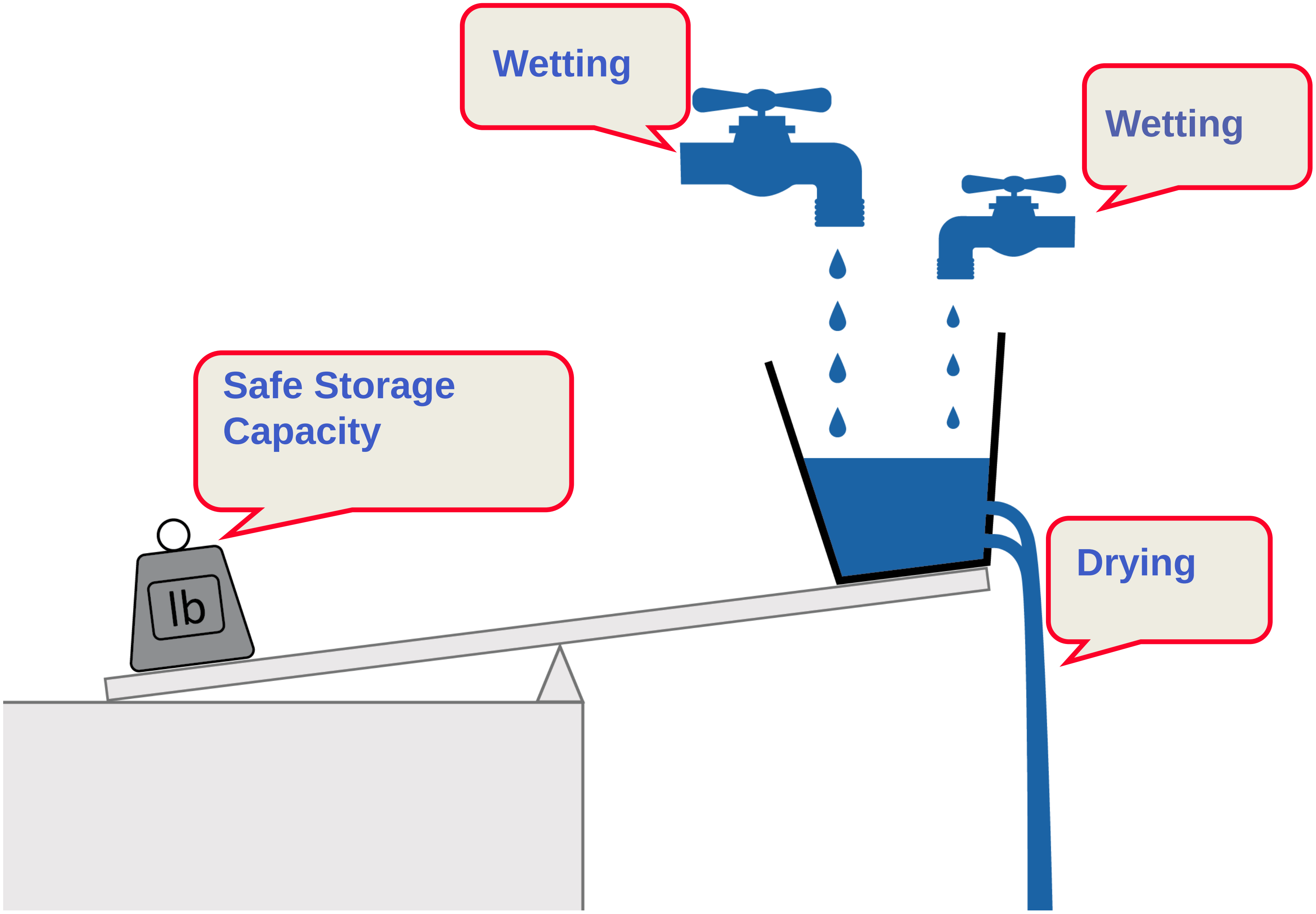
- → Massive benefits for energy, better HVAC design, and reduced condensation risks
  - → Known, predictable airtightness more important than super low numbers

Section 3: Durability in Highly Insulated Buildings

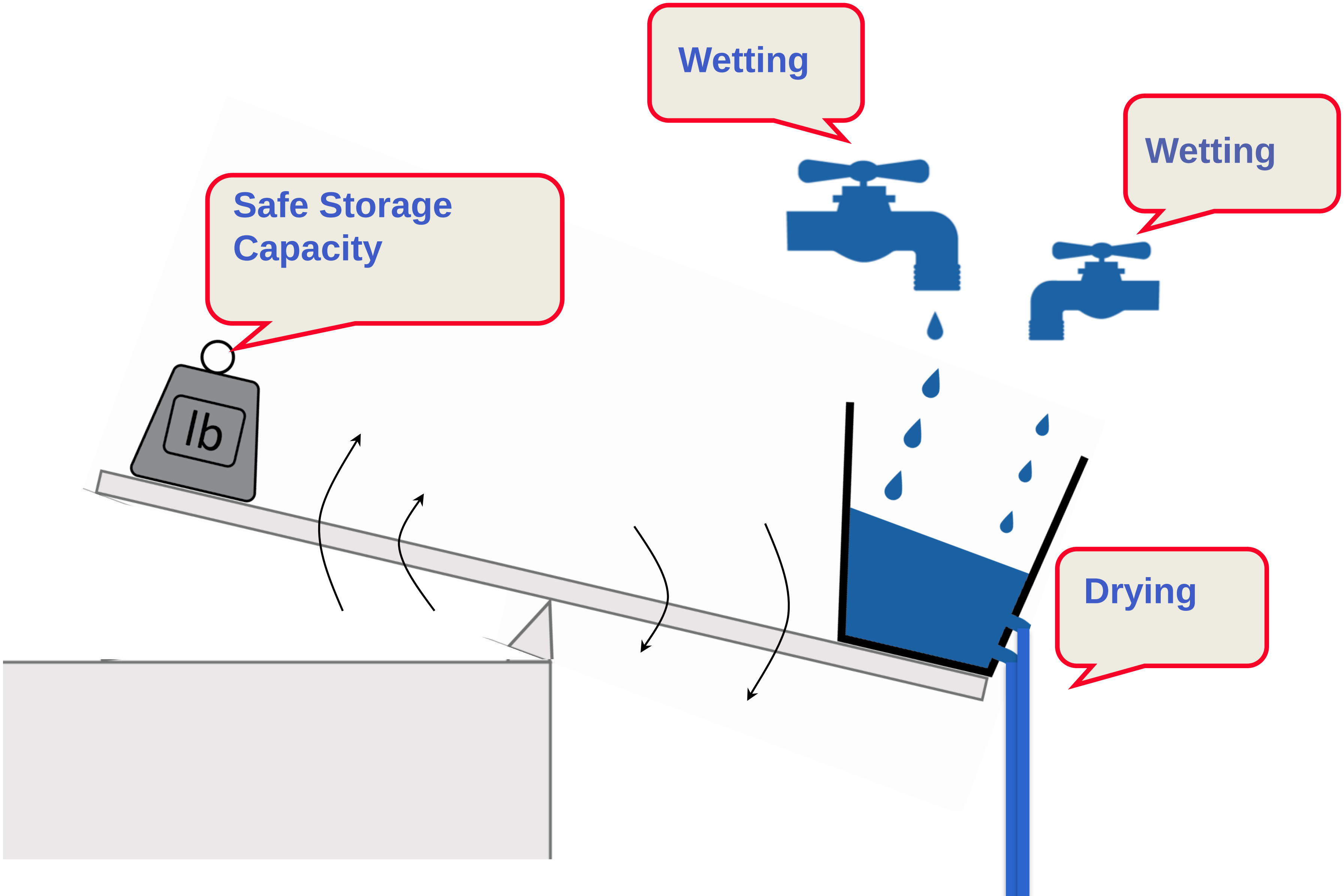
Durability

- → Most concerns are related to moisture
  - → Rot, corrosion, mould
- → High Insulated Enclosures can be more at risk
  - → Increasing insulation reduces heat flow
  - → Lower heat flow means less drying
  - → Response: more resilient design and/or better quality control

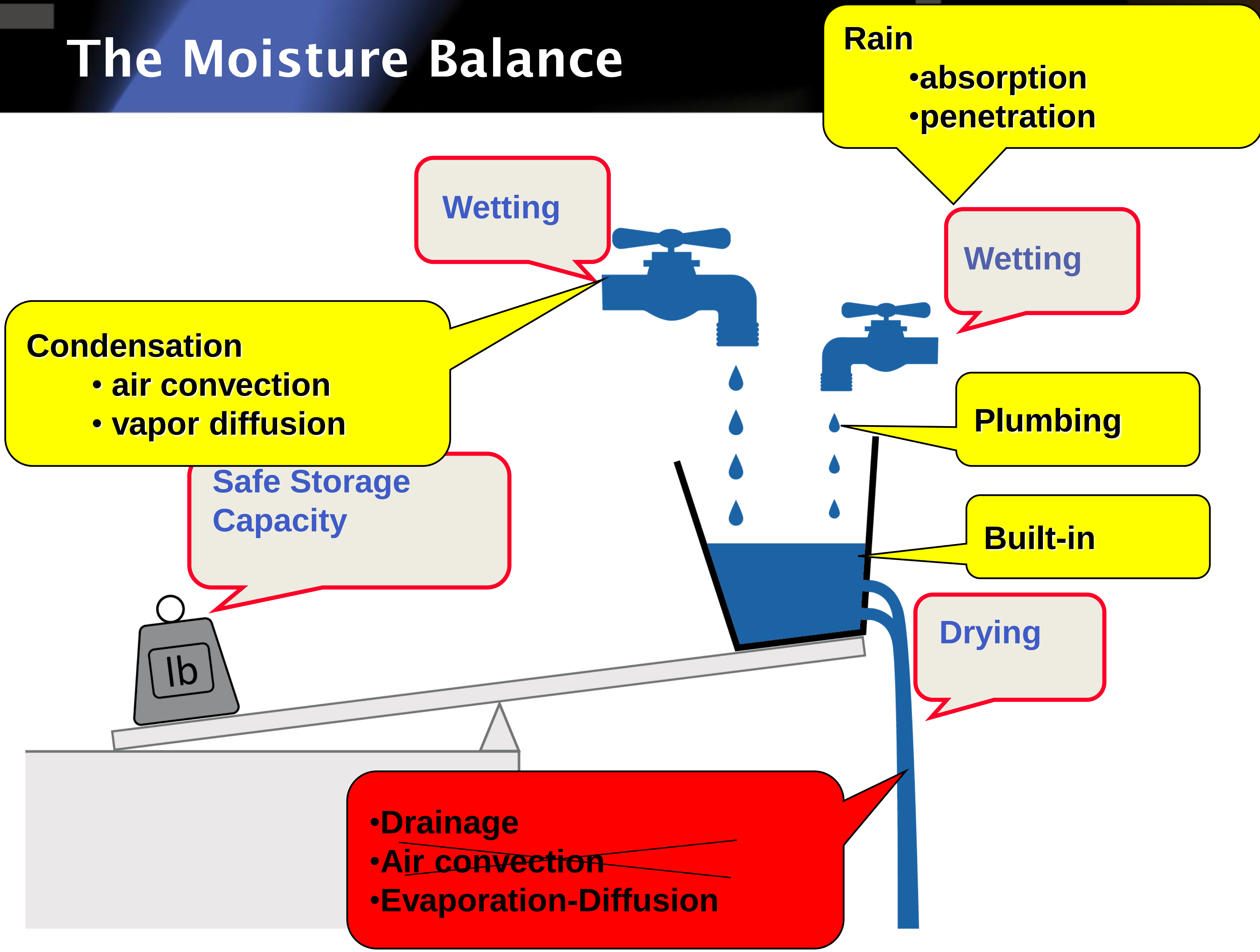
The Moisture Balance



The Moisture Balance



The Moisture Balance



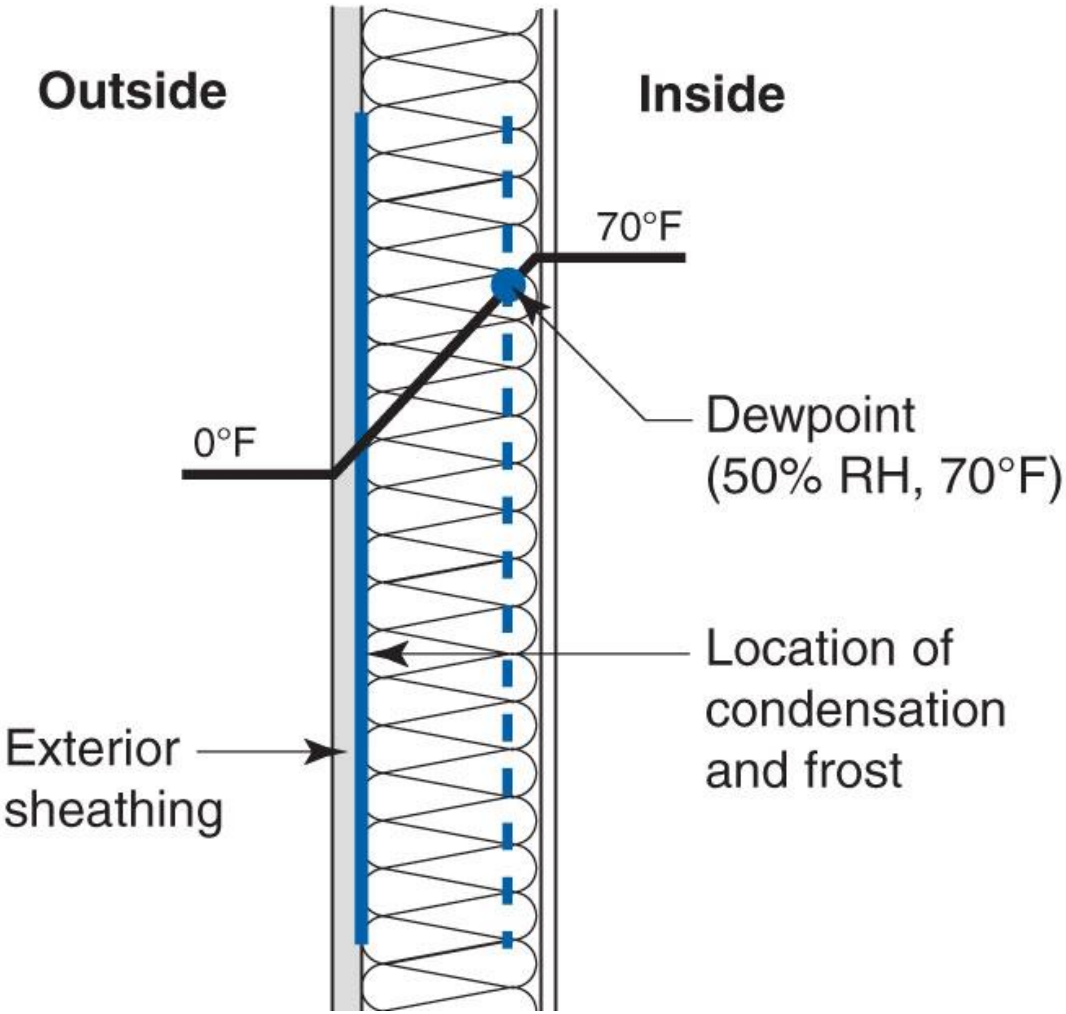
Moisture Balance

- → Select materials to tolerate moisture expected
- → Rain management is most important
  - → Flashing, drainage, penetrations
- → Air leakage condensation next
  - → Air barriers, exterior insulation
- → Remember: Construction moisture
  - → Management, drying
- → Allow drying by vapor diffusion
  - → None of us is perfect

