Meeting & Exceeding Thermal Requirements of the Code

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2017 THERMAL PERFORMANCE REQUIREMENTS SEMINAR SERIES

MEETING AND EXCEEDING CURRENT AND FUTURE ENERGY EFFICIENCY REQUIREMENTS

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Seminar Series

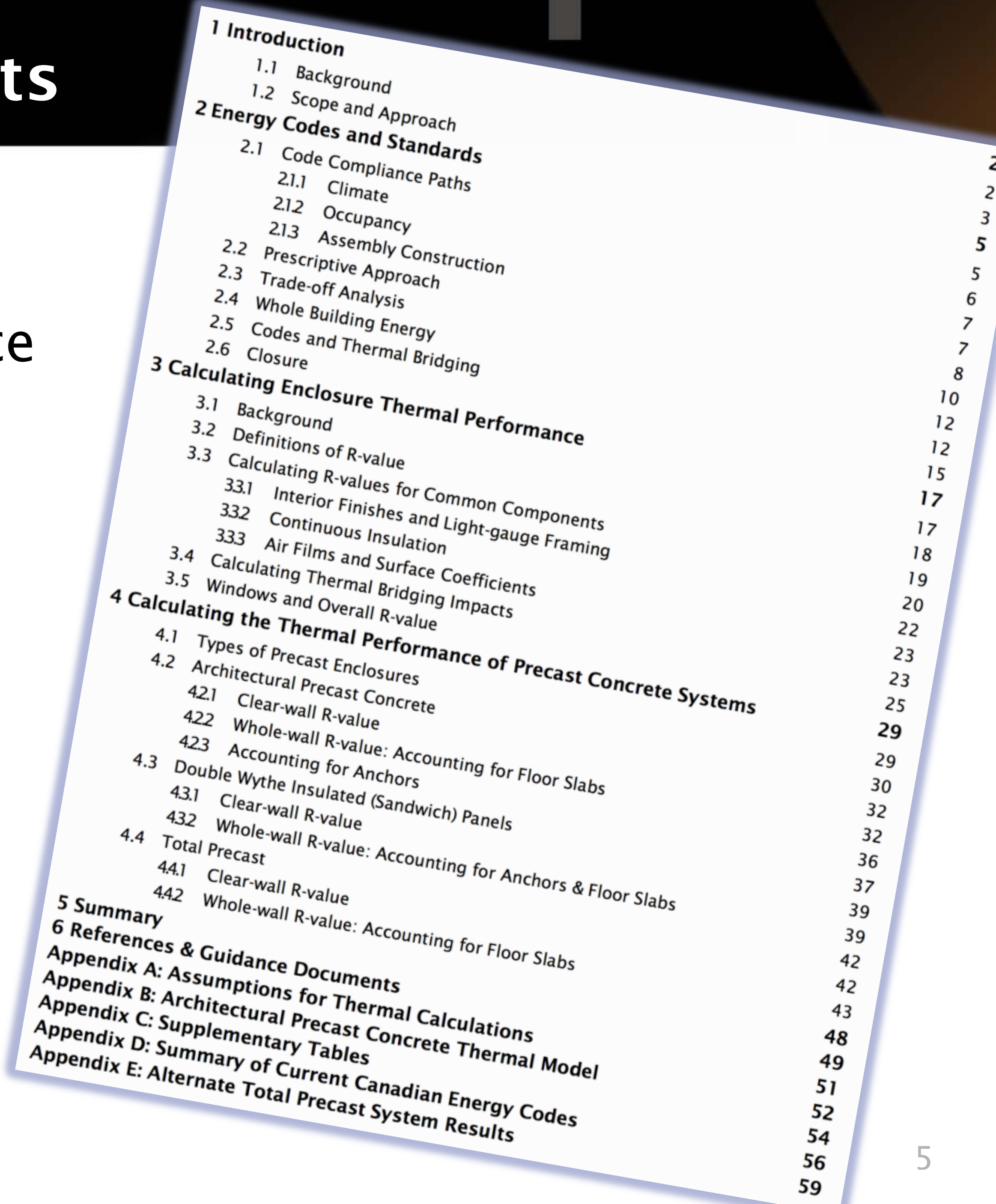
- → Not an interpreting code seminar
- → **Learning objectives:**
  - → Understanding the thermal performance implications of key **early-stage design decisions** related to basic enclosure design and window area.
  - → Being able to identify **multiple compliance paths** for meeting the thermal performance requirements in Canadian building codes, for precast concrete, concrete masonry and cast-in-place concrete enclosure systems.
  - → Being able to define **thermal bridging**, recognize it in architectural details, and define solutions.
  - → Understanding different definitions of R-value and how they are used in design and code compliance for **common precast concrete, concrete masonry and cast-in-place concrete systems**.

Presentation Outline

- → New Guide
- → Responds to current needs & tougher codes
- → **Focus** is to assist early-stage design :*simplified* :*approximate*
- → **Goal**: to guide design, not to demonstrate compliance

Table of Contents

1. Why High-performance
2. How codes work
3. Basic thermal calculations
4. Applications to precast / conc. masonry / cast-in-place



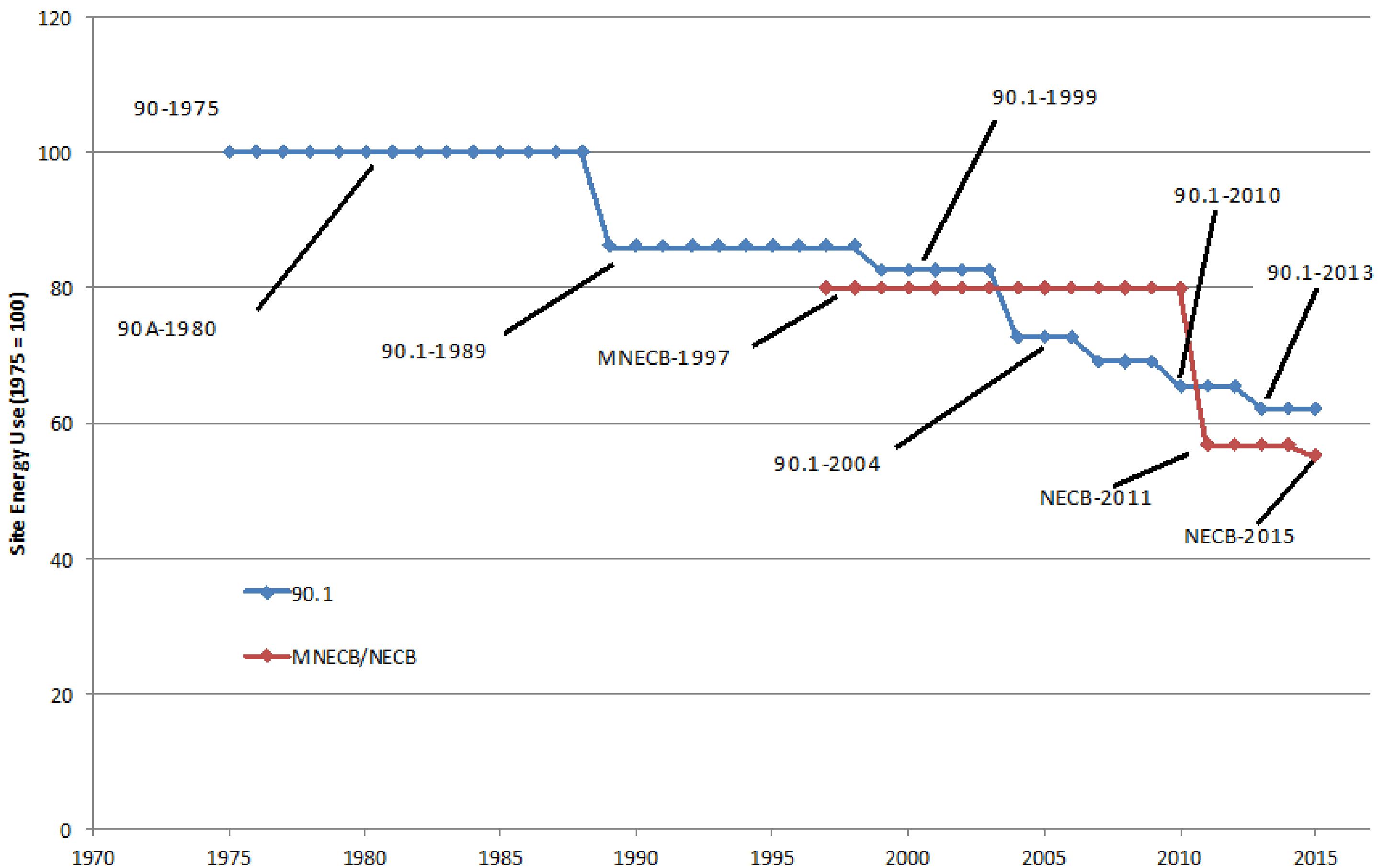
1. Why High Performance

Why High-Performance

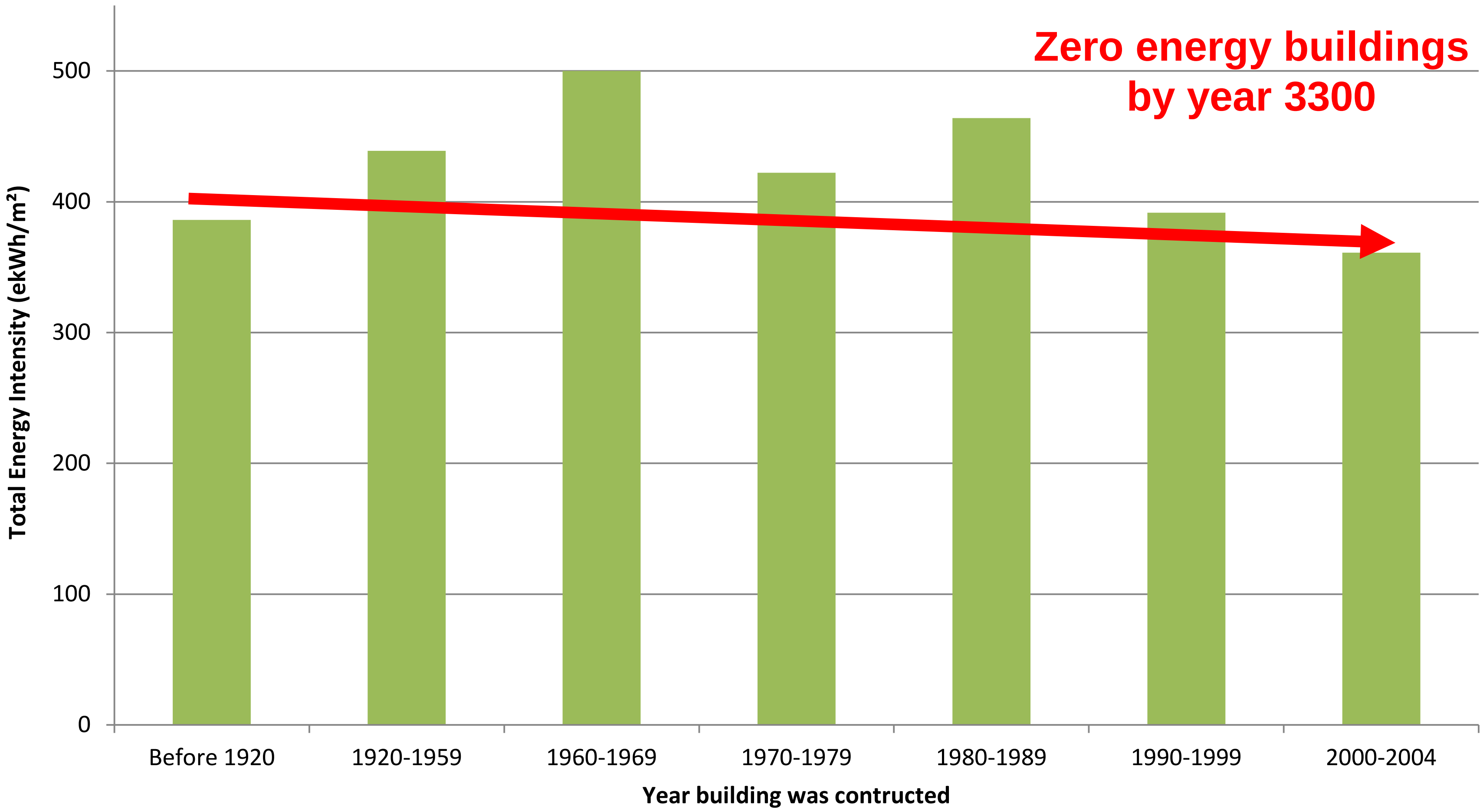
- → Codes are changing
- → Striving to achieve real energy savings, carbon reductions, and peak shaving
- → More resiliency in the face of disaster
- → Owners looking for more comfort, lower operating cost, better asset protection
- → Longer-term outlook for some… how to plan for churn, renewal, repair