Air Leakage Condensation & exterior insulation

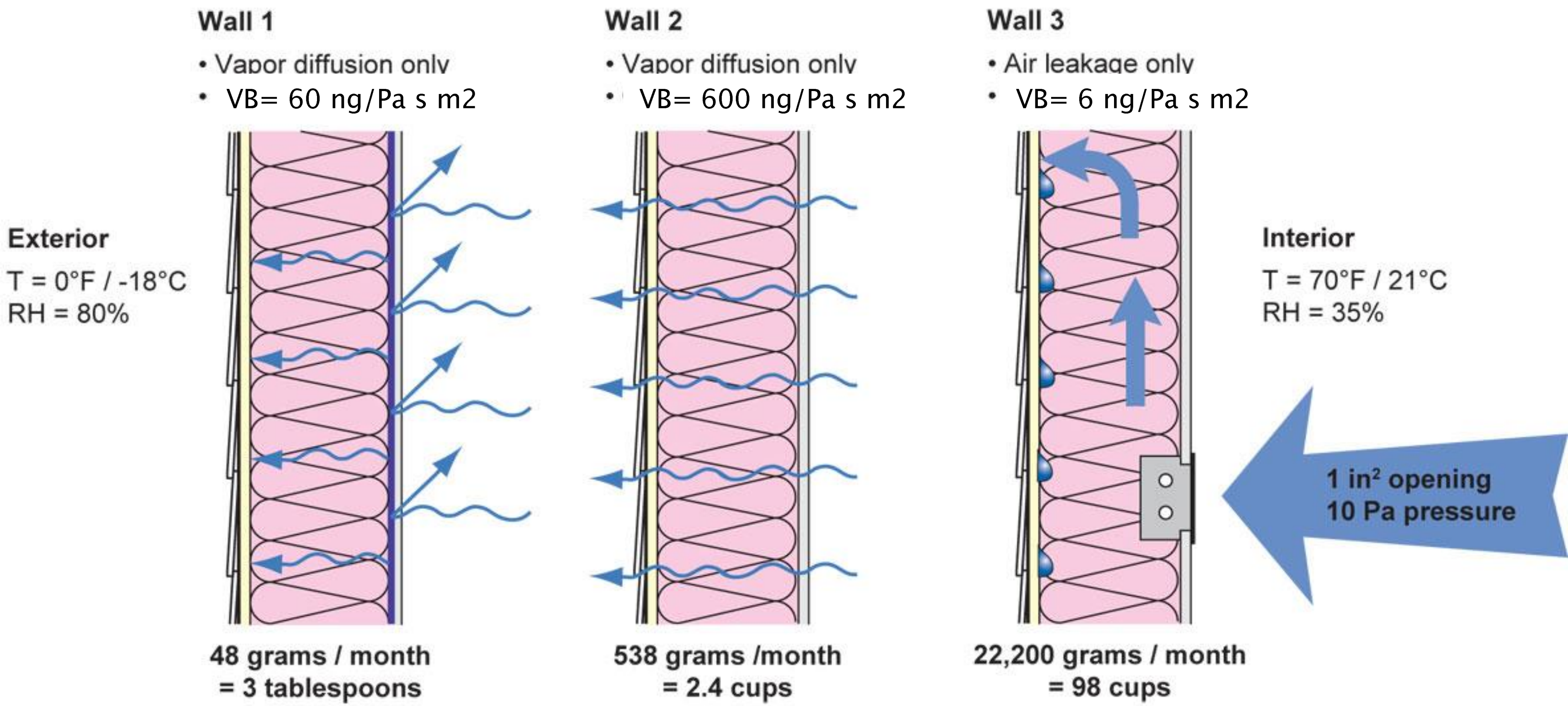
Question: Where does condensation occur?

Answer: on a cold *solid* surface



Air leakage or diffusion

Significance of air flow

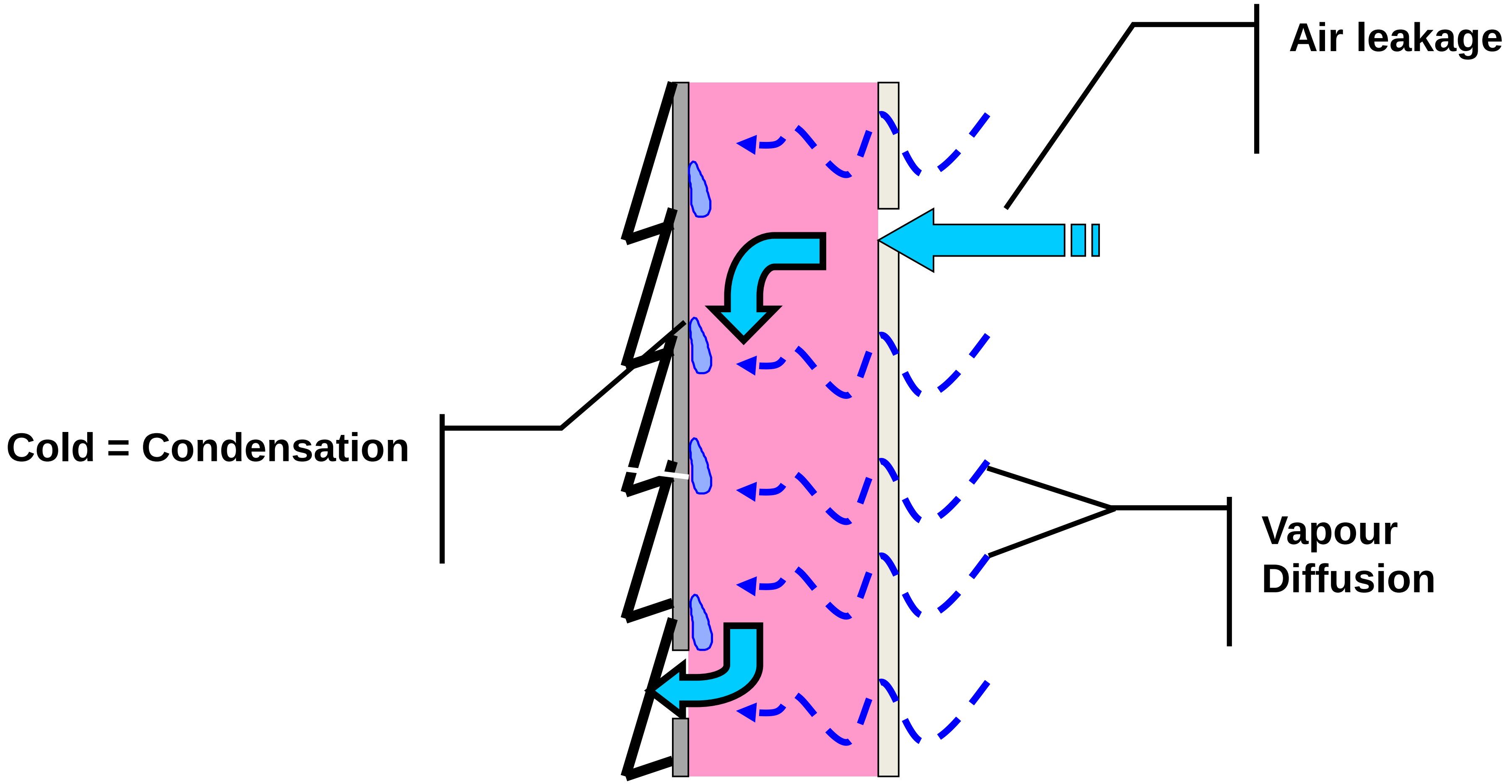


It is air barrier, not vapor barrier, that matters most

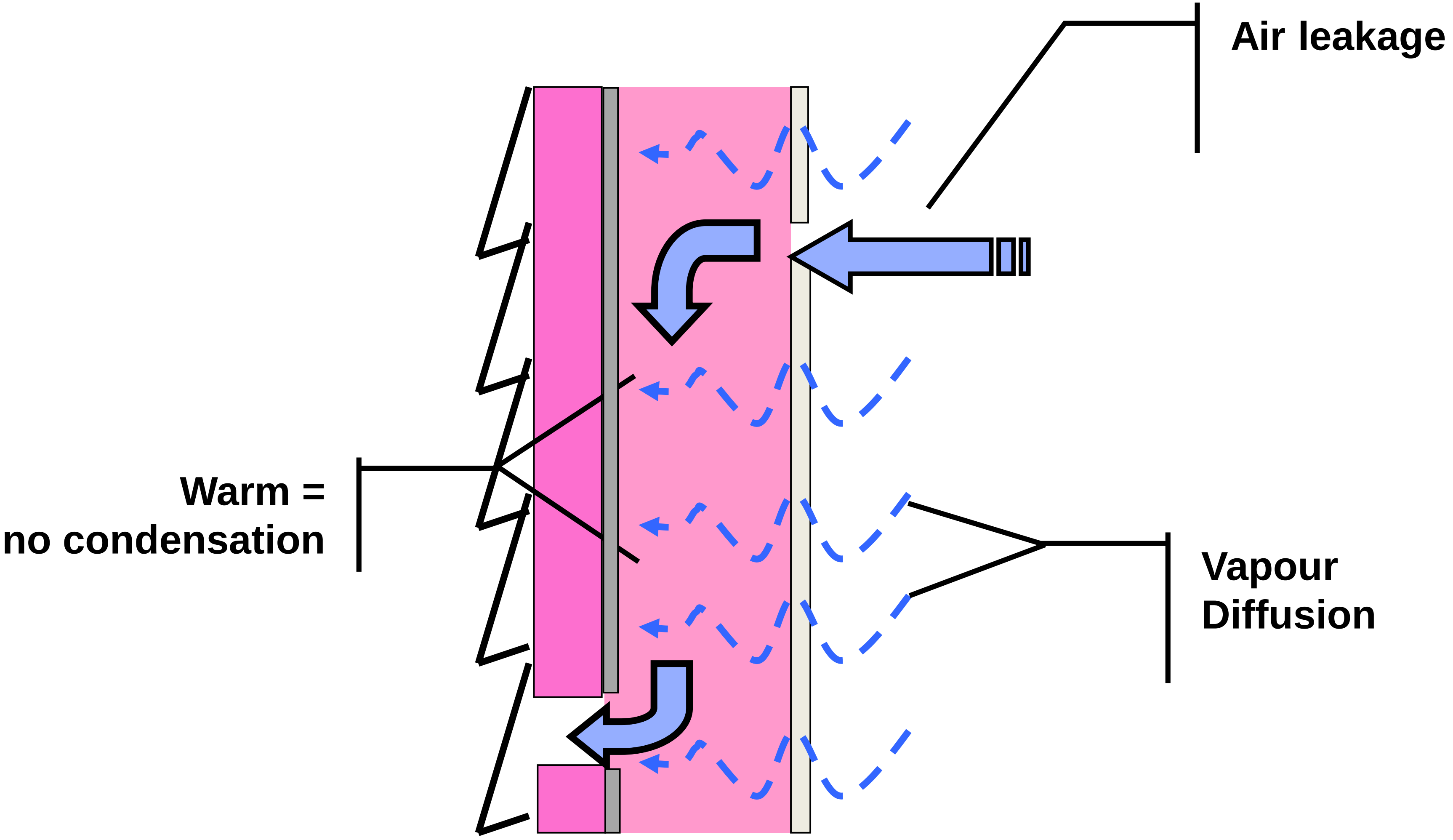
Air Leakage Condensation: Control Strategies

1. "Plug all holes" – an air barrier system
   - → Hard to be perfect, so …
2. Control driving forces
   - → HVAC pressure differences, stack effect, wind
   - → Reduce interior moisture (control interior RH!)
3. Control Temperature of condensing surface
   - → insulated sheathing, special heating, etc.

Wall w/o Insulated Sheathing

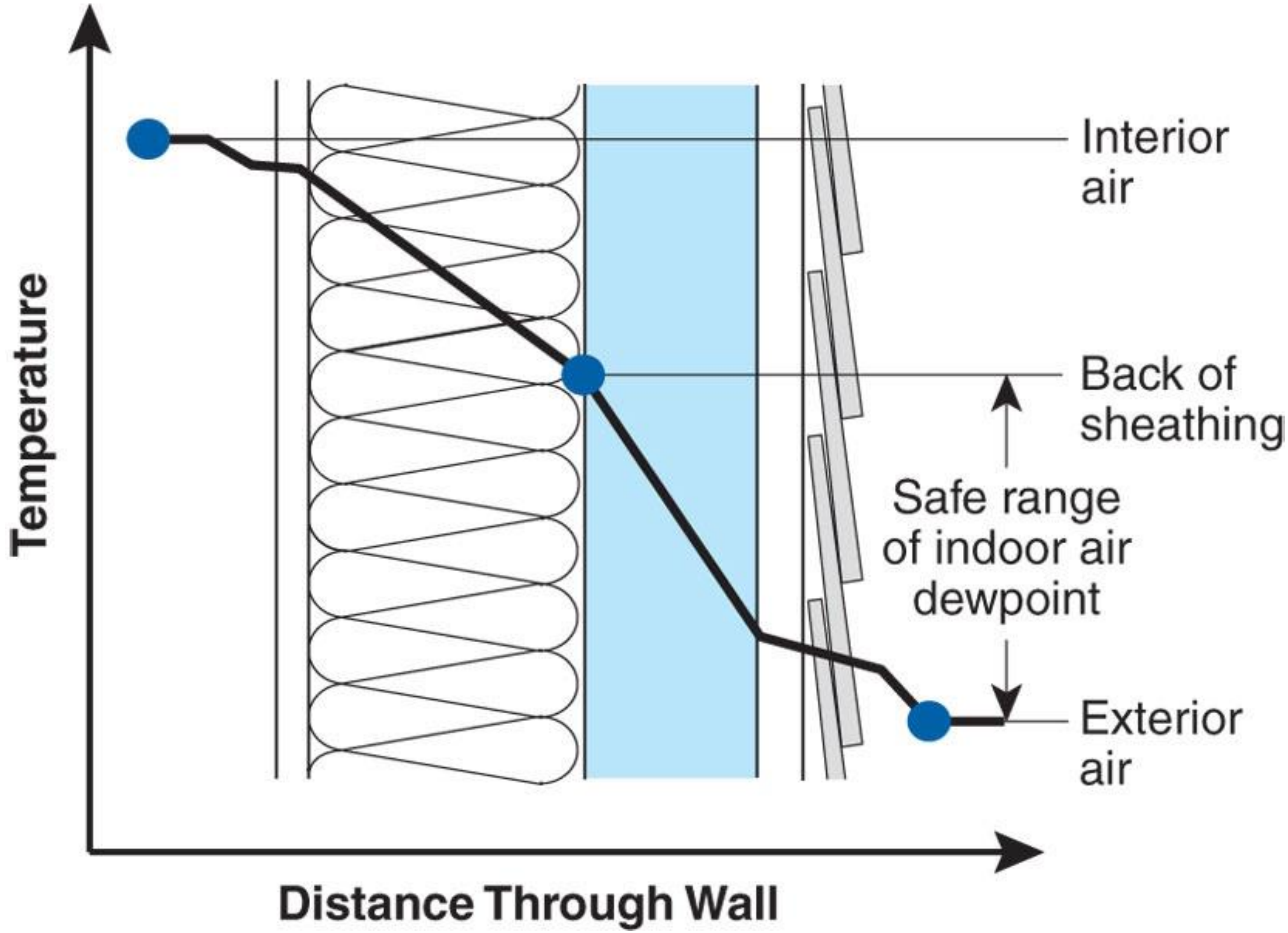


Wall with Insulated Sheathing

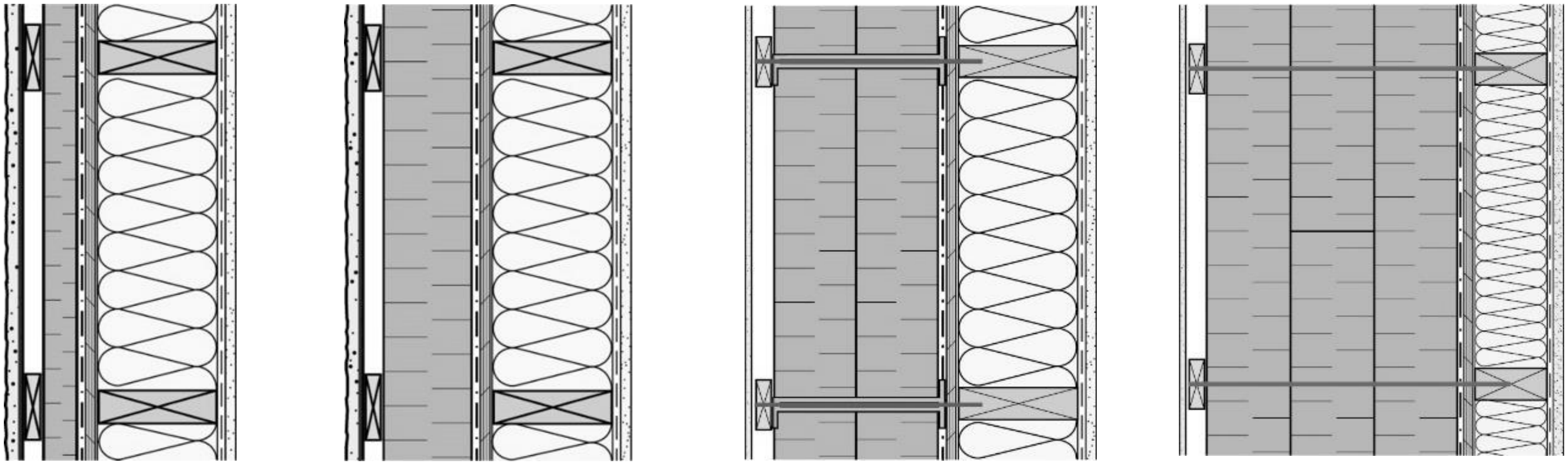


See: BSD-163 at buildingscience.com

$$T_{\text{back of sheathing}} = T_{\text{interior}} - (T_{\text{interior}} - T_{\text{exterior}})\ R_{\text{batt}}/R_{\text{total}}$$



Insulation Ratios



RATIO OF EXTERIOR TO TOTAL INSULATION NOMINAL* R-VALUE TO CONTROL AIR LEAKAGE CONDENSATION RISK					
Indoor RH / $T_{outdoor}$ (°C)	20%	**30%**	40%	50%	60%
0	0	0.12	0.32	0.47	0.60
-10	0.23	0.40	0.54	0.64	0.73
-20	0.41	0.55	0.65	0.73	0.80
-30	0.53	0.64	0.72	0.78	0.84
-40	0.66	0.70	0.76	0.82	0.86

**prudent to assess w/ temperature dependent insulation R-value*

Vapor diffusion & foam sheathing

Vapour Retarder / Barrier Materials

- → Concrete, glass, metal **<0.1**
- → Impermeable peel & stick **<1**
- → Polyethylene sheet **3**
- → Vapour Barrier Paint, smart vapour retarder
- → Vinyl Wallpaper **10-30**
- → Plywood/OSB (at low RH levels) **20-60**
- → XPS, **60-90/ inch**
- → Closed-cell sprayfoam **60-120 / inch**

Super-Insulation Strategies

- → All exterior insulation is moisture safest
- → Split and thick walls require care in vapor diffusion control, drying

Thick wall approach

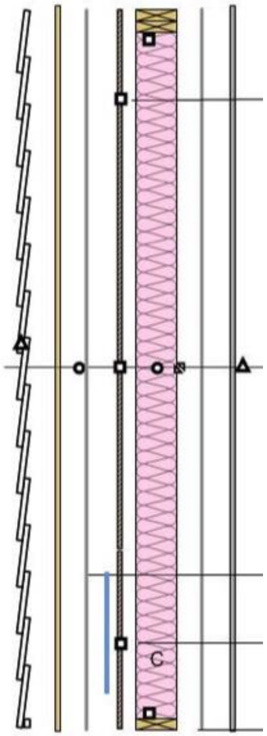
Split Insulation Approach

Canadian Higher R-value Wall Research

- North and south elevations were used for testing
- Natural weather exposure (Southern Ontario)
- Interior Conditions: 21 °C, 40% RH (winter)

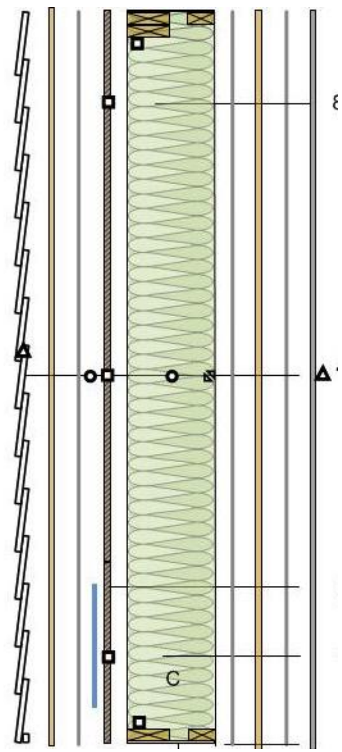
High R-value Wall Research

2x6 Datum



R-24 (installed)

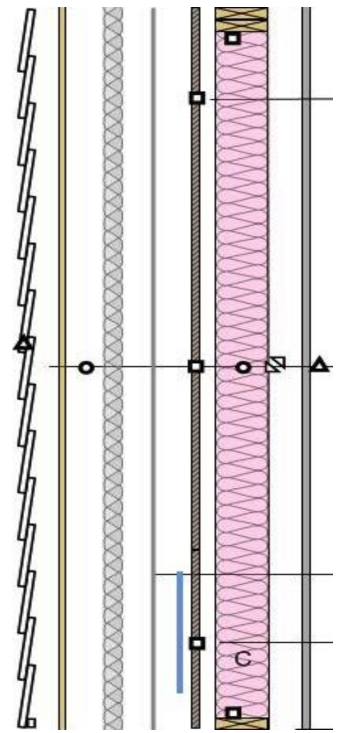
Double Stud



R-35 (installed)

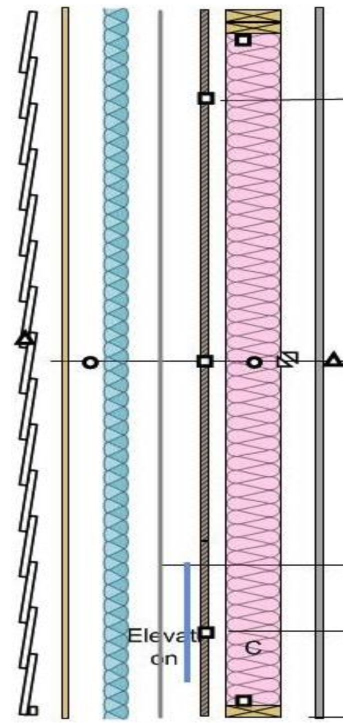
I-Joist similiar

Split – Polyiso



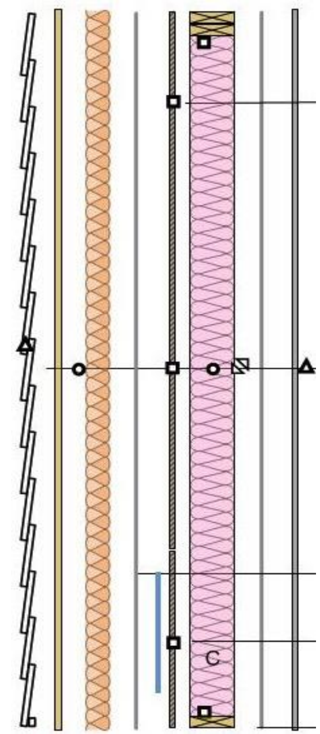
R-35 (installed)

Split – XPS



R-35 (installed)

Split – Mineral Wool



R-34 (installed)

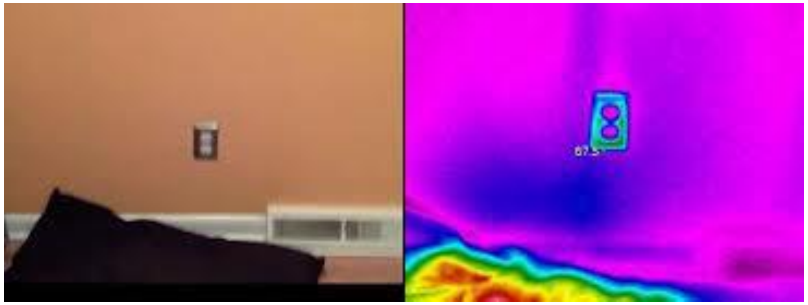
Test walls in test hut

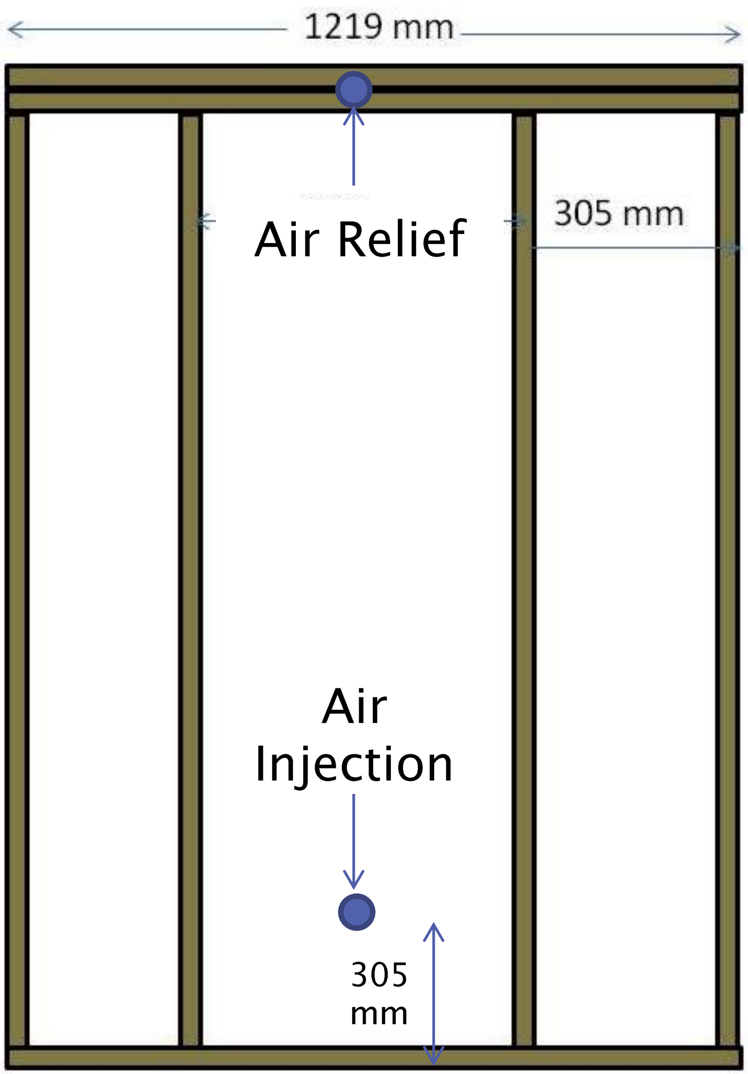
3 exterior insulated samples

Finished, under test

Air Leakage Apparatus

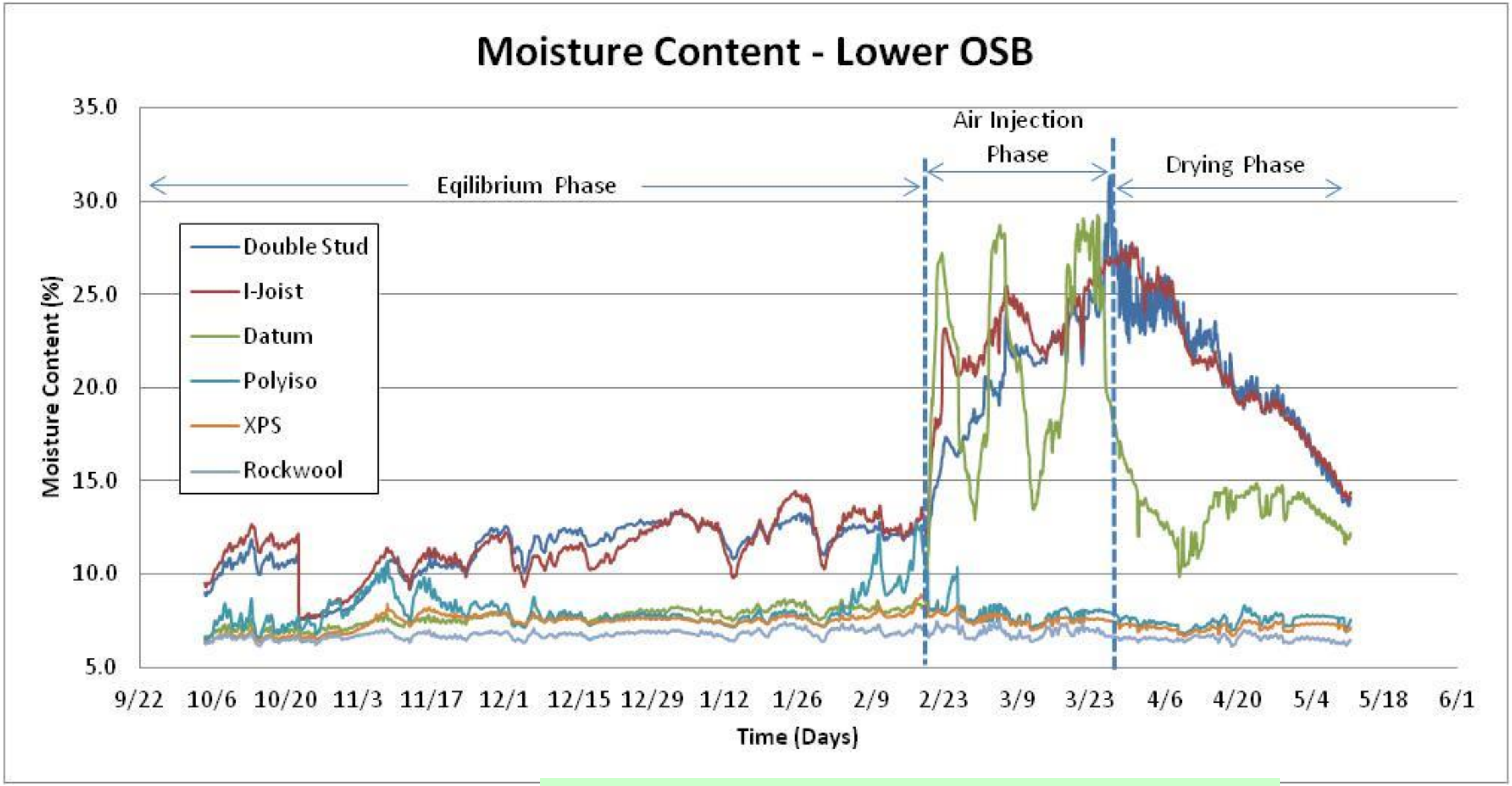
- Inject room air at bottom of wall
- Control air flow path using upper air relief hole
- Represents air leakage at electrical outlet





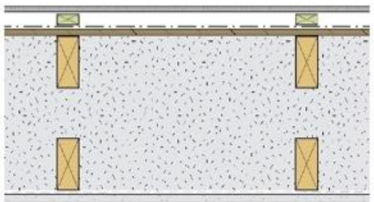
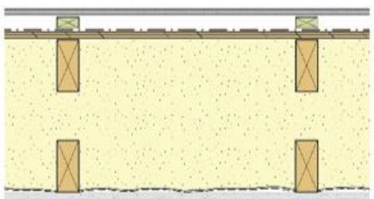
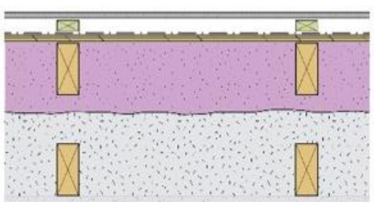
North Side OSB Moisture Content

Many results, here is one example….