Codes . . . They are a changing

→ Maximum code-allowed energy use has dropped significantly



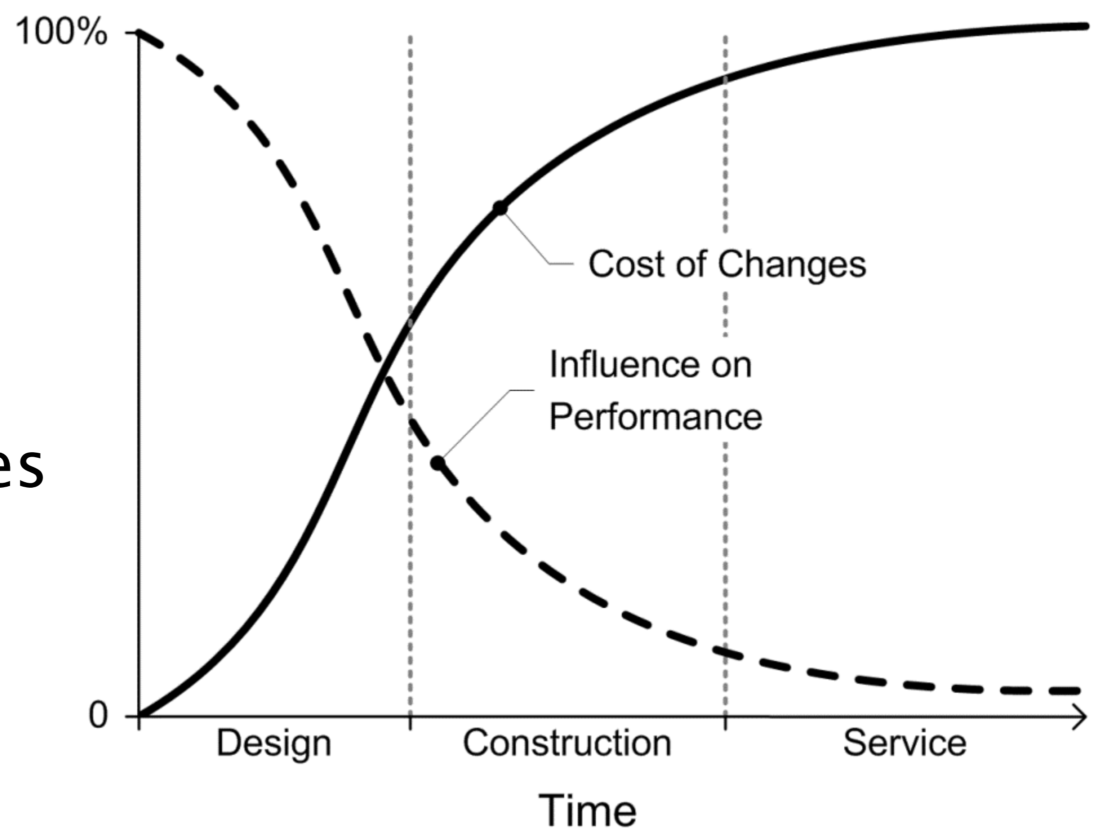
Energy Use of All Buildings – By Age of Construction



Ref: Commercial and Institutional Building Energy Use, NRCAN 2005

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

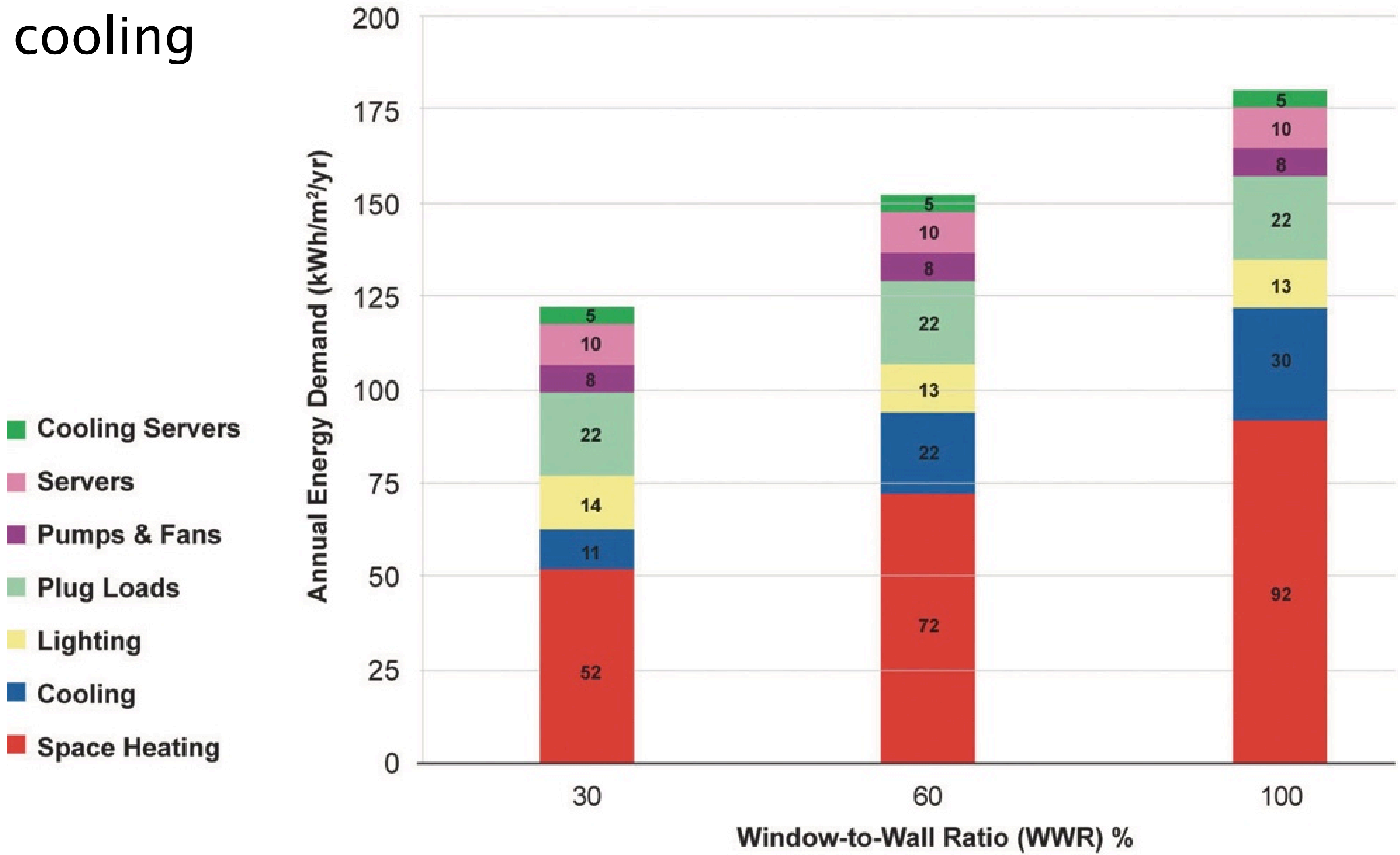


Role of Factors

- → **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

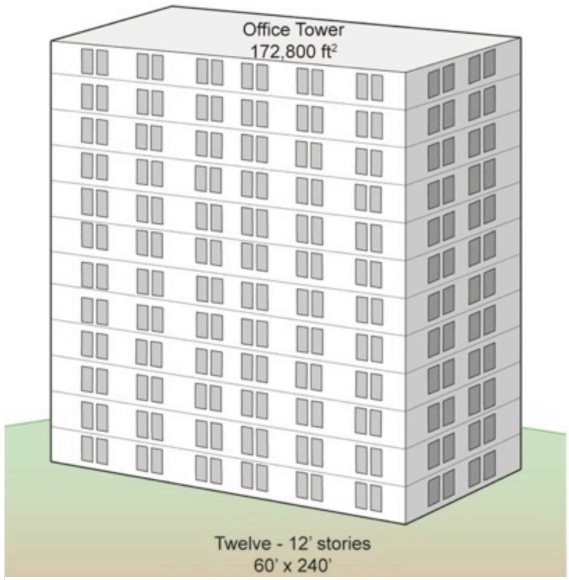
Example Low-energy Office Building

→ Adding window area = more energy for heating & cooling

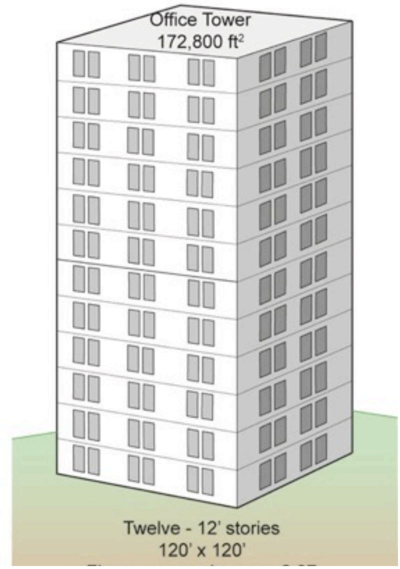


Shape & Size

Office: 12 ft. floor-to-floor
Floor plate: 14,000 ft²

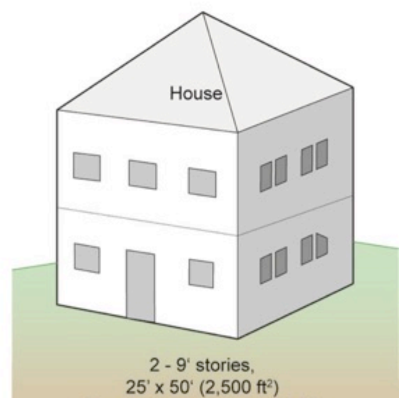


0.58 Enclosure per 1 Floor Area



0.48 Enclosure per 1 Floor Area

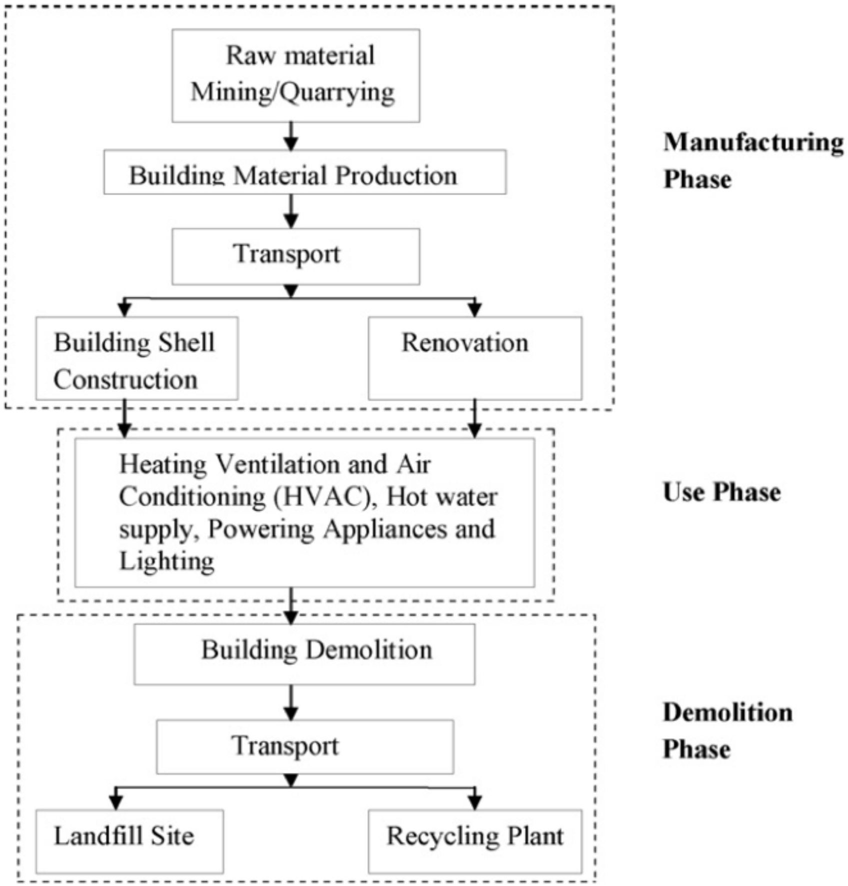
1.56 Enclosure per 1 Floor Area



1.58 Enclosure per 1 Floor Area

Aside: Embodied Energy

- → Operation / use comprises 80-90% of life-cycle energy of common buildings
- → Material choice is a small overall factor
- → Energy-efficiency & design-efficiency are 90-95%
- → Durable buildings are lower GHG



Aside: Embodied Energy

News

'Visionary' £7m eco-school to be demolished because of leaky roof

share

Durability matters

Dartington Primary School's eco buildings opened in 2010, were vacated in 2014, and now they are to be demolised
CREDIT: APEX NEWS AND PICTURES

By Telegraph Reporters
3 AUGUST 2016 • 3:10PM

The school was meant to be one of the first zero carbon primary schools to be built in the country.