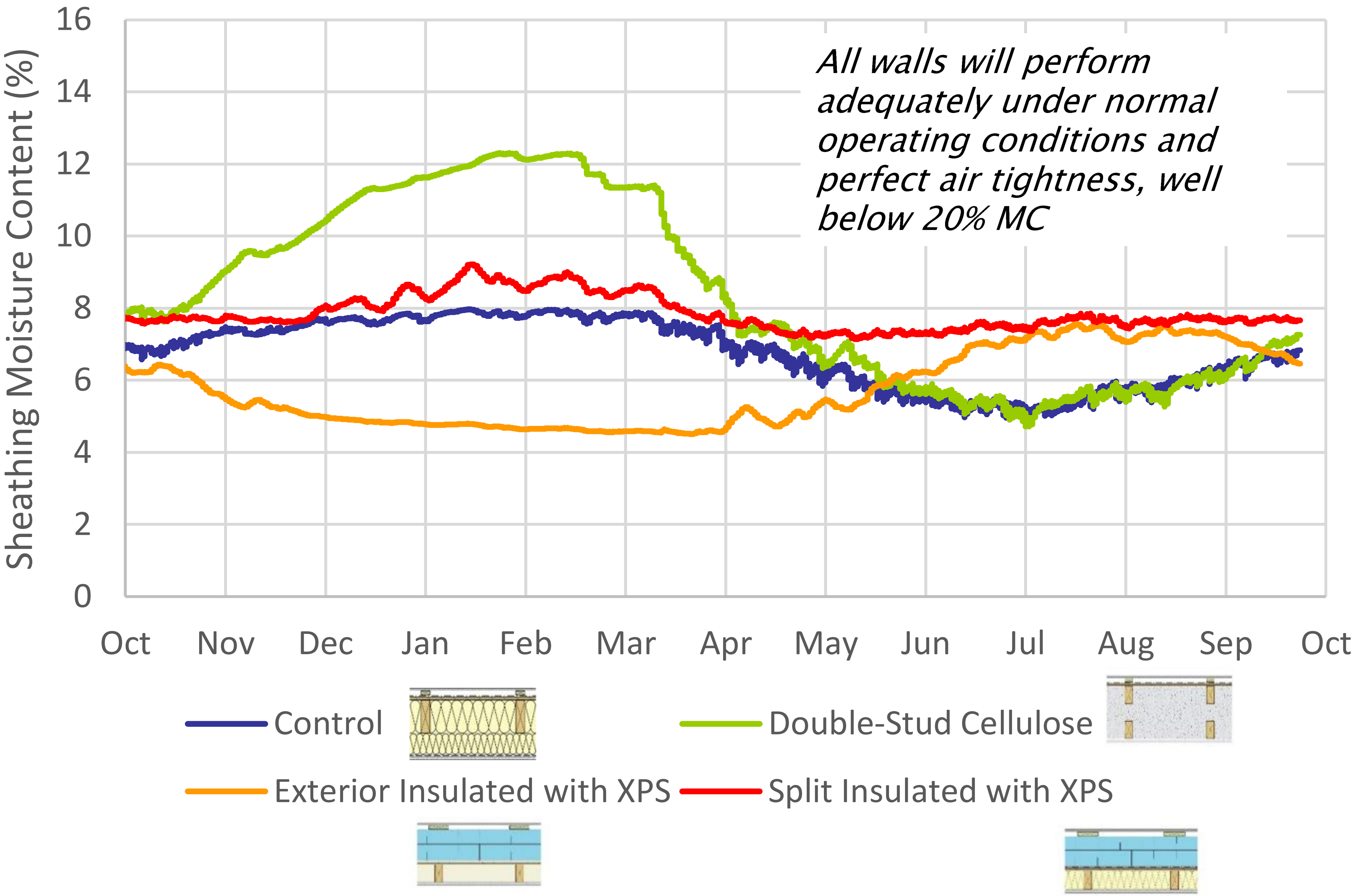


Enough exterior insulation avoids air leakage condensation risk

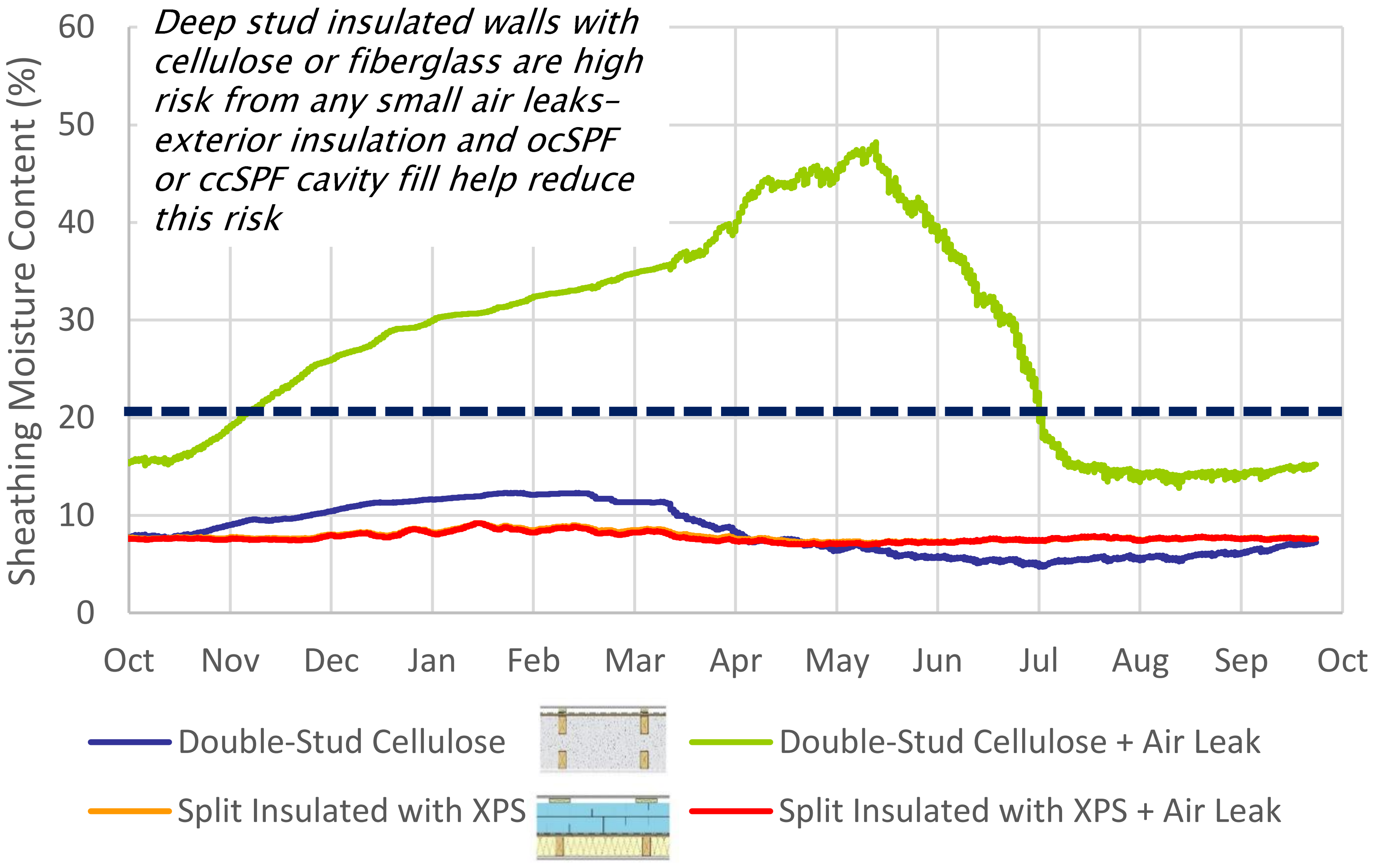
Insulation Variables – Double Stud Walls/SIPs

		Effective R-value @ Standard 24°C	**Effective R-value @ Cold -20°C**
	13.5” Dense-packed (4pcf) cellulose (CFI), 6.5” gap between 2x4s	R-38	**R-41**
	13” Open-cell ½ pcf sprayfoam (ocSPF), 6” gap between 2x4s	R-37	**R-40**
	5” Closed-cell 2 pcf sprayfoam (ccSPF) and 7” Dense-packed (4pcf) cellulose (CFI), 5” gap between 2x4s	R-38	**R-40**
	8” EPS SIPs	R-32	**R-40**