But Devon County Council now aims to replace the troubled school site with a new complex which

2. How Codes Work

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 what the thermal performance of their walls are
  - → to compare to tabulated values
  - → to provide information to energy modelers
- → Level of detail in calculations depend on the code and the AHJ

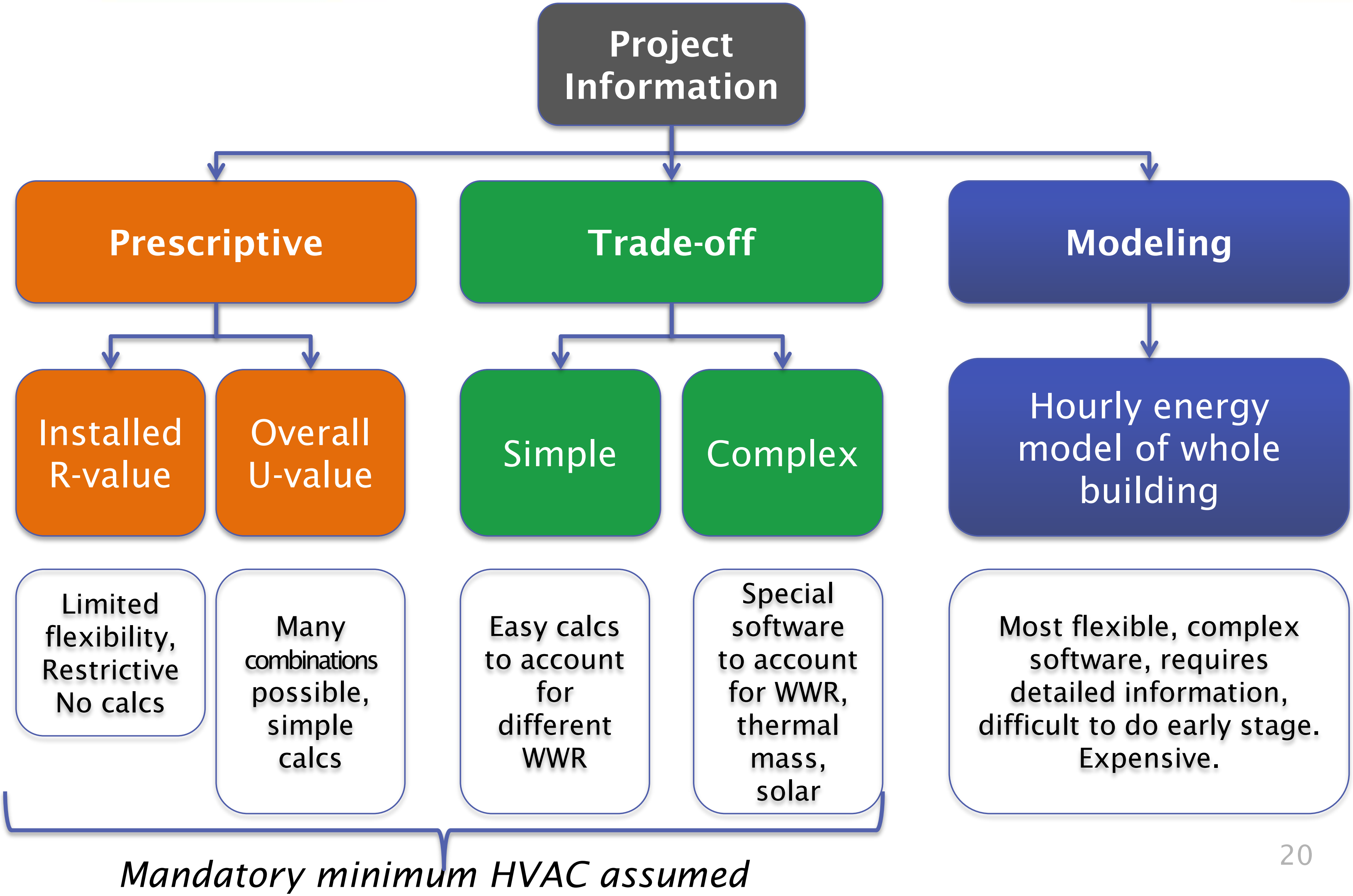
Common Codes in Canada

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

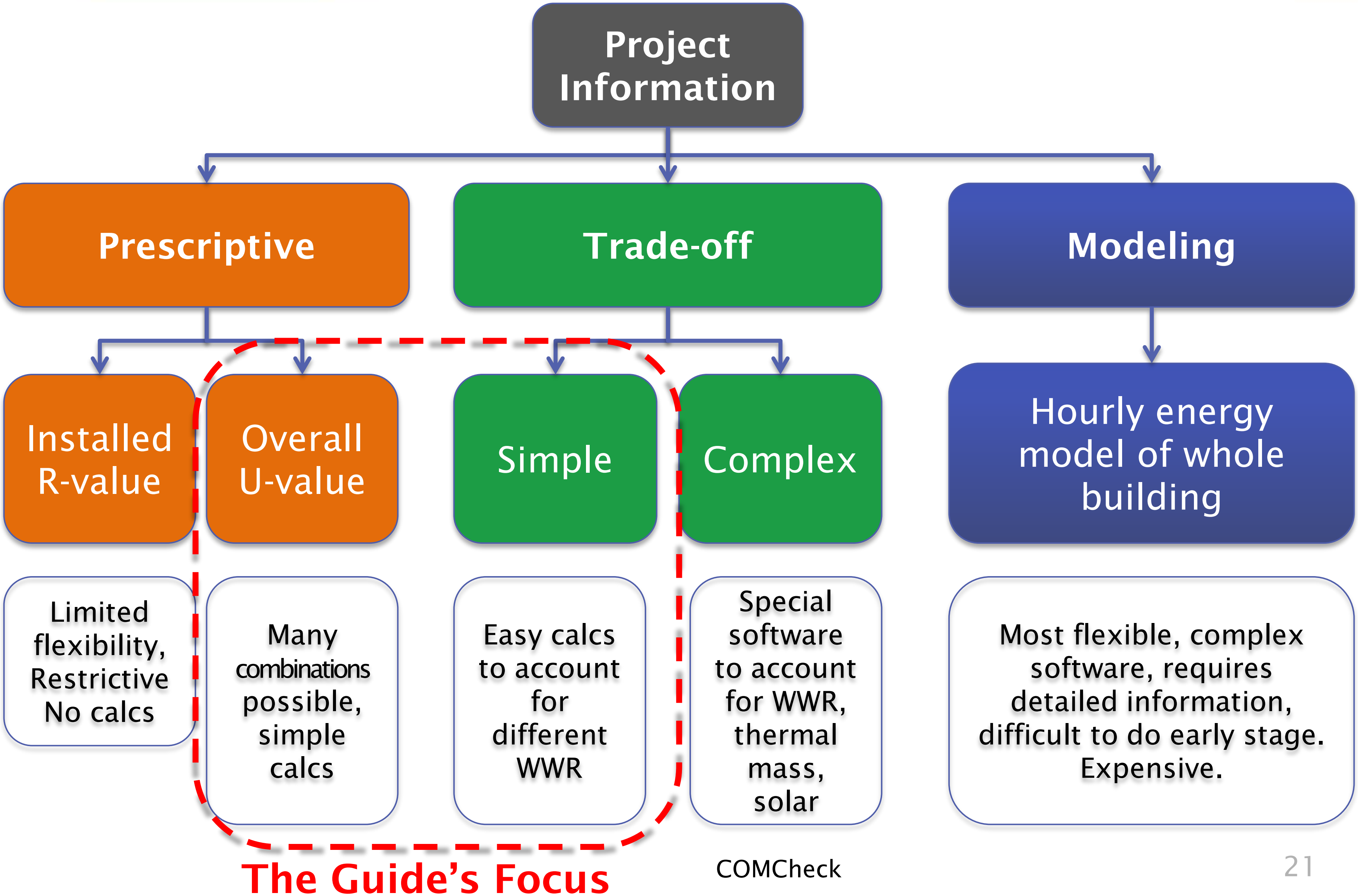
Project specifics

- The following usually impact code requirements
- **Governing Code / Standard**
  - ASHRAE 90.1-2010 (BC), NECB 2011/2015, SB-10 (Ontario), Quebec
- **Climate Zone**
  - Zone 4 through 8
- **Occupancy**
  - Residential, non-res, semi-heated
- **Material** Assembly (for ASHRAE-based codes)
  - **mass**, steel-stud, wood framed, metal building

Code Compliance Paths



Code Compliance Paths



Prescriptive: Installed R-value

- Still an option in 90.1 / Ontario SB -10
- Very Limiting e.g. RSI 2.3 + 1.8 ci... But what if we need a 6”/150 mm stud? Have to fit RSI 2.3 into stud

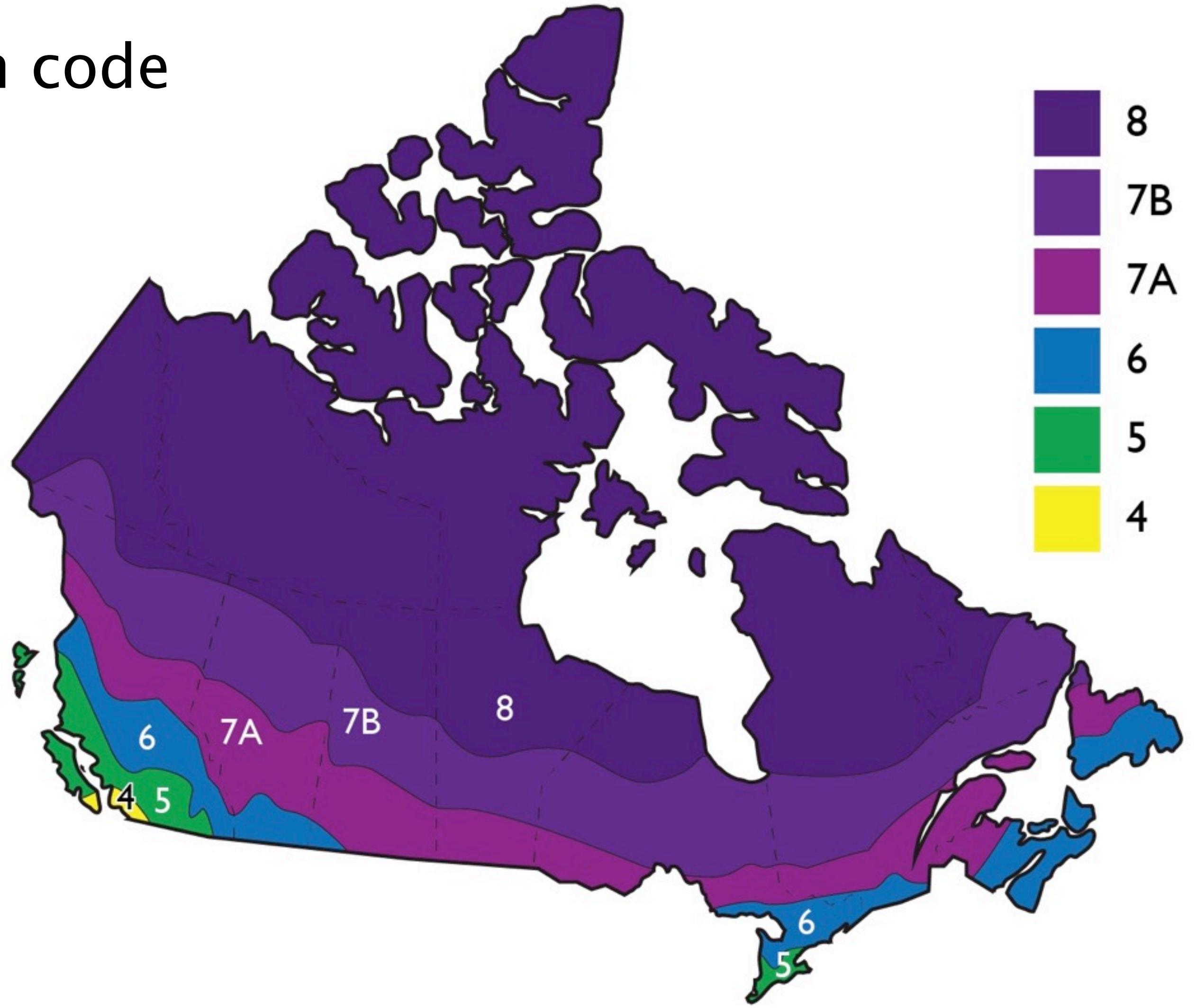
Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly	Insulation [d]	Assembly	Insulation [d]	Assembly	Insulation [d]
	Max. U	Min. RSI-Value	Max. U	Min. RSI-Value	Max. U	Min. RSI-Value
Roofs						
Insulation Entirely above Deck	U-0.16	6.2 ci	U-0.16	6.2 ci	U-0.36	2.6 ci
Metal Building	U-0.16	5.3 + 1.9 Ls	U-0.16	5.3 + 1.9 Ls	U-0.39	2.3 + 3.3
Attic and Other	U-0.10	10.6	U-0.10	10.6	U-0.15	6.7
Walls, Above Grade						
Mass	U-0.34	3.5 ci	U-0.34	3.5 ci	U-0.51	2.0 ci
Metal Building	U-0.30	2.3 + 2.3 ci	U-0.22	2.3 + 3.4 ci	U-0.45	2.3 + 1.1 ci
Steel Framed	U-0.31	2.3 + 1.8 ci	U-0.21	2.3 + 3.3 ci	U-0.48	2.3 + 0.7 ci
Wood Framed and Other	U-0.26	2.3 + 1.8 ci	U-0.26	2.3 + 1.8 ci	U-0.36	2.3 + 0.7 ci