Yellowknife Computer model – Normal Conditions



Yellowknife Computer model – with Incidental Air Leakage



Section 4: Getting into the Details

Enclosure assemblies

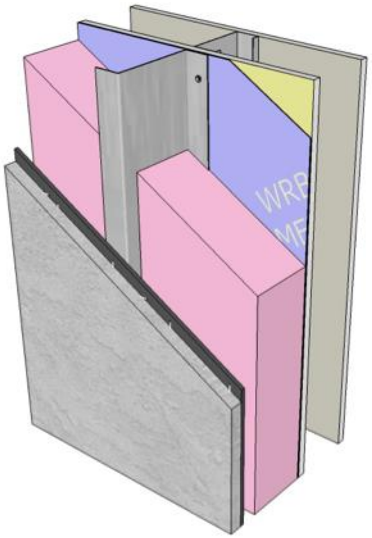
→ Walls

→ Roofs

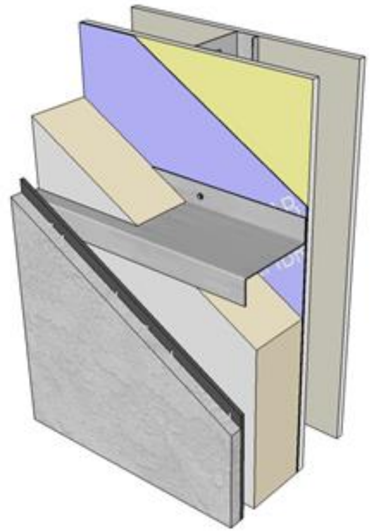
→ Basements and Slab

Cladding attachment

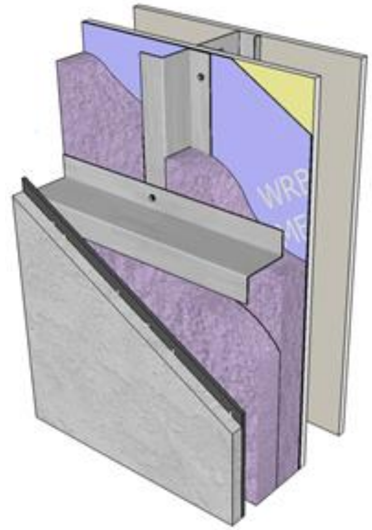
Many Cladding Attachment Options



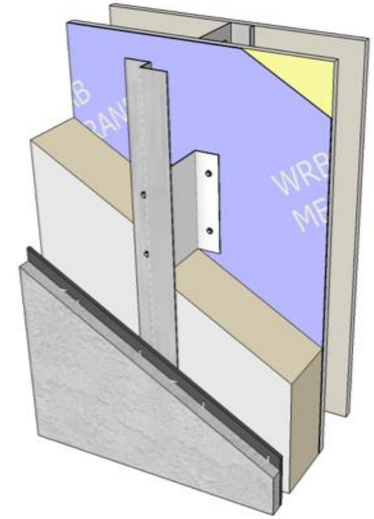
Vertical Z-girts



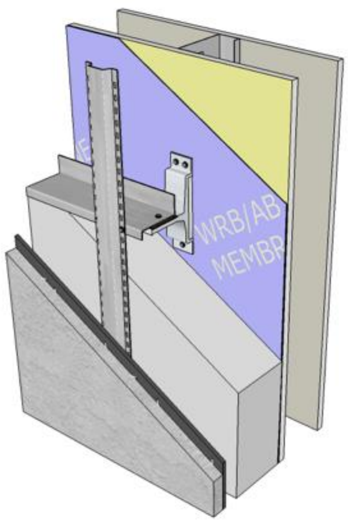
Horizontal Z-girts



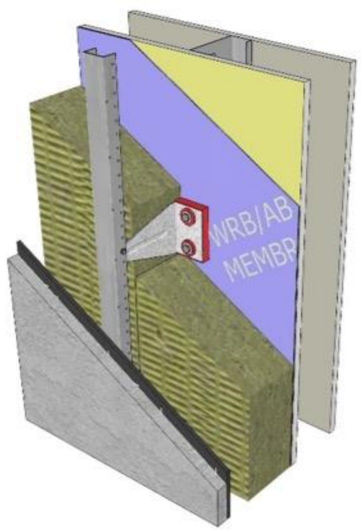
Crossing Z-girts



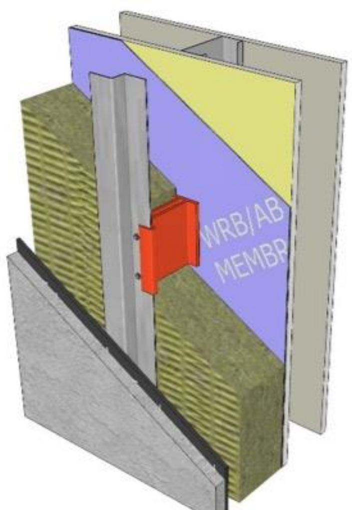
Galvanized/Stainless Clip & Rail



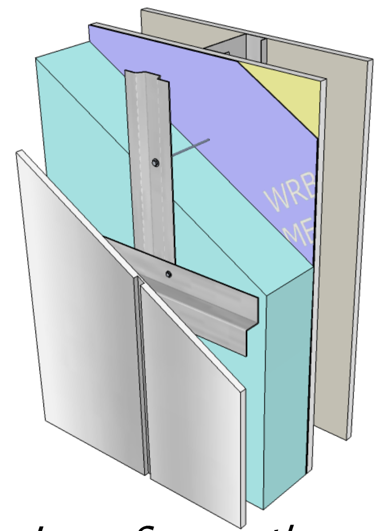
Aluminum Clip & Rail



Thermally Improved Clip & Rail

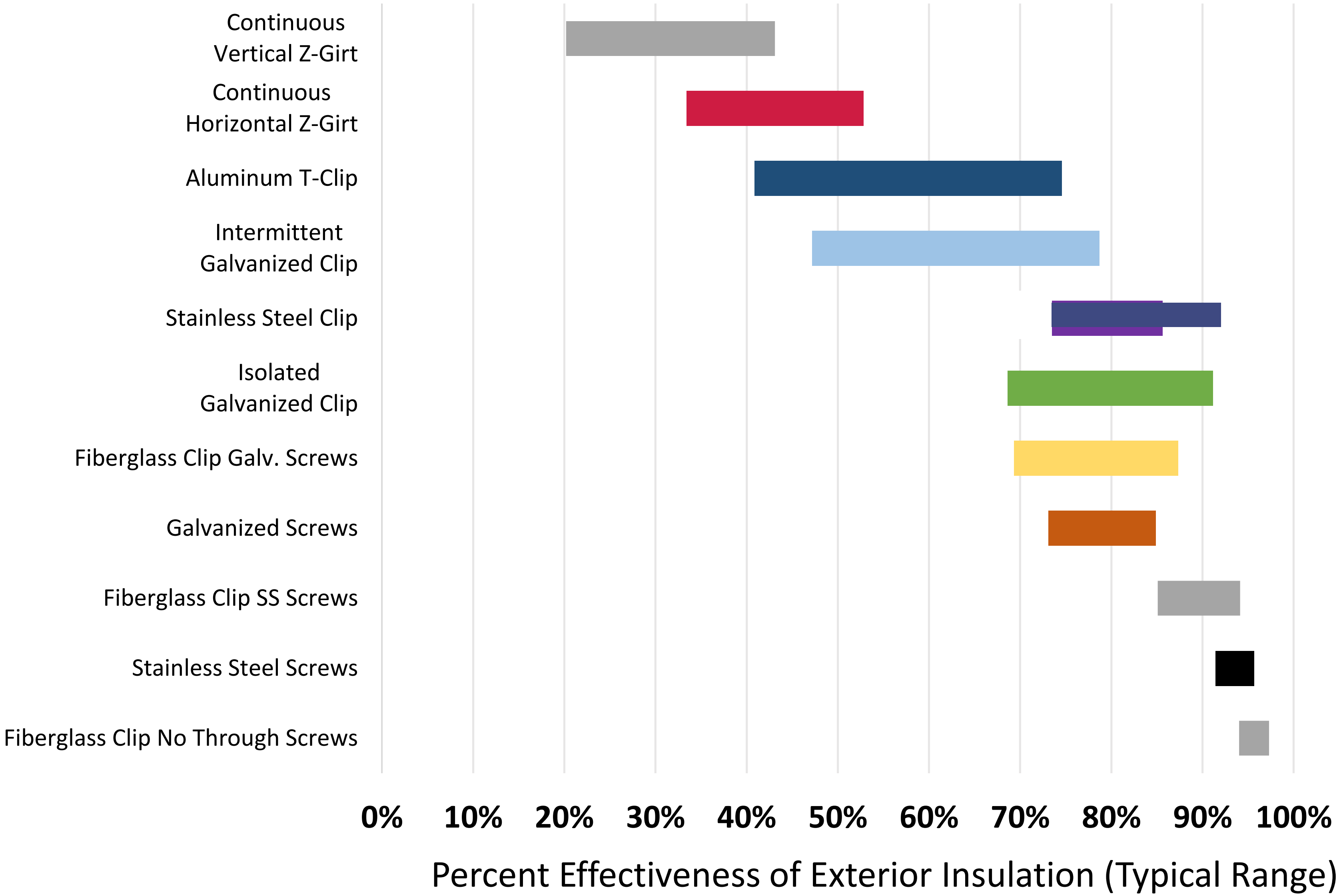


Non-Conductive Clip

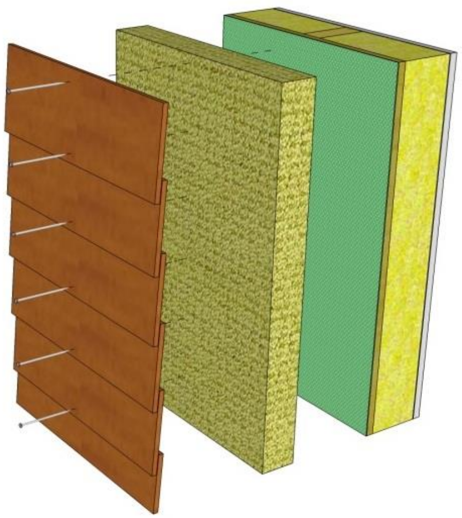


Long Screws through Insulation

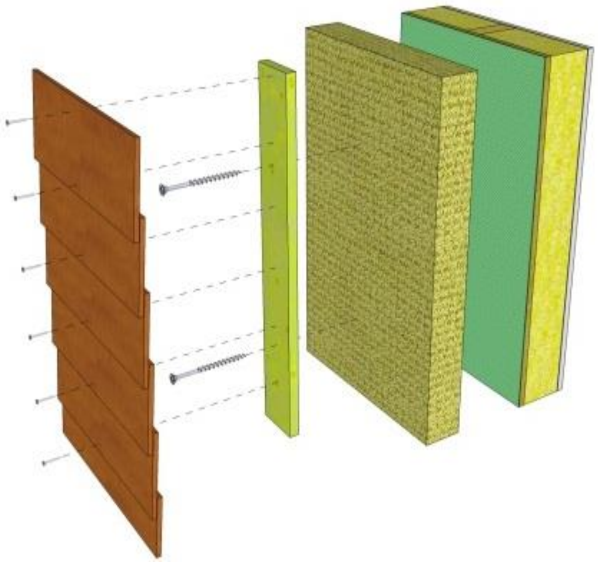
Summary of Cladding Support Performance



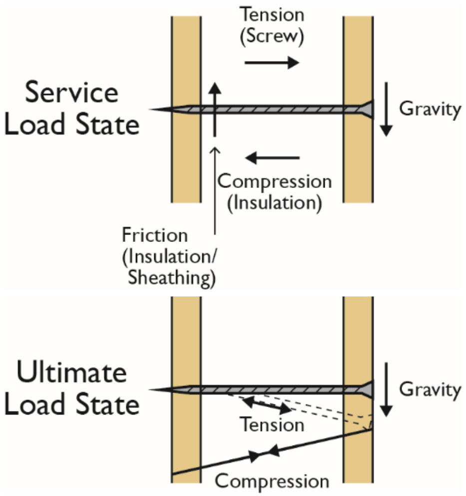
Cladding Attachment: Screws through Insulation

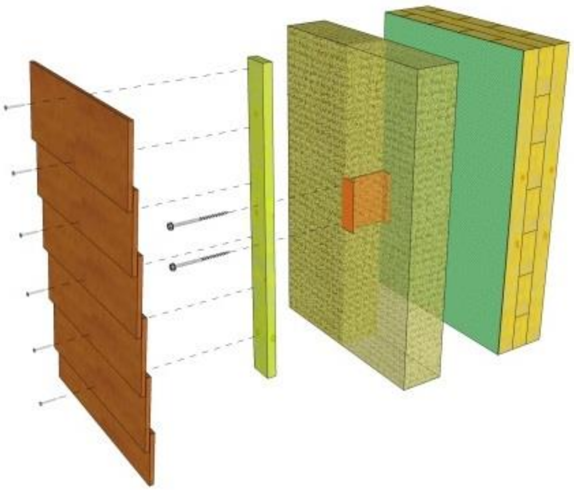


Longer cladding Fasteners directly through rigid insulation (up to 2" for light claddings)



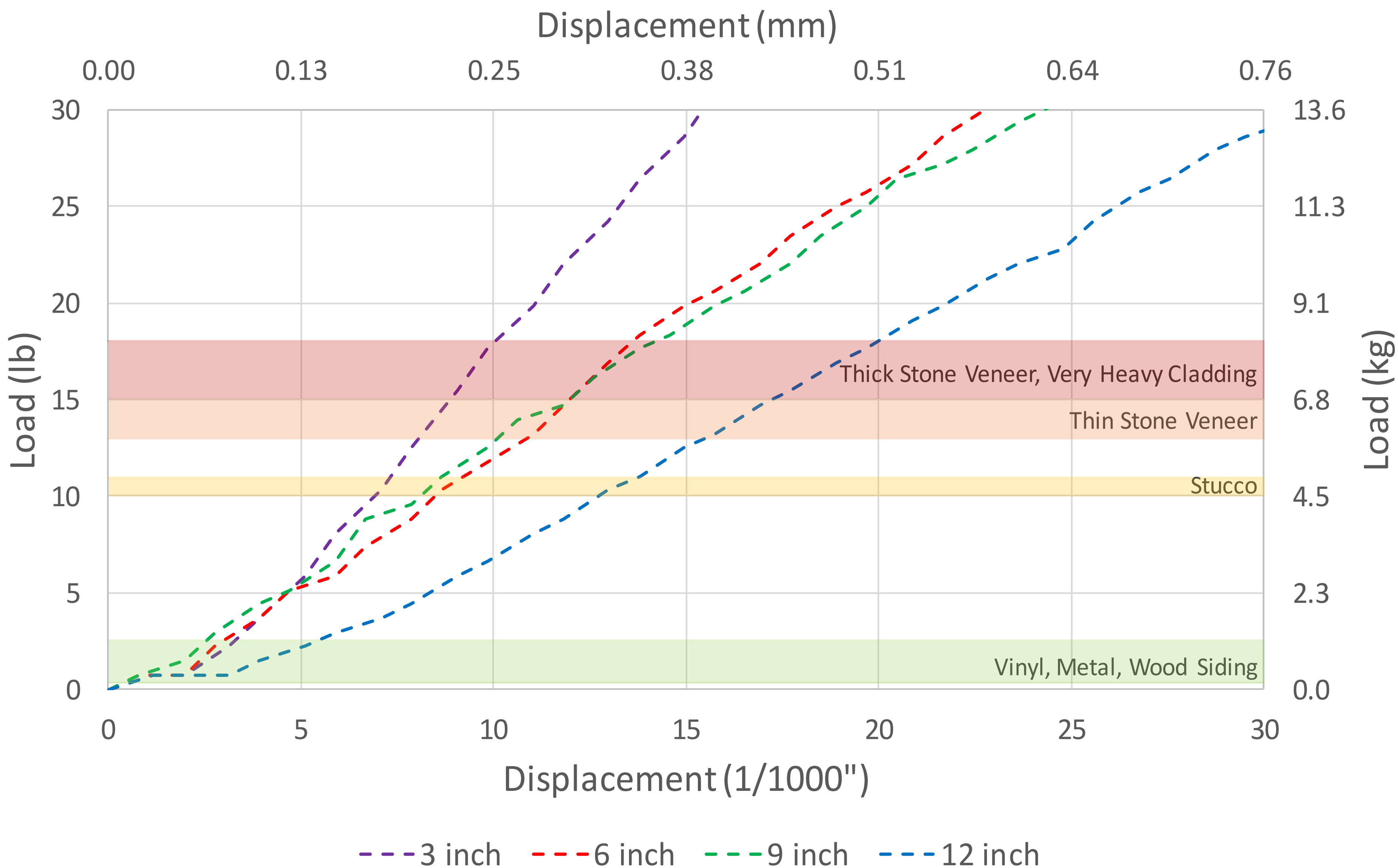
Long screws through vertical strapping and rigid insulation creates truss – short cladding fasteners into vertical strapping



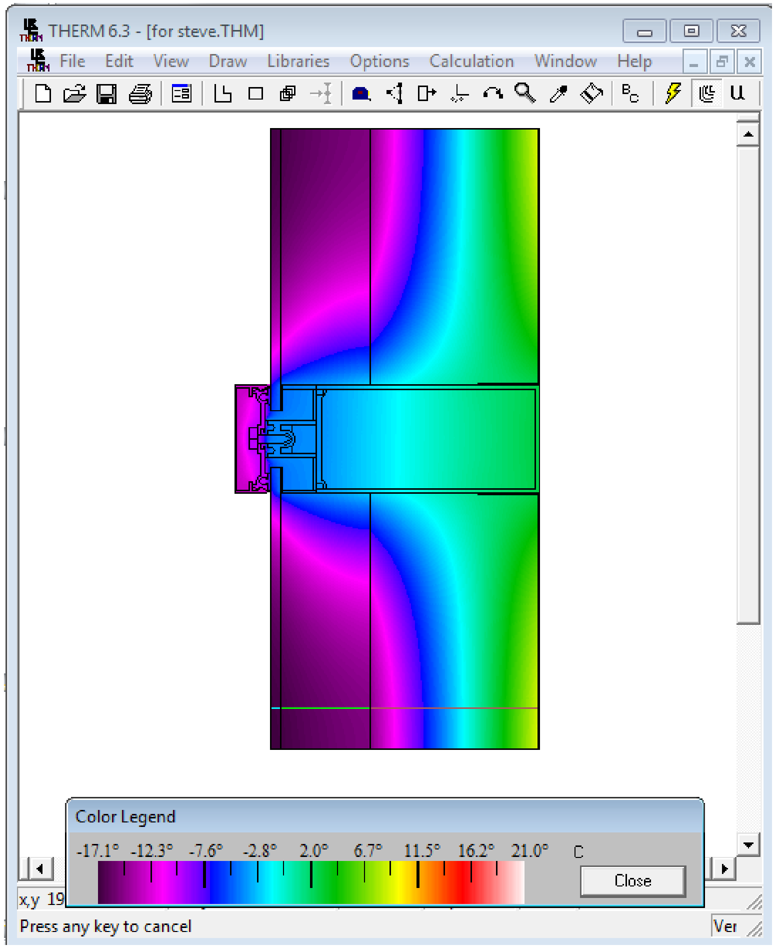


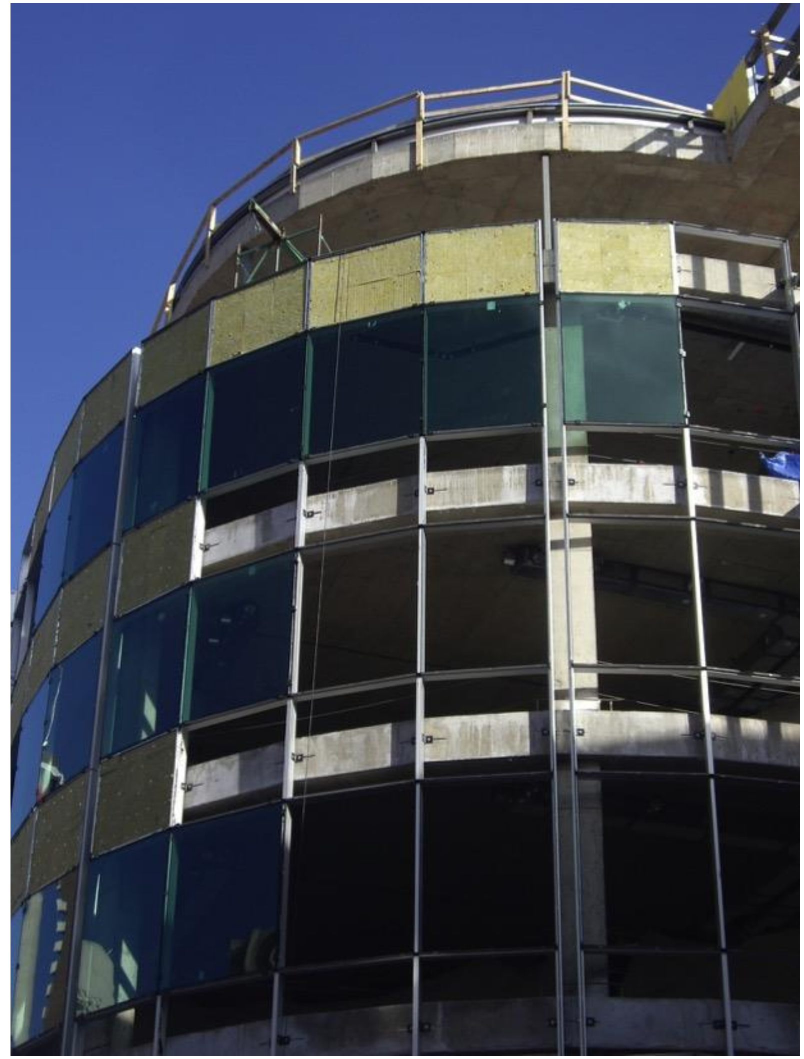
Rigid shear block type connection through insulation, short cladding fasteners into vertical strapping

What about Really Thick Exterior Insulation?



Spandrels





Nominal R-14

Actual R-4.0 Assembly: U-0.250 BTU/hr-ft^2-°F

Even R-20 spandrel < R-5

→

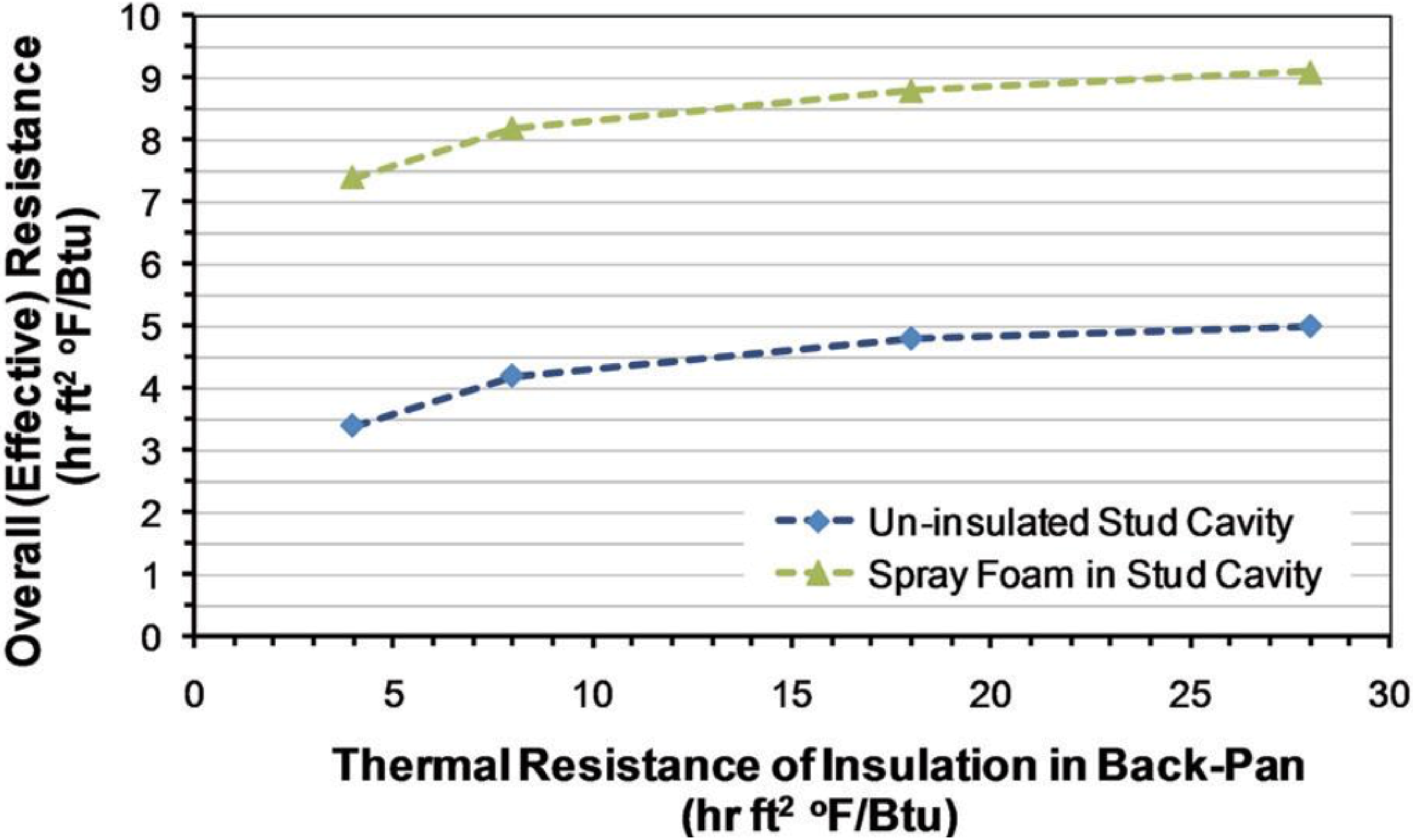
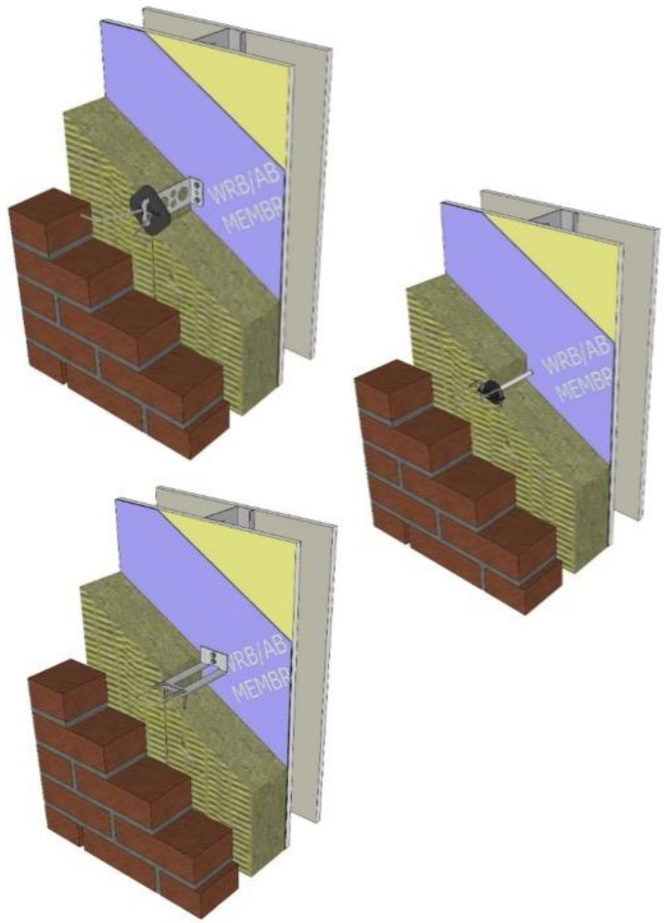
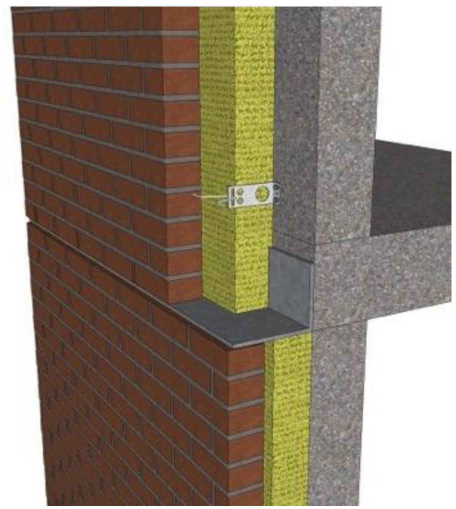


Figure 1: Diminishing Rate of Return of Spandrel Section Overall Thermal Reaction.

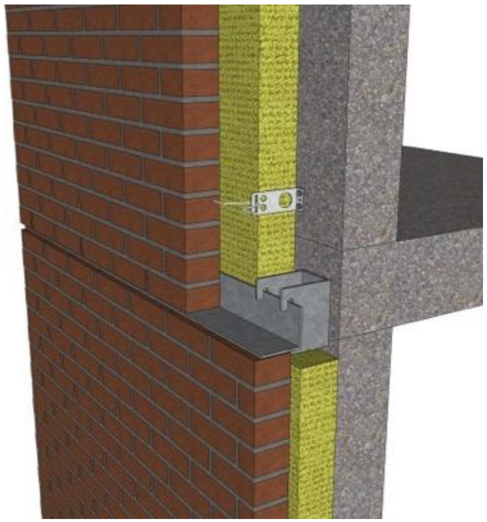
Source: Morrison-Hershfield

Cladding Attachment: Masonry Ties & Shelf Angles





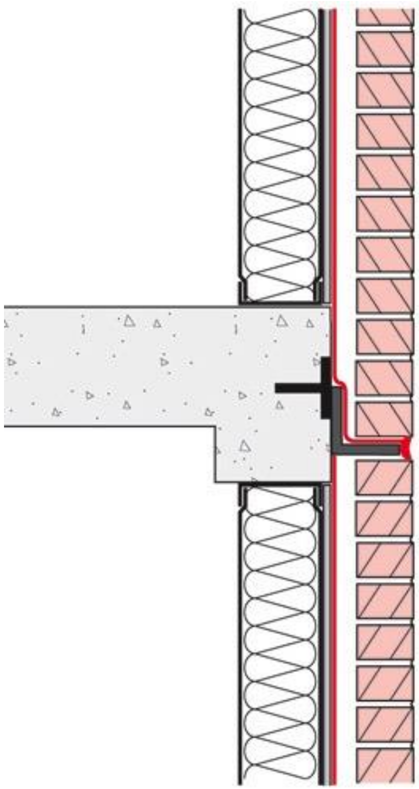
Continuous shelf angles
~40-50% R-value loss



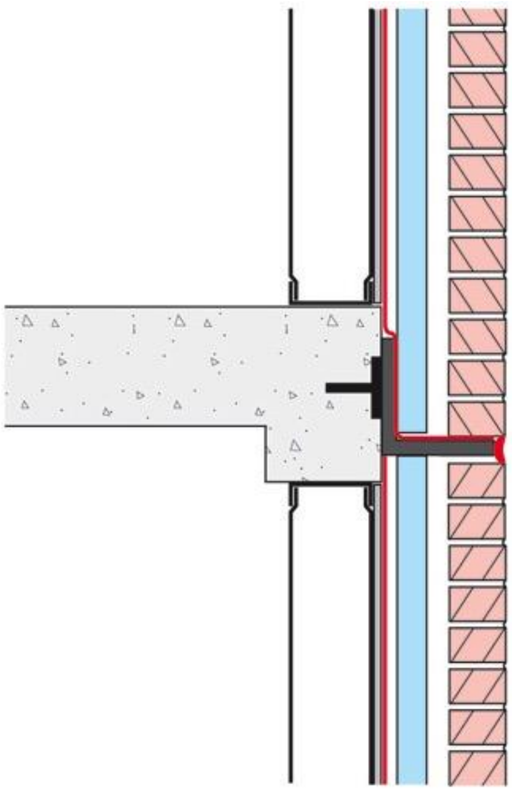
Brick ties
10-30% loss for most galvanized ties,
5-10% loss for stainless steel

Shelf angle on stand-offs
only ~15%-20 R-value loss

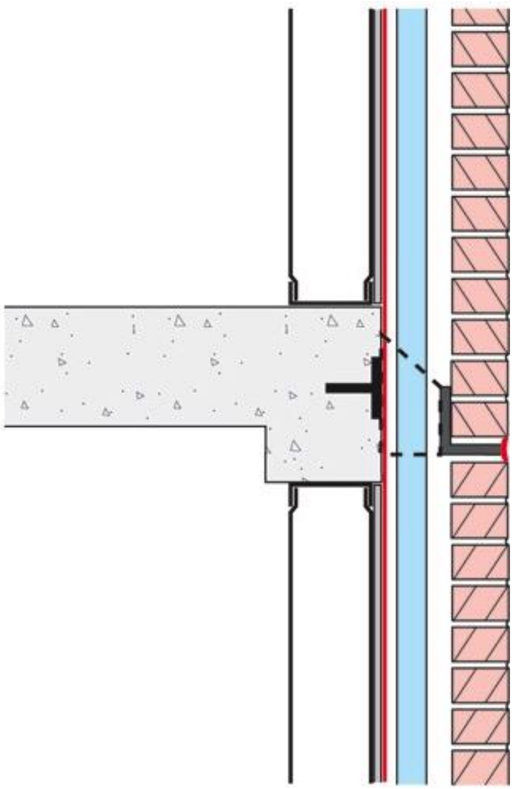
Relieving Angles



"The Ugly"



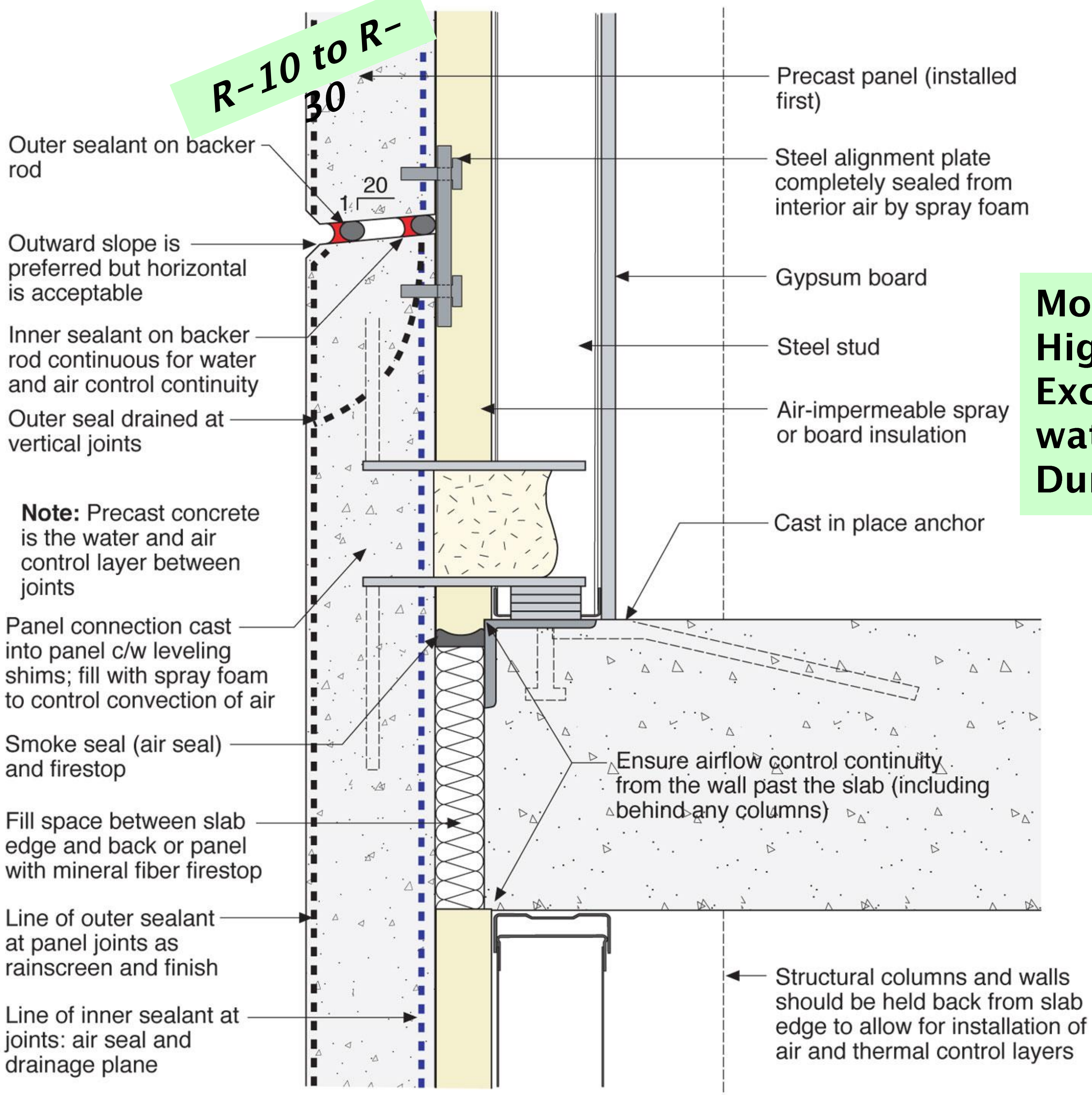
"The Bad"



"The Good"