- *Continuous Insulation (c.i.) is “insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior or exterior or is integral to any opaque surface of the building envelope.”*

Climate Zones

→ Generally the same in all codes (except Quebec)

→ Cities listed in code



Occupancy

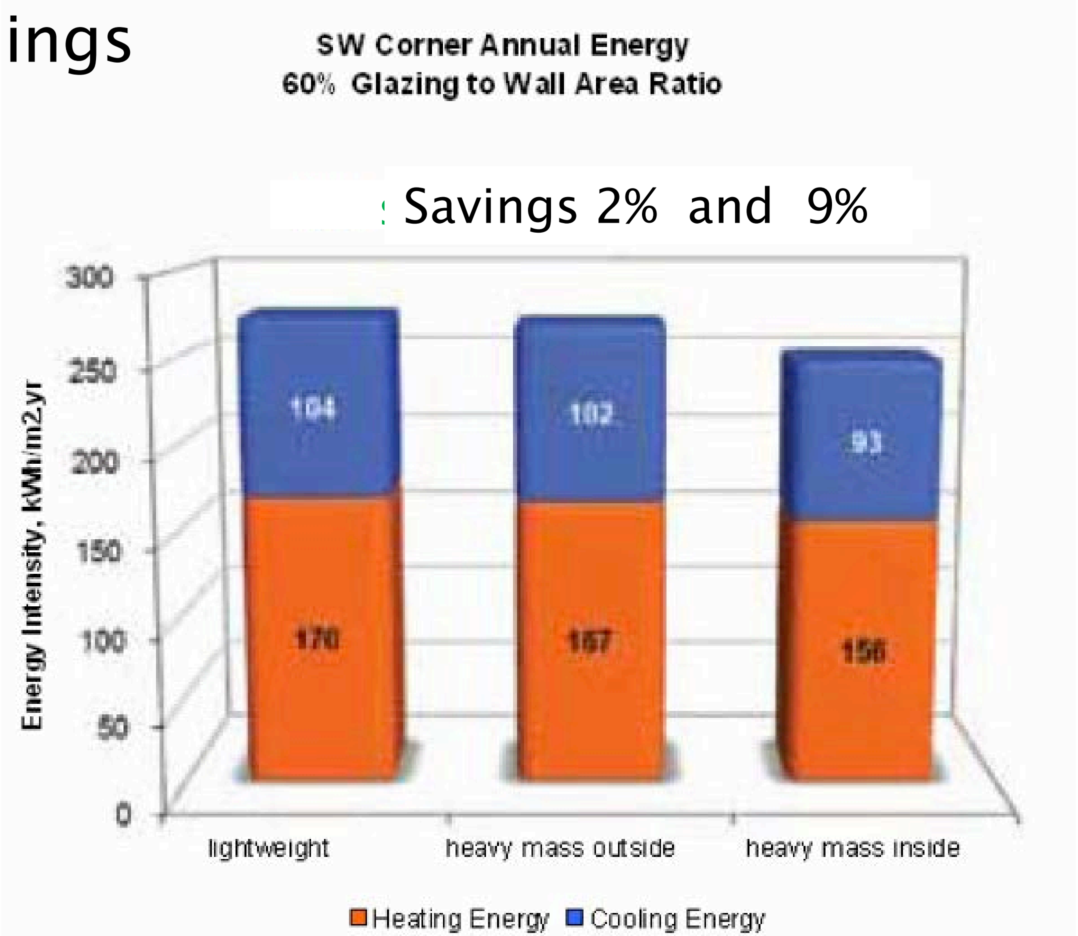
- → Typically, Residential requires higher thermal performance
- → Non-residential doesn't require as much
  - → Assumption is that non-res buildings generate a lot more internal heat
  - → Lights, process, etc.

Material / Assembly

- Thermal mass benefits are considered by some standards
  - Yes in ASHRAE 90.1
  - Not in NECB
- Thermal bridging of framing implied in most tabulated installed R-values
  - Must be accounted for in all codes (NECB, 90.1, SB-10)

Aside: Thermal Mass & Energy

- → Thermal mass can improve comfort, resiliency, and save energy
- → Mass in exposed ceilings is most valuable
- → Exterior walls also helpful- but keep it inside



RDH Study of Vancouver MURB

Example Prescriptive Assembly R-Values

Système international U-values (W/m²K)						
Climate Zone	HDD (18C)	ASHRAE 90.1-2010 Non-Residential	ASHRAE 90.1-2010 Residential	NECB-2011 All	Ontario SB-10 Non-Residential	Ontario SB-10 Residential
		mass	*mass*	*any*	*mass*	*mass*
4	<3000	0.104	0.09	0.315		
5	3000-4000	0.09	0.08	0.278	0.450	0.400
6	4000-5000	0.08	0.071	0.247	0.400	0.340
7/7A	5000-6000	0.071	0.071	0.21	0.340	0.340
7/7B	6000-7000	0.071	0.071	0.21	0.340	0.340
8	>7000	0.071	0.052	0.18	0.340	0.340

Inch-Pound R-values						
	(18C)	ASHRAE 90.1-2010 Non-Residential	ASHRAE 90.1-2010 Residential	NECB-2011 All	Ontario SB-10 Non-Residential	Ontario SB-10 Residential
		mass	*mass*	*any*	*mass*	*mass*
4	<3000	9.6	11.1	18.0		
5	3000-4000	11.1	12.5	20.4	*12.6*	*14.2*
6	4000-5000	12.5	14.1	23.0	*14.2*	*16.7*
7/7A	5000-6000	14.1	14.1	27.0	16.7	*16.7*
7/7B	6000-7000	14.1	14.1	27.0	16.7	*16.7*
8	>7000	14.1	19.2	31.5	16.7	*16.7*

Guide assumes mass walls where allowed

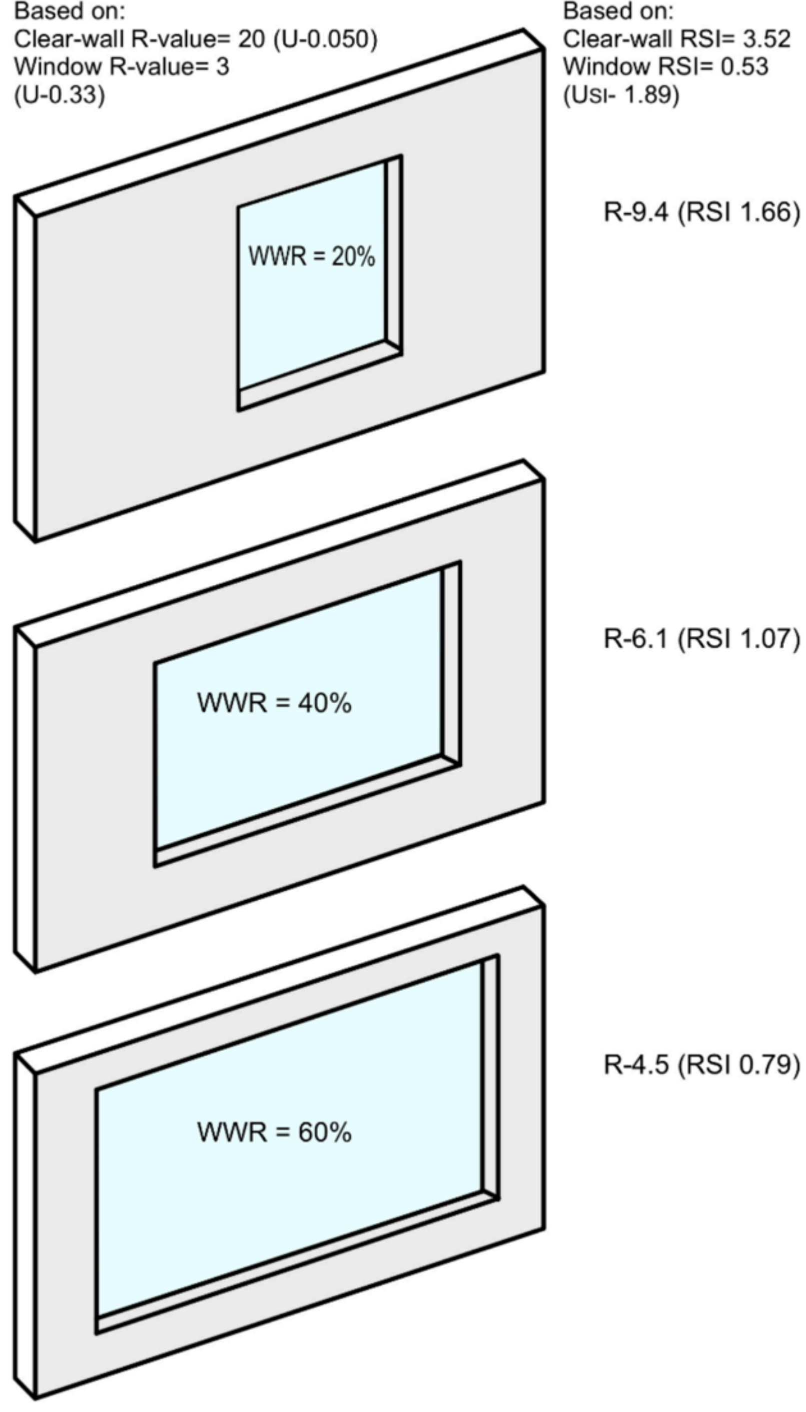
Simple Trade-off Method

- → Allows different types of walls, and different windows to have different R-value

- → Calculate overall heat transfer of code-minimum
  - → Usually max 40%WWR
  - → NECB has sliding scale… more restrictive