Architectural Precast

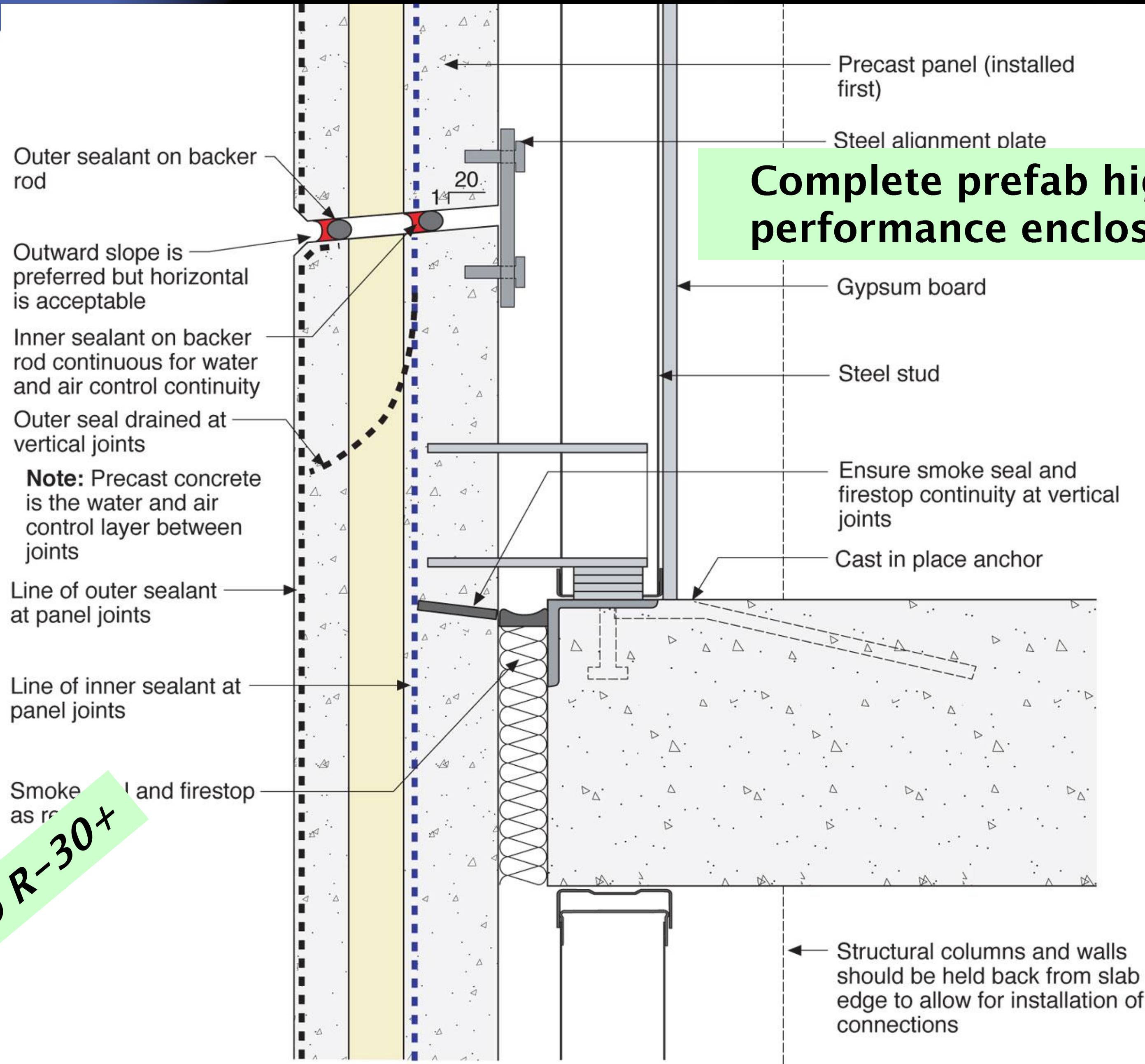
R-10 to R-30



Modern Approach
High thermal
Excellent air / water
Durable

Architectural Precast

Multi-wythe Insulated Sandwich panels

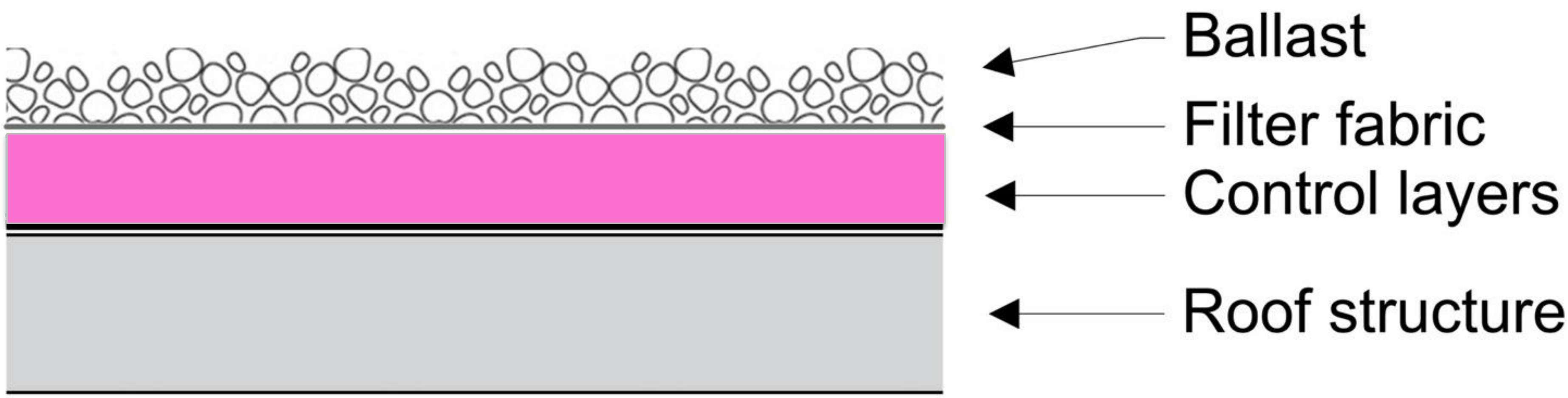


Complete prefab high-performance enclosure

R-10 to R-30+

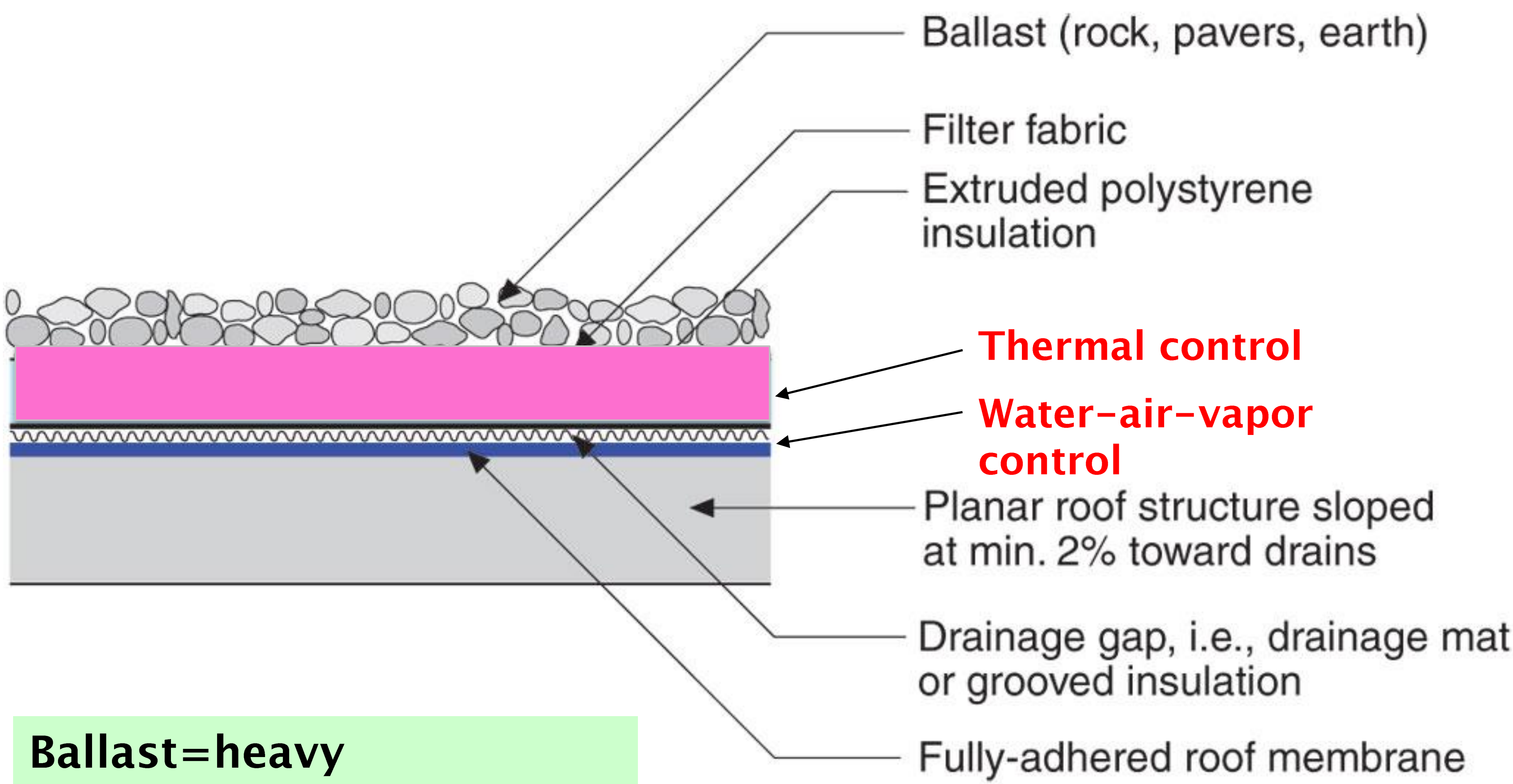
Waterloo Region Courthouse
NORR Architects

The "Perfect" Roof?: Protected Membrane Roof



Some owners insist on it. Eg. US Federal Government (GSA)

The "Perfect" Roof?: Protected Membrane Roof

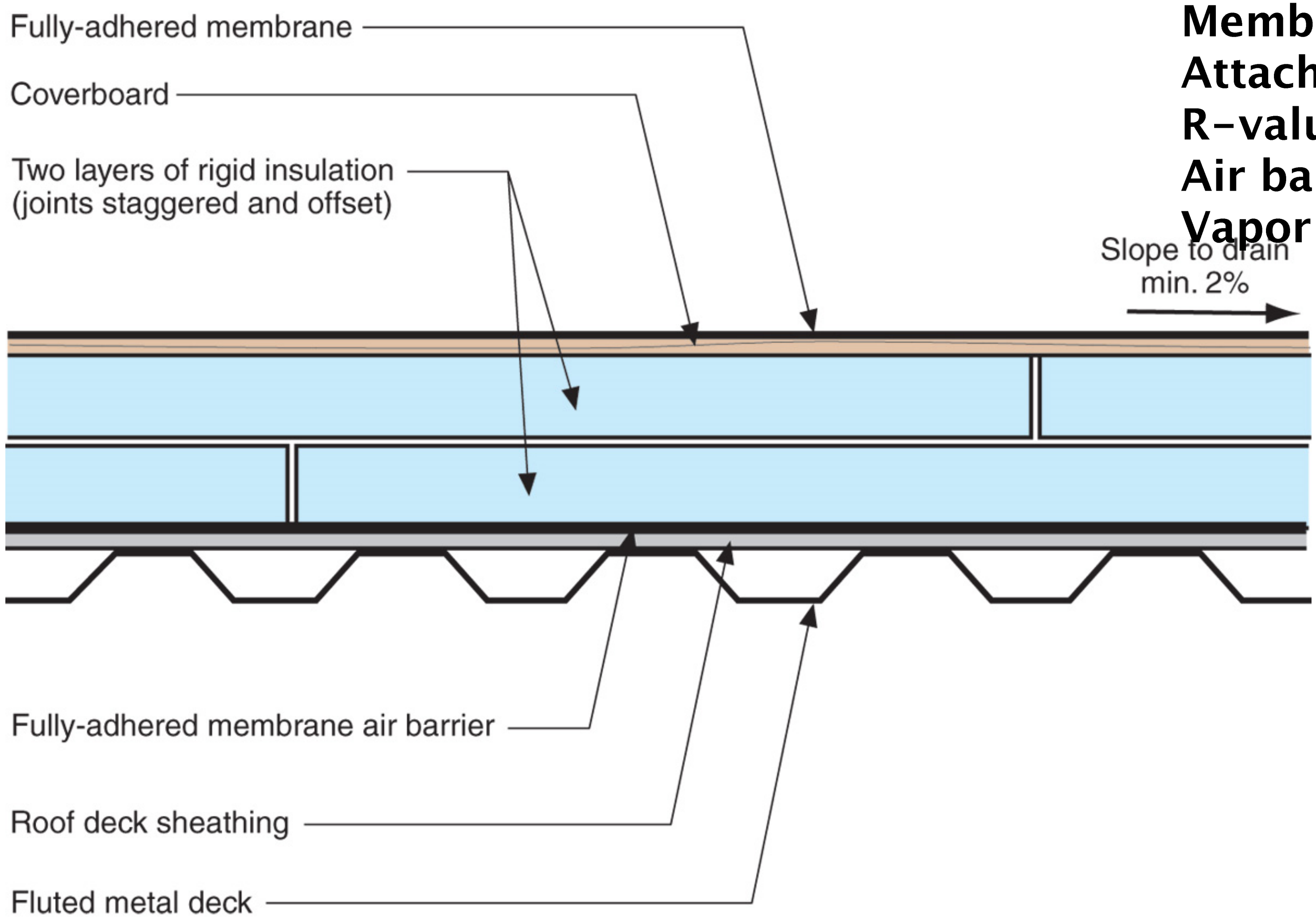


Ballast=heavy
Premium insulation cost

Plaza Decks and PMR

The tried and true, light-weight alternate

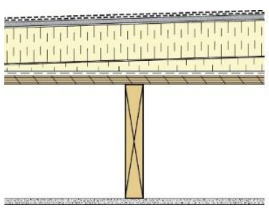
Questions:
Membrane chemistry?
Membrane color?
Attachment?
R-value?
Air barrier?
Vapor barrier?



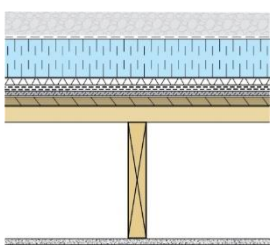
From: Straube, J.F. *High-Performance Enclosures*, Building Science Press 2012.

High R-value Roof Assemblies

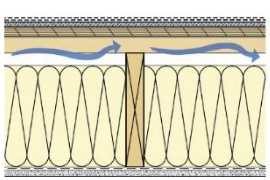
Code Minimum Insulated Low-Slope Roofs



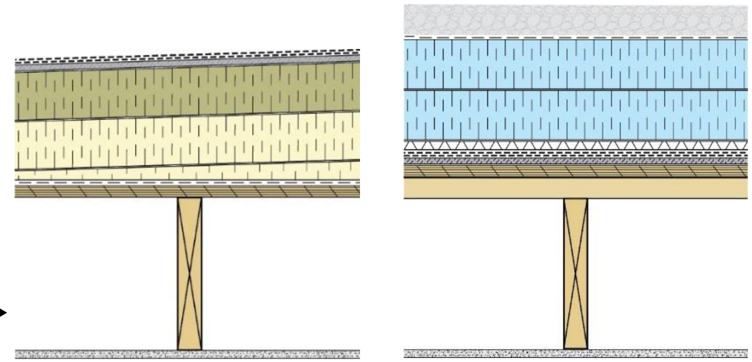
Conventional



Inverted/PMR

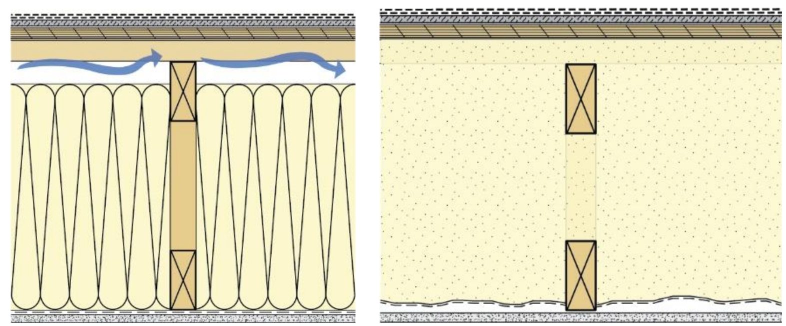


Vented



Exterior Insulated+ *(conventional or inverted/PMR)*

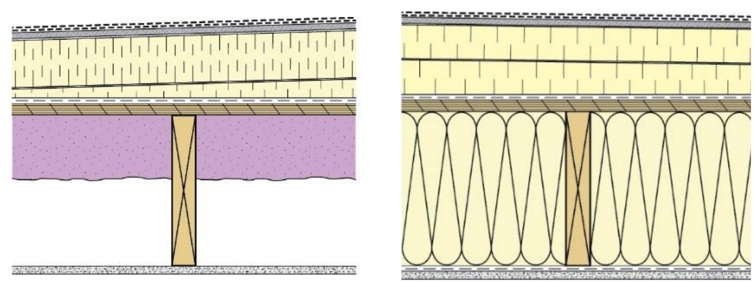
- Best durability but most expensive
- Some challenges with more layers of insulation & detailing
- Simple design