Simple Trade-off

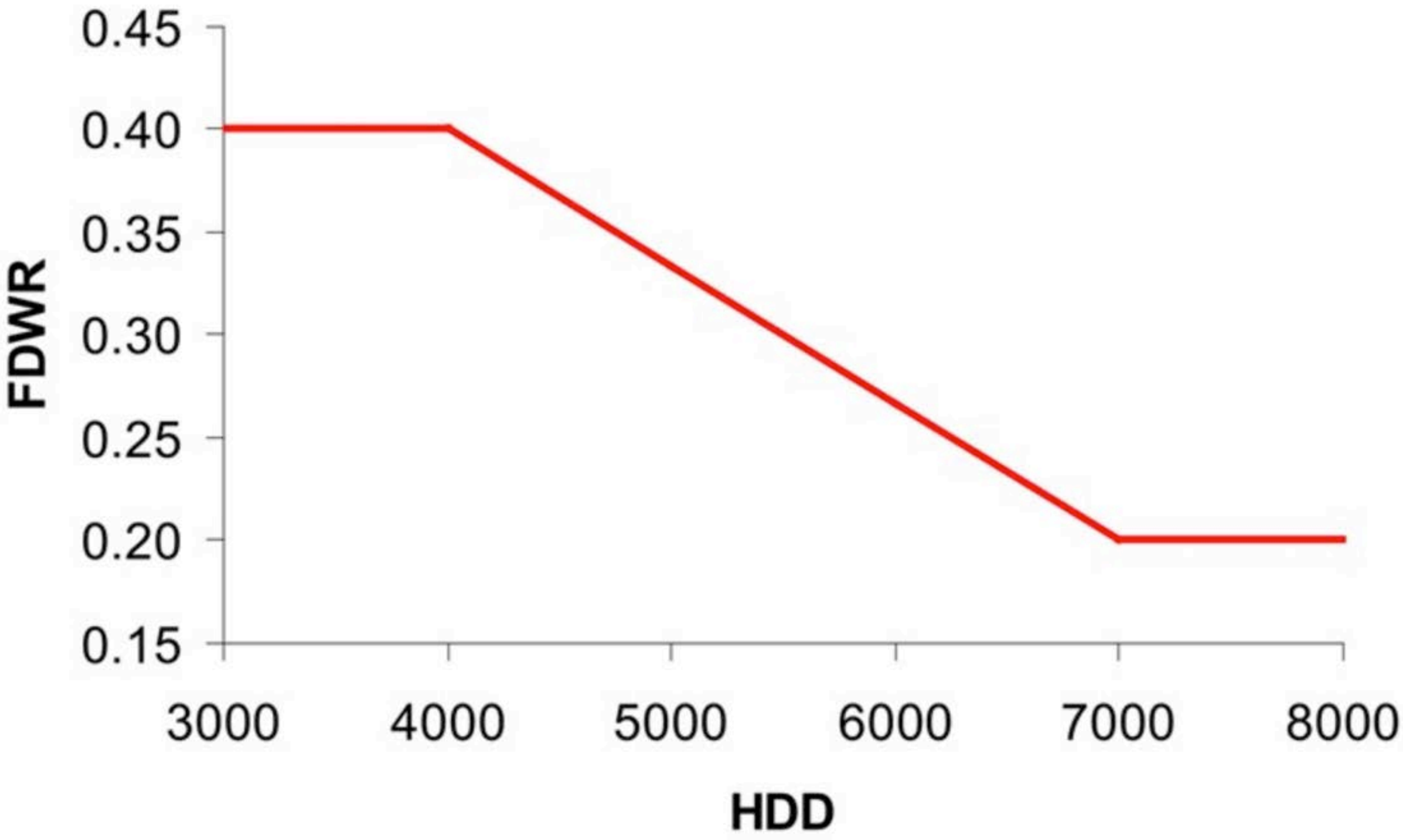
→ Simple trade-off allows for the effects of **window & wall areas** and **assembly choices** to be accounted for



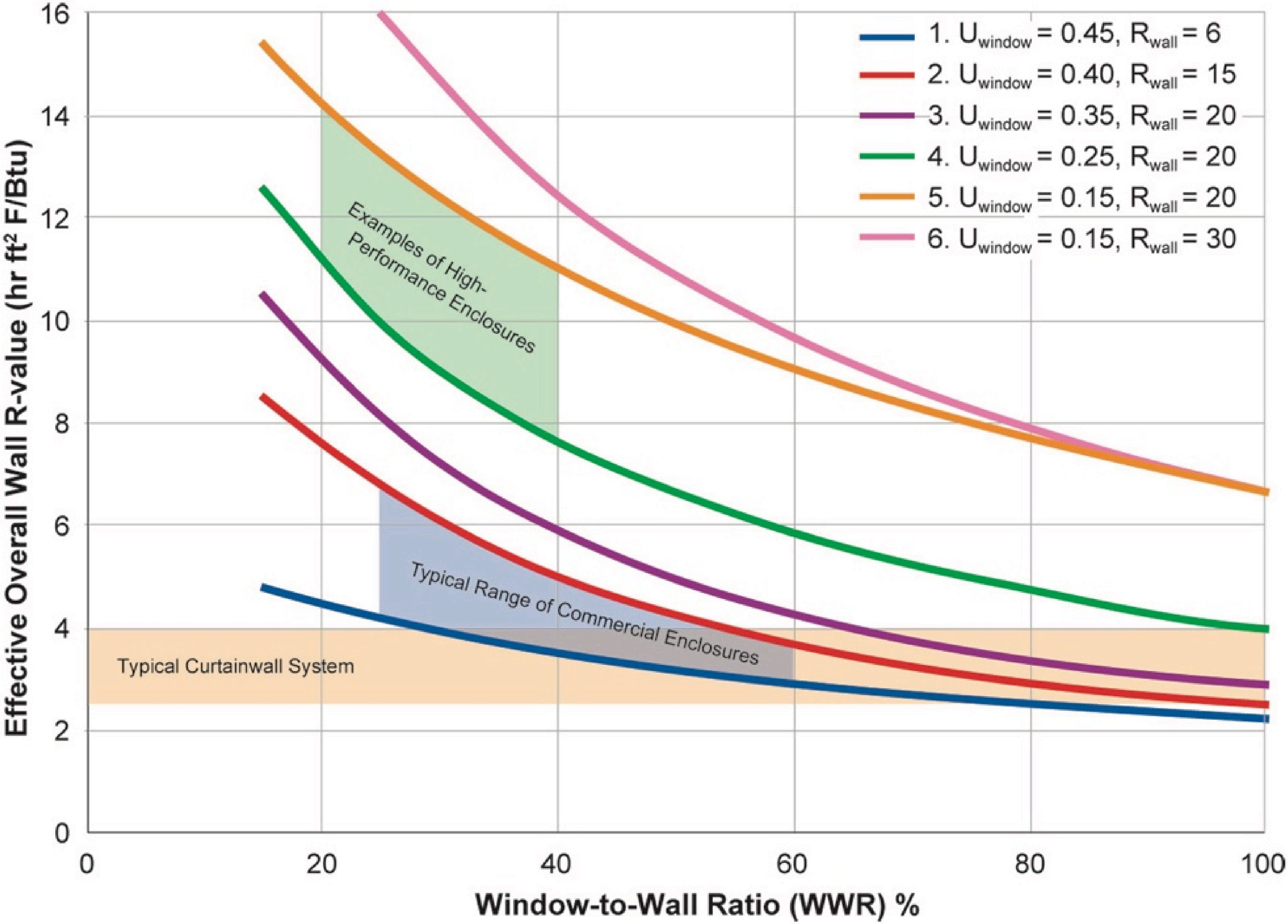
Maximum prescriptive Window Area

→ ASHRAE 90.1 / SB-10: 40% WWR

→ NECB 2011/2015 Doors included, varies with HDD



Windows have a major impact!

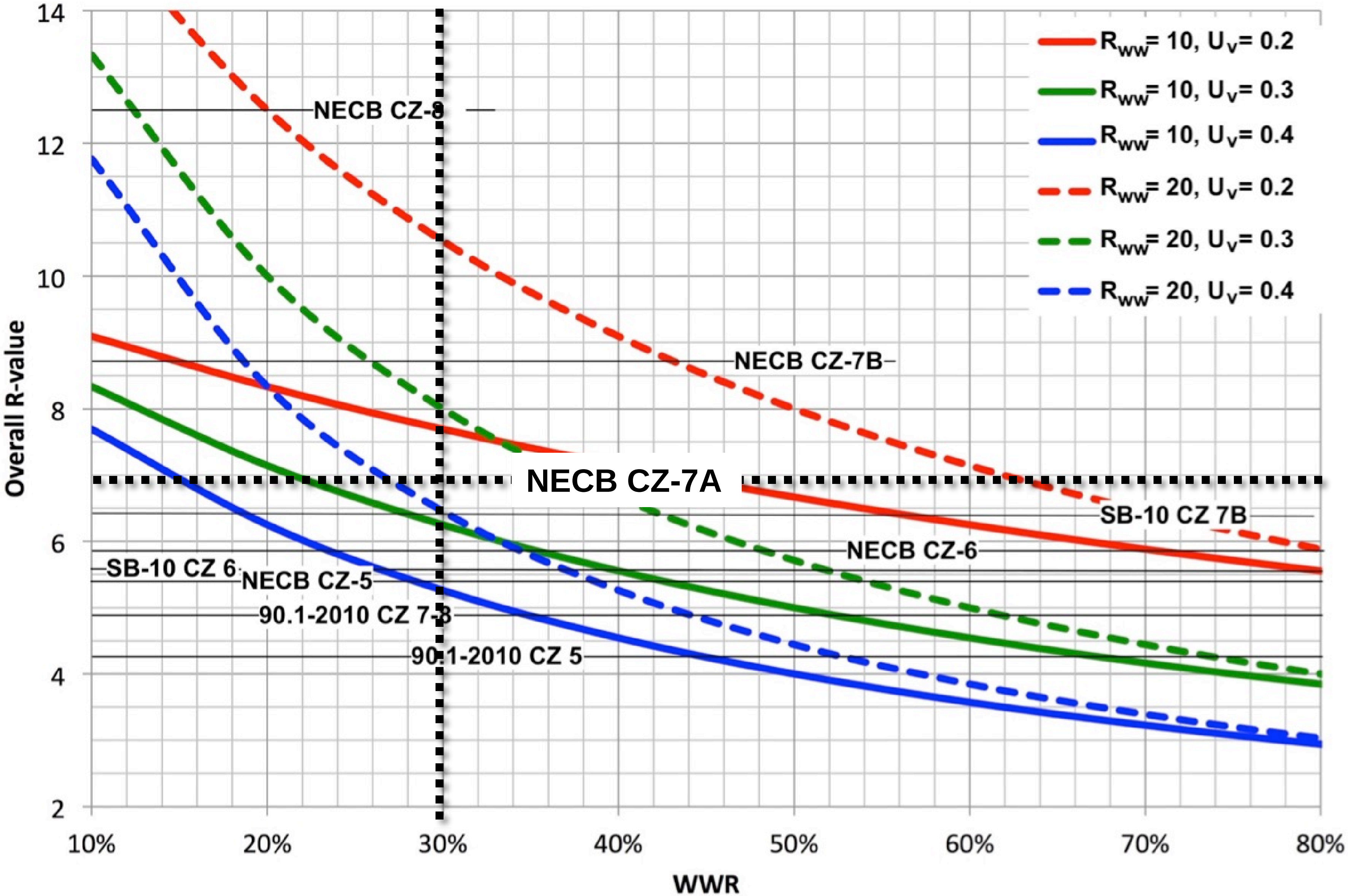


Overall Wall R-value: for trade-off

Système international U-values							
Climate Zone	**HDD (18°C)**	**ASHRAE 90.1-2010**		**NECB-2011**		**OBC SB-10**	
		Non-Residential	**Residential**	**Any occupancy**		**Non-Residential**	**Residential**
		mass	*mass*	WWR (%)	*all walls*	*mass*	*mass*
4	<3000	1.49	1.44	40	1.15	--	--
5	3000-4000	1.33	1.29	40	1.05	1.07	1.03
6	4000-5000	1.29	1.26	37.5	0.98	1.03	1.00
7/7A	5000-6000	1.15	1.15	30	0.81	0.89	0.89
7/7B	6000-7000	1.15	1.15	22.5	0.66	0.89	0.89
8	>7000	1.15	1.09	20	0.46	--	--

Inch-Pound R-values							
Climate Zone	**HDD (18°C)**	**ASHRAE 90.1-2010**		**NECB-2011**		**OBC SB-10**	
		Non-Residential	**Residential**			**Non-Residential**	**Residential**
		mass	*mass*	WWR (%)	*all walls*	*mass*	*mass*
4	<3000	3.81	3.94	40	4.94	--	--
5	3000-4000	4.27	4.39	40	5.42	5.33	5.49
6	4000-5000	4.39	4.49	37.5	5.80	5.49	5.68
7/7A	5000-6000	4.94	4.94	30	7.04	6.41	6.41
7/7B	6000-7000	4.94	4.94	22.5	8.63	6.41	6.41
8	>7000	4.94	5.23	20	12.24	--	--

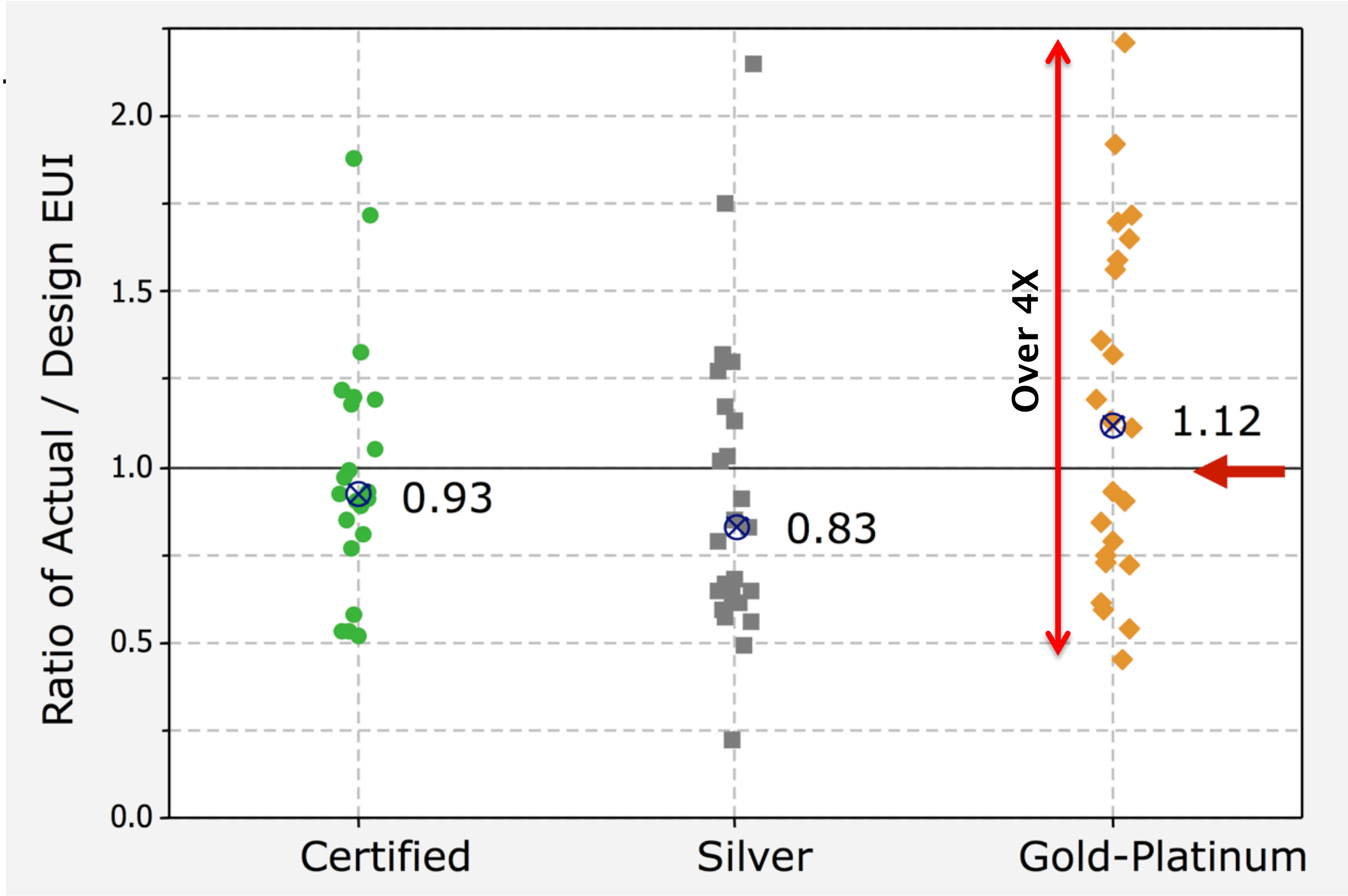
Overall R-value vs some codes



Energy Modeling

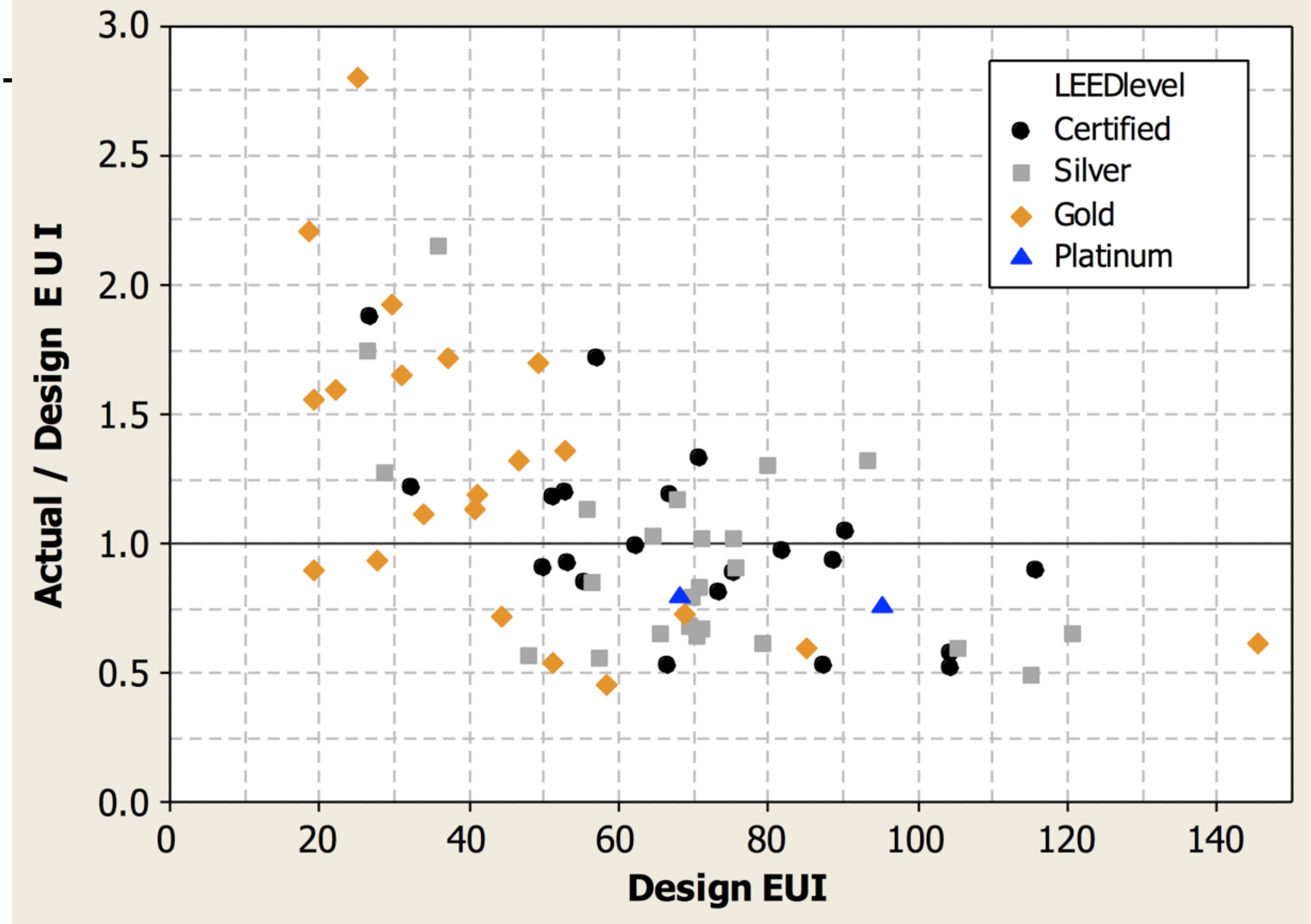
- → Allows for great flexibility
- → Model code minimum building, including all HVAC, lighting, DHW, etc. ("Reference Building")
- → Demonstrate Design Building is same or lower energy use
- → Often require too much information at early stage.
- → Can't wait for modeling to make important design decisions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

Energy Models



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

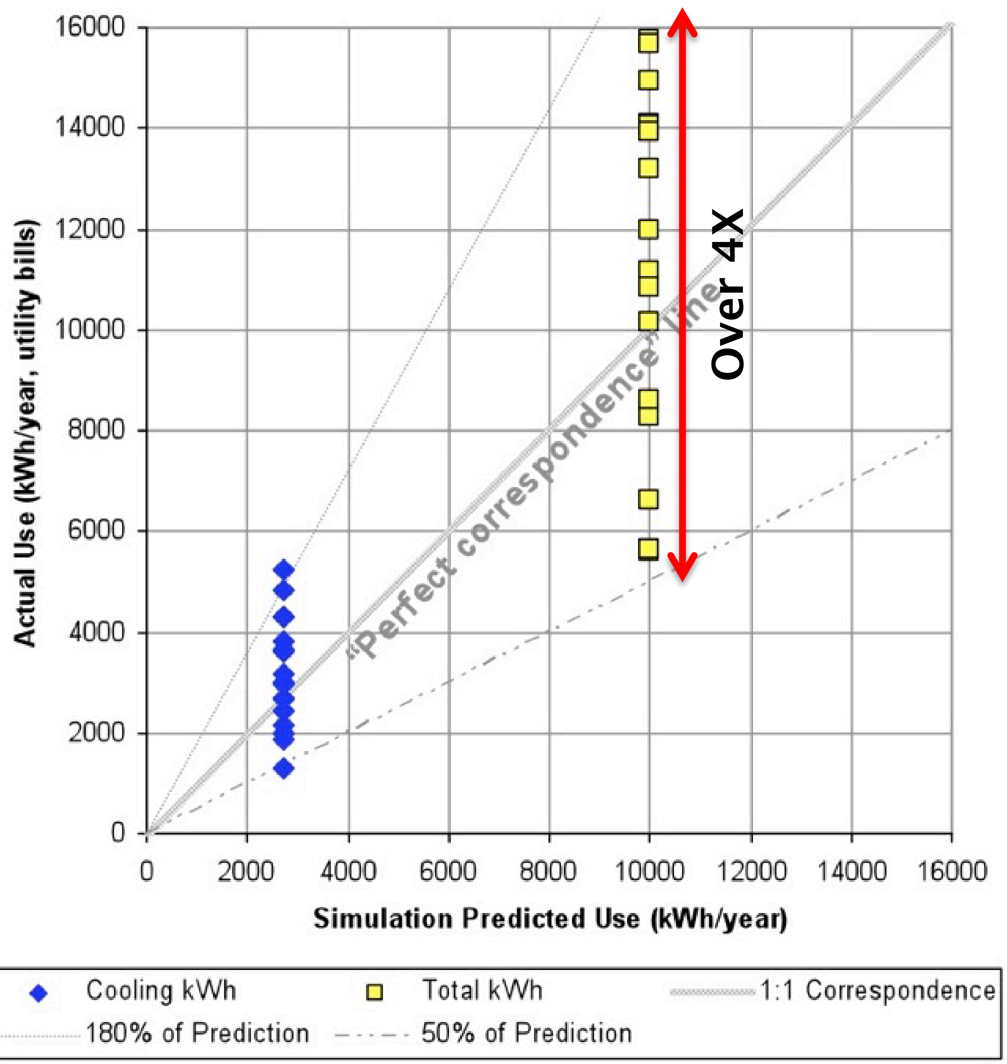
Low-energy Buildings are harder



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

Occupancy matters

- → Energy use varies with occupancy
- → Modeling can't capture all
  - → Code prescribes many things
- → Beware, NZE / PH



Simulation (horizontal) vs. actual (vertical) electric use for 17 identical houses in OK

3. Heat Flow Fundamentals

Calculating R-value of a *layer*

- → RSI = R-value / 5.678
  - › E.g., R-12 = RSI 2.1
- → U-value = 1/ R-value
  - → E.g., R-10 = U-0.10
  - → R_{SI} 2.0 = U_{SI}-0.50
  - → RSI 3.0 = U=0.33

- → R_{layer} = R/in * number of inches
- → R_{layer} = thermal conductivity/thickness

R-value of materials (from Guide)

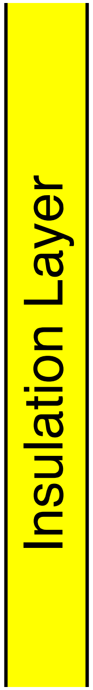
Material	Conductivity (R/inch)	R-value at 2"	R-value at 2.5"	R-value at 3"	R-value at 3.5"	R-value at 4"
Open-cell foam (ocSPF)	3.8	7.6	9.5	11.4	13.3	15.2
Spray Cellulose	3.8	7.6	9.5	11.4	13.3	15.2
Mineral Wool semi-rigid	4.0	8.0	10.0	12.0	14.0	16.0
Expanded polystyrene Type 2		same as semi-rigid mineral wool				
Extruded polystyrene	5.0	10.0	12.5	15.0	17.5	20.0
Polyisocyanurate	5.5	11.0	13.8	16.5	19.3	22.0
ccSPF	6.0	12.0	15.0	18.0	21.0	24.0
Reinforced Concrete	0.06	0.12	0.15	0.18	0.21	0.24
Clay Brick Veneer	0.13				0.45	