Deeper Joist/Truss – *(vented or unvented)*

Least durable but least expensive

- Simple design
- Standard details with deeper structure

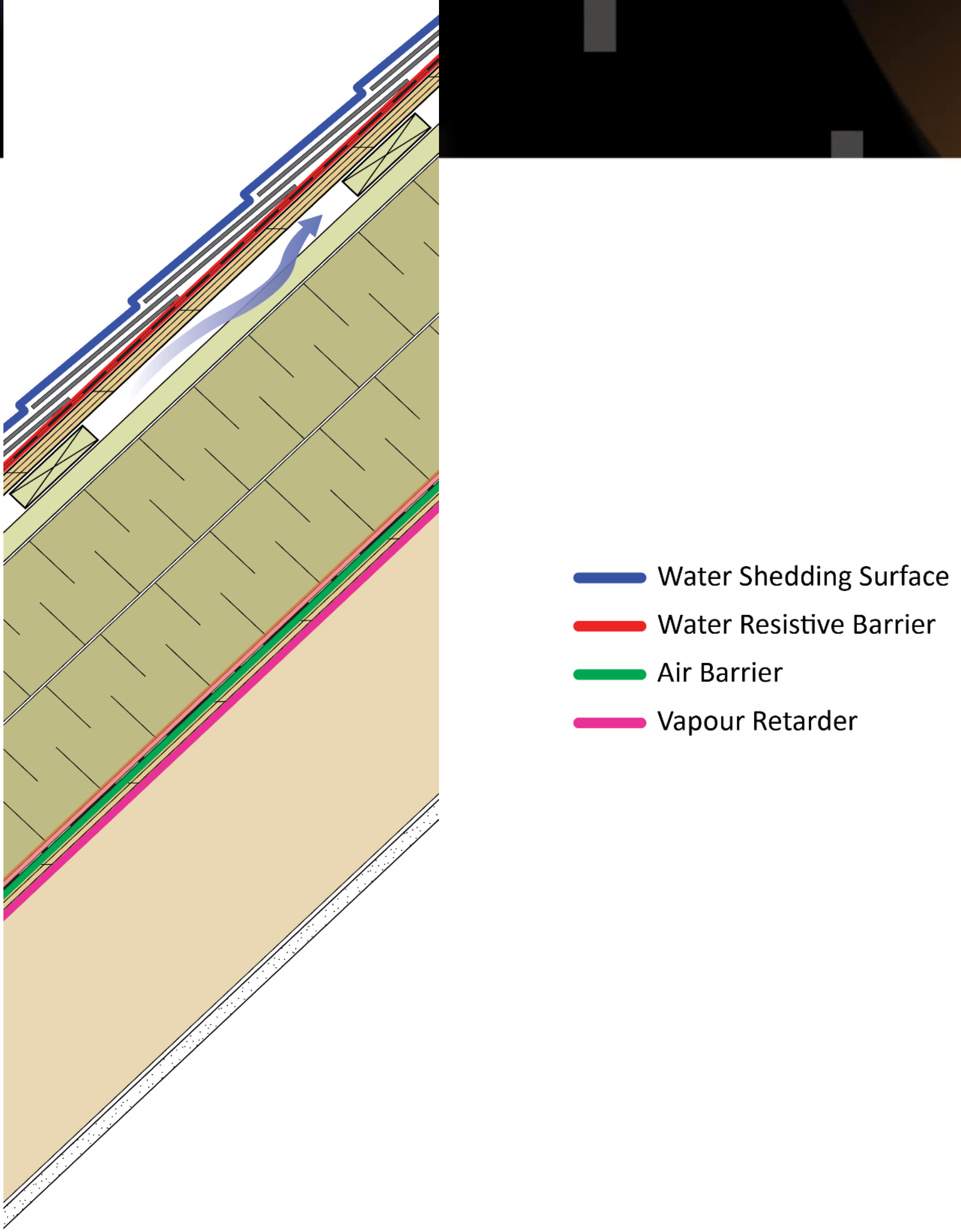


Split Insulated *(unvented)*

- Decent durability
- Moderate cost
- More complex design

Insulating Sloped & Compact Roofs

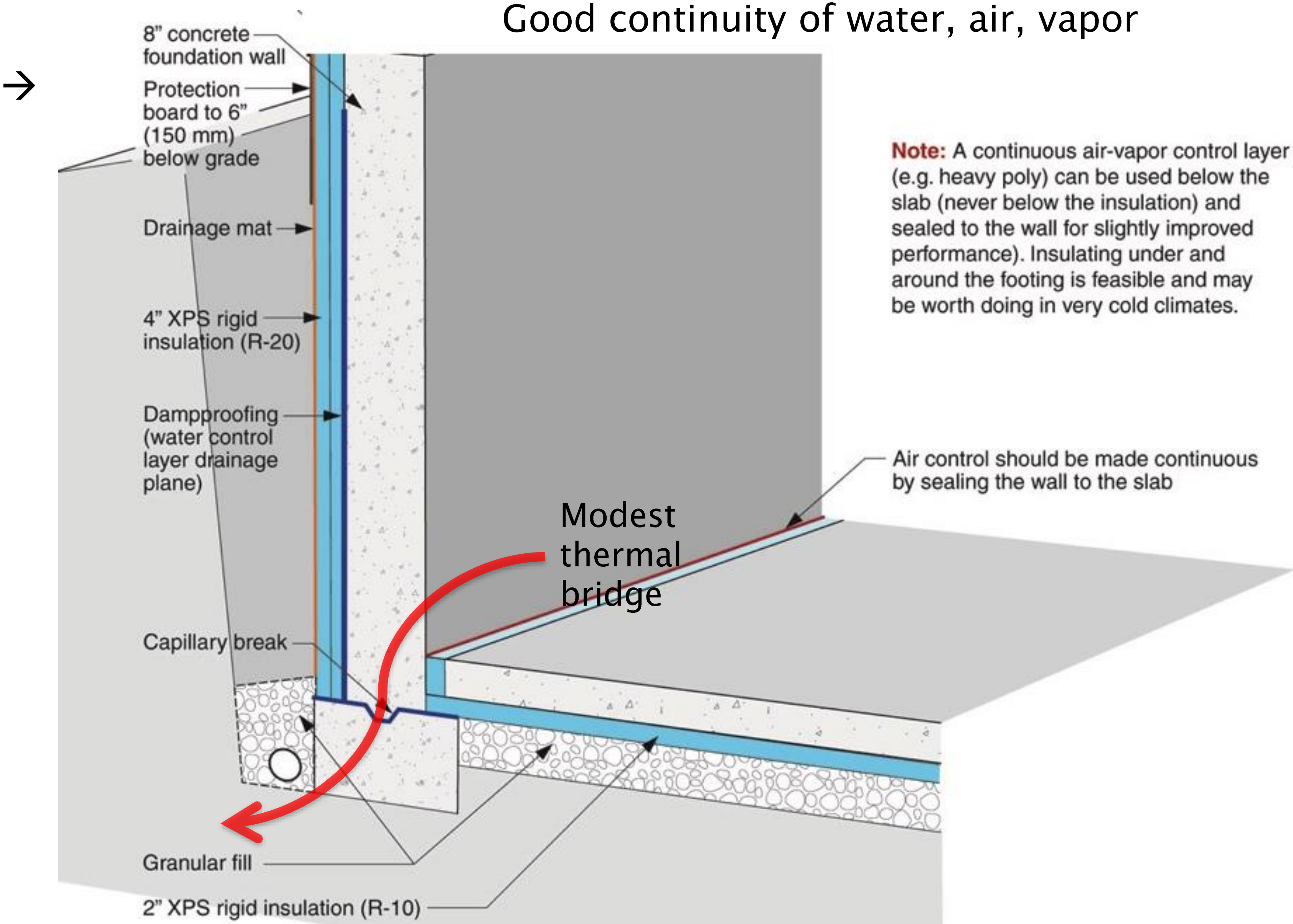
New Challenges:
- Getting to higher R-values (R-60 to R-100+)
- Vapour control?
- Air Barrier & Air Permeable insulation
- Constructability & Thickness
- Roofing Materials
- Roof Venting
- Interior Services



Unvented Exterior insulated roof

Basements

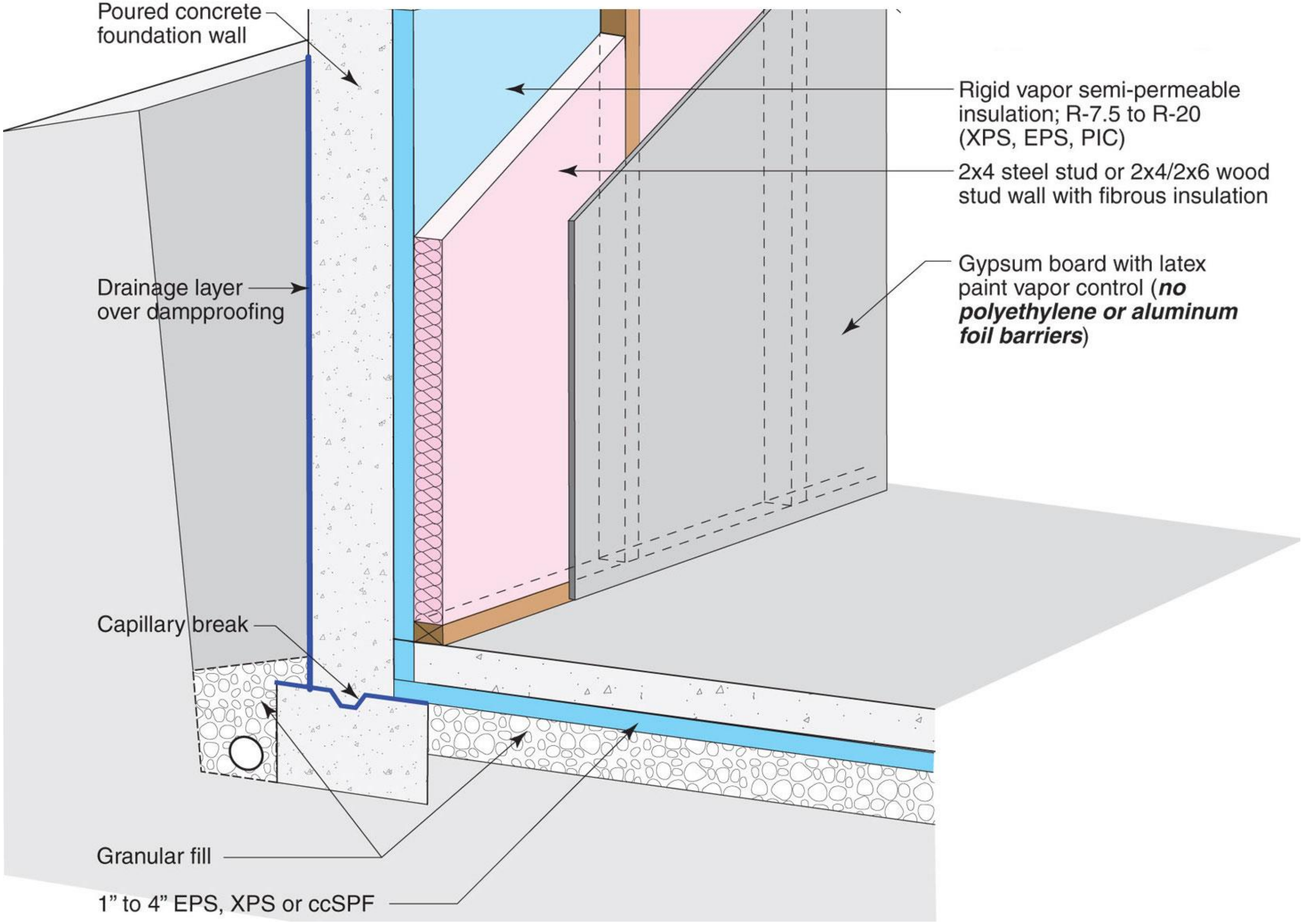
Good continuity of water, air, vapor



Exterior Insulation

→ Bituminous air-water-vapor barrier on concrete

Interior Insulation Solution

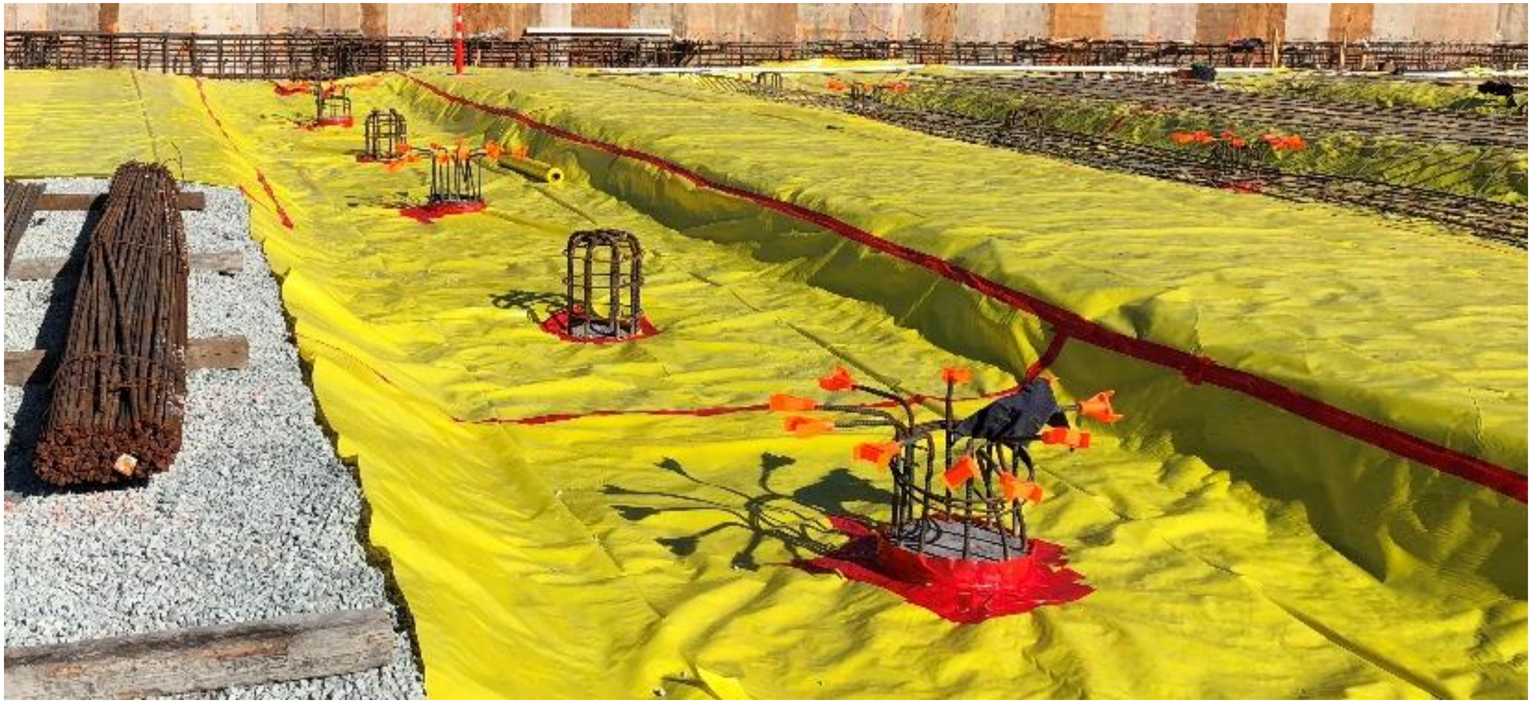


Slabs

Slabs

→ Airtightness still important

→ Radon control, moisture part of airtightness



ccSPF as on-grade insulation

Conclusions

- → High performance enclosures are the future
- → Eventually Net Zero, or close, will be the norm
- → Modern principles of building enclosure design can be extended to deliver the future
  - → Higher R-value
  - → Limited thermal bridges
  - → Excellent Airtightness
  - → Usually, exterior continuous insulation

Exterior Water-Air-Thermal Barriers