Material	Conductivity (W/mK)	RSI for 50 mm	RSI for 63 mm	RSI for 75 mm	RSI for 90 mm	RSI for 100 mm
Open-cell foam (ocSPF)	0.038	1.3	1.7	2.0	2.3	2.7
Spray Cellulose	0.038	1.3	1.7	2.0	2.3	2.7
Mineral Wool semi-rigid	0.036	1.4	1.8	2.1	2.5	2.8
Expanded polystyrene Type 2		same as semi-rigid mineral wool				
Extruded polystyrene	0.029	1.8	2.2	2.6	3.1	3.5
Polyisocyanurate	0.026	1.9	2.4	2.9	3.4	3.9
ccSPF	0.024	2.1	2.6	3.2	3.7	4.2
Reinforced Concrete	2.4	0.02	0.03	0.03	0.04	0.04
Clay Brick Veneer	1.2				0.08	

Calculating R-value of a ***layer***

- → R_{layer} = R/in * number of inches
- → R_{layer} = thermal conductivity/thickness

- → *Example*
  - → R = 2” x 5/inch = R-10
  - → RSI = .051m / 0.029
    = RSI 1.76



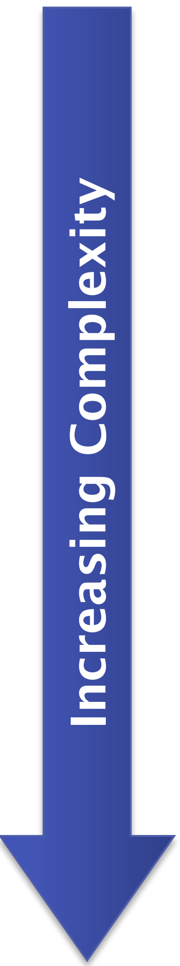
Example:
2” of R5/inch
51 mm of k=0.029 W/mK

Airfilms and Airgaps

- → Fictitious layers represent resistance to convective and radiative heat flow at surfaces
- → Not very significant
  - → Airfilms (R-0.84/ RSI0.15)
  - → Airgaps (R-1.0 / RSI 0.18)
    - › Low-emissivity coatings increase R-value

Condition	RSI-value	R-value
Interior Surfaces	0.120	0.68
Exterior Surfaces	0.029	0.16
20 mm (3/4") Air space	0.18	1.0

Which R-value?



- → ***Rated R-value***, rating printed on the package / tech sheet
- → ***Installed R-value***, rated R-value of the insulation products in their installed condition (e.g. compressed batt insulation or not)
- → ***Assembly R-value*** or ***Center-of-Cavity*** thermal resistance of all layers (e.g. add up layers) (e.g., NECB Section 3.2)
- → ***Clear-wall R-value*** (R_{cw}) thermal resistance of the layers (Assembly R-value) but *also* includes the two-dimensional effect of standard repetitive framing (e.g. steel studs and tracks)
- → ***Whole-wall R-value***, (R_{ww}) which includes the Clear-wall R-value (R_{cw}) *plus* conductive penetrations (e.g. floors), additional framing at openings (e.g. windows and doors), other interfaces (e.g. foundation-to-above-grade wall, wall-to-roof, balconies, etc.)
- → ***Overall R-value*** ($R_{overall}$) entire enclosure type (such as wall, or roof) including Whole-Wall R-value (R_{ww}) plus windows, doors, and curtainwalls.

Reference: Christian, J.E., and Kosny, J., "Toward a National Opaque Wall Rating Label". *Proc. Thermal Performance of the Exterior Envelopes VI*, ASHRAE, Clearwater Beach,1995.

Effective R-value

- → Effective R-value is not universally defined
- → *Beware*: Definition is context-sensitive
  - → For example, “effective” may describe clear-wall R-value, or partial whole-wall, or include thermal mass effect, etc.

Installed R-value

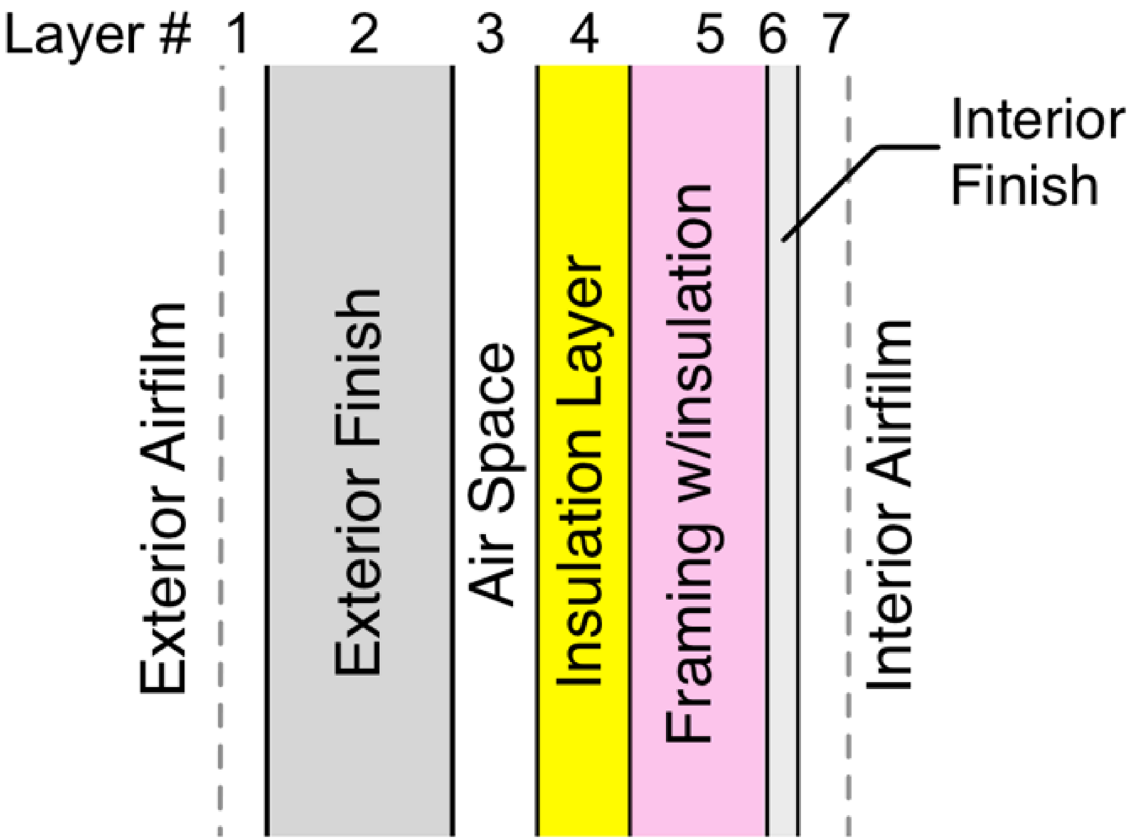
→ Rated R-value vs Installed R-value

Nominal Lumber Size	Cavity Depth[1]	Insulation R-													
I joist	14"	49													
I joist	11-7/8"	44	38												
2 x 12	11-¼"	42	37												
I joist	9-½"	38	33												
2 x 10	9-¼"	37	32	35	30										
2 x 8	7-¼"		27	29	25	27	24								
2 x 6[3]	6"				22	24	21	21							
2 x 6	5-½"				21	22	20	19	21	20	18				
2 x 4[3]	4"						16	15	16	16	14				
2 x 4[3]	3-5/8"						15	14	15	15	13				
2 x 4	3-½"						14	14	15	14	13	15	13	11	
2 x 3	2-½"										10	11	10	8.9	8.0
2 x 2[3]	1-5/8"												7.1	6.5	6.1
2 x 2	1-½"												6.6	6.1	5.7
2 x 1	¾"														3.3
Product R-Value		R-49	R-38	R-38C	R-30	R-30C	R-25	R-22	R-21	R-20	R-19	R-15	R-13	R-11	R-8
Label Thickness		14"	12"	10-¼"	9-½"	8-¼"	8"	6-¾"	5-½"	5-½"	6-¼"	3-½"	3-½"	3-½"	2-½"

Reference: Owens-Corning

Assembly R-value (Center-of-Cavity)

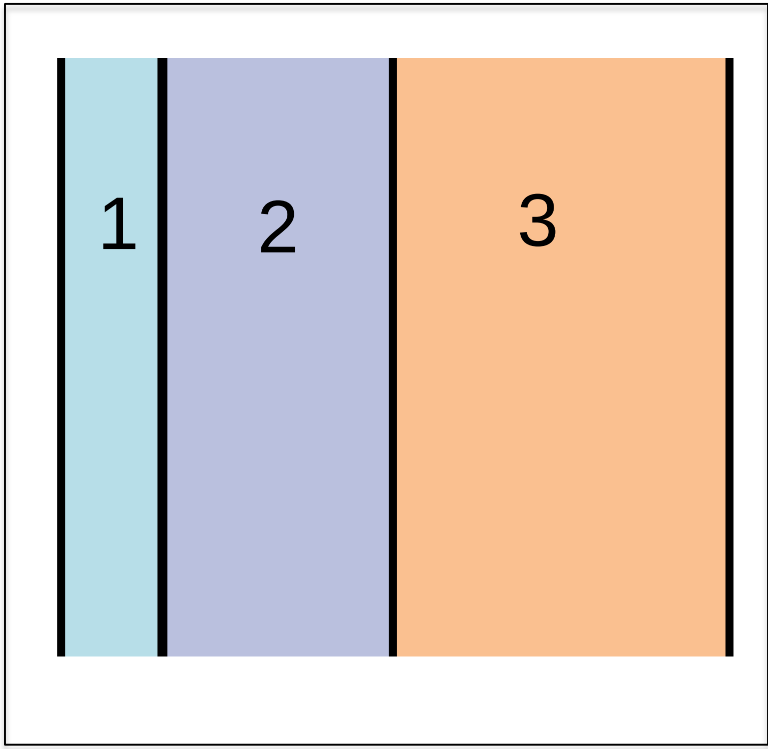
→ Just add each of the layer *R-values*



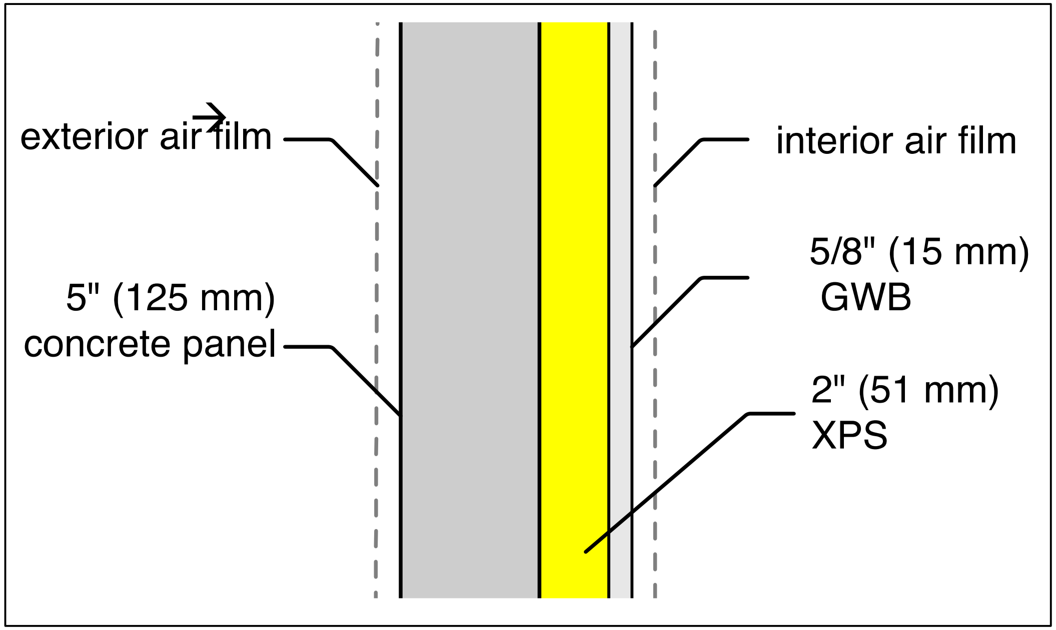
$$R_{total} = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7$$

Assembly R-value / U-value (in SI units)

- → Code U-values include R-value of insulation, drywall, *airfilms*, *air gaps*, concrete, masonry
- → The insulation is the vast majority of the total
- → Example: what is the RSI and U for system?
  - → Layer 1: RSI 0.3
  - → Layer 2: RSI 2.1
  - → Layer 3: RSI 0.5
- → Total RSI:
  - → 0.3 + 2.1 + 0.5 =RSI 2.9
  - → R-value = 16.5 (=2.9 * 5.678)
  - → $U = 1/R_{SI} = 0.345\ W/m^2\ C$



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**

Supporting tables from Guide

Material	Conductivity (R/inch)	R-value at 2"	R-value at 2.5"	R-value at 3"	R-value at 3.5"	R-value at 4"
Open-cell foam (ocSPF)	3.8	7.6	9.5	11.4	13.3	15.2
Spray Cellulose	3.8	7.6	9.5	11.4	13.3	15.2
Mineral Wool semi-rigid	4.0	8.0	10.0	12.0	14.0	16.0
Expanded polystyrene Type 2		same as semi-rigid mineral wool				
Extruded polystyrene	5.0	10.0	12.5	15.0	17.5	20.0
Polyisocyanurate	5.5	11.0	13.8	16.5	19.3	22.0
ccSPF	6.0	12.0	15.0	18.0	21.0	24.0
Reinforced Concrete	0.06	0.12	0.15	0.18	0.21	0.24

Condition	RSI-value	R-value
Interior Surfaces	0.120	0.68
Exterior Surfaces	0.029	0.16
20 mm (3/4”) Air space	0.18	1.0

But …

→ Few assemblies are simply layers of materials

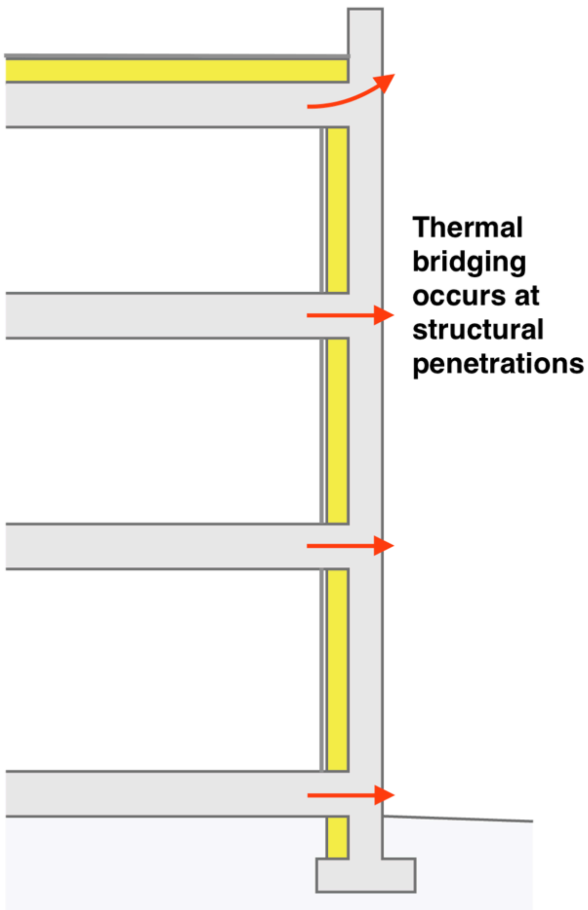
→ We have moved to

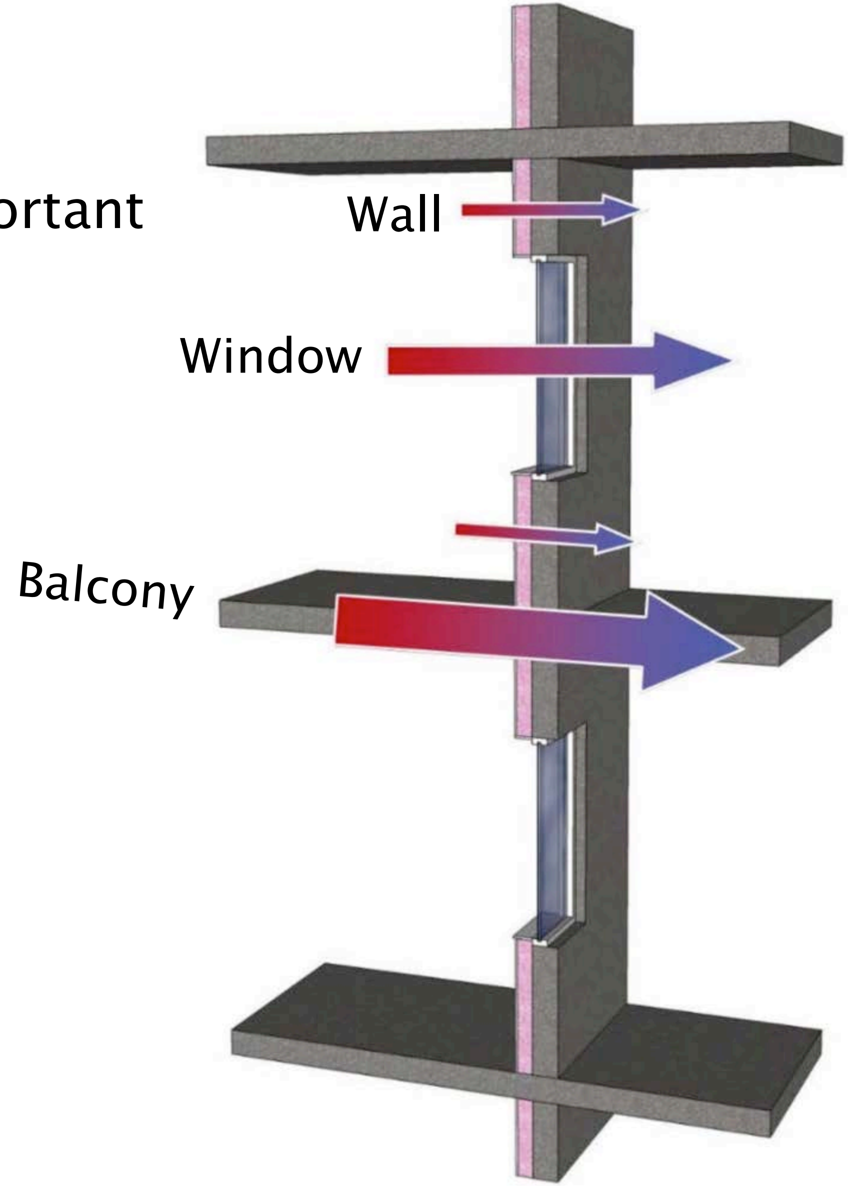
- → 3-D frame work (steel/conc/wood frames, truss)
- → hollow element (CMU, hollow core slab, window)

→ R-value is no longer so simple ….

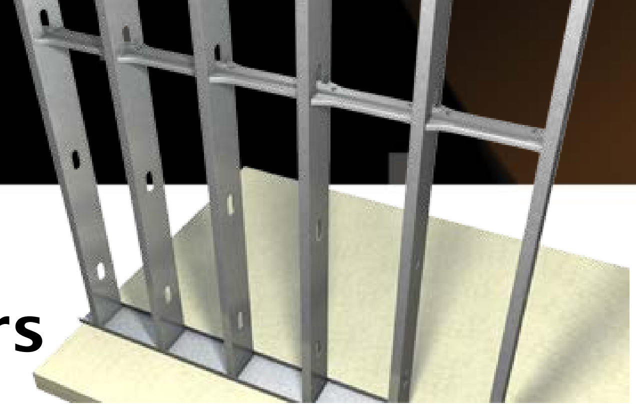
Thermal Bridging

- A local area of the enclosure that has higher heat loss
- Steel studs, floor slabs most important





Accounting for framing



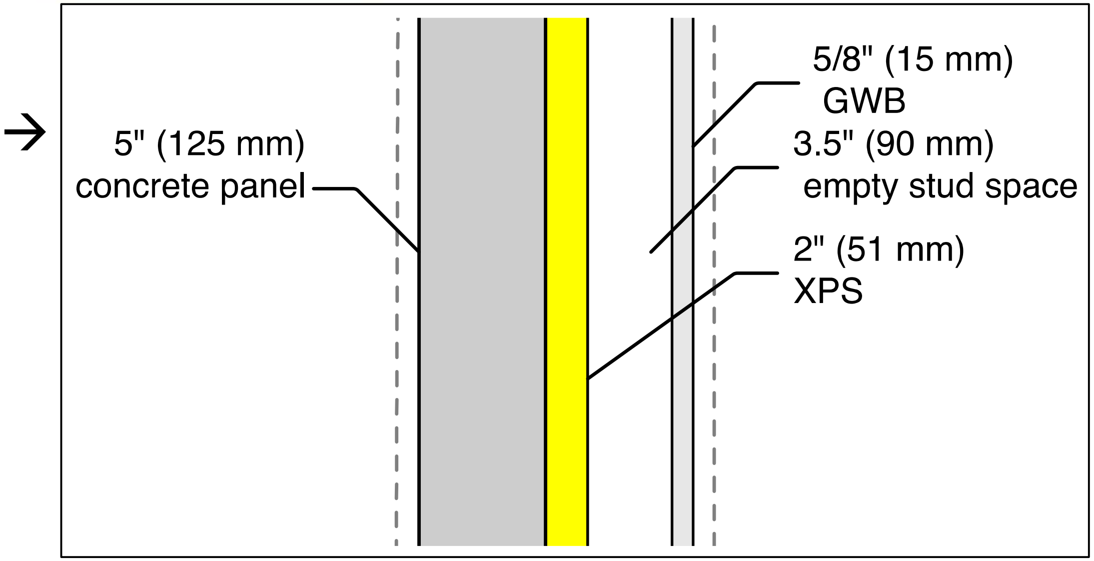
→ We can convert 3-D frames to **layers**

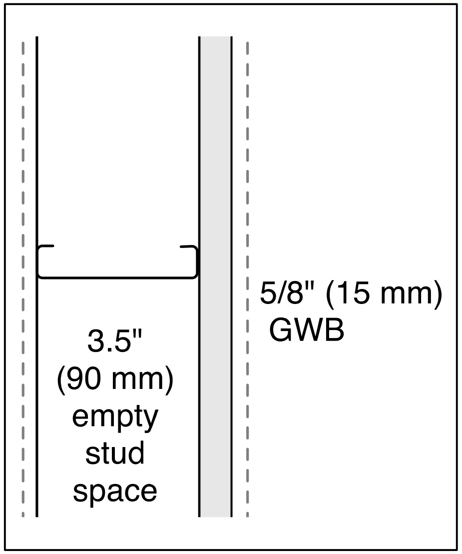
→ Note the poor performance of steel stud insulation

Cavity Depth In	Cavity Depth mm	Rated Cavity R-value	Layer R_{cw}-value @ 16 inch centres	Layer RSI_{cw} @ 405 mm centres	
2.5	64	Empty	2.15	0.37	$
3.5	89	Empty	2.19	0.39	$
		R-13	7.4	1.31	$$
		R-15	7.8	1.38	$$$
6.0	152	Empty	2.24	0.39	$
		R-19	8.5	1.50	$$
		R-21	8.8	1.55	$$$
		R-24 (4” ccSPF)	9	1.59	$$$$$

Note: “ccSPF” is closed-cell Sprayed Polyurethane Foam insulation

Clear-wall R-value (R_{cw})





Layer	R-value
Exterior air film	Incl in stud
5” (125 mm) concrete	0.30
2” (51 mm) XPS insulation	10.0
3.5”(90mm) empty stud	2.19
5/8” (15 mm) GWB	Incl in stud
Interior air film	Incl in stud
Total	**12.5**

Includes steel stud wall, GWB and airfilms as a “layer”, of about R2.2

Supporting tables from Guide

Material	Conductivity (R/inch)	R-value at 2"	R-value at 2.5"	R-value at 3"	R-value at 3.5"	R-value at 4"
Open-cell foam (ocSPF)	3.8	7.6	9.5	11.4	13.3	15.2
Spray Cellulose	3.8	7.6	9.5	11.4	13.3	15.2
Mineral Wool semi-rigid	4.0	8.0	10.0	12.0	14.0	16.0
Expanded polystyrene Type 2		same as semi-rigid mineral wool				
Extruded polystyrene	5.0	10.0	12.5	15.0	17.5	20.0
Polyisocyanurate	5.5	11.0	13.8	16.5	19.3	22.0
ccSPF	6.0	12.0	15.0	18.0	21.0	24.0
Reinforced Concrete	0.06	0.12	0.15	0.18	0.21	0.24

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	2.15	0.37
3.5	89	Empty	2.19	0.39
		R-13	7.4	1.31
		R-15	7.8	1.38
6.0	152	Empty	2.24	0.39
		R-19	8.5	1.50
		R-21	8.8	1.55
		R-24 (4" ccSPF)	9	1.59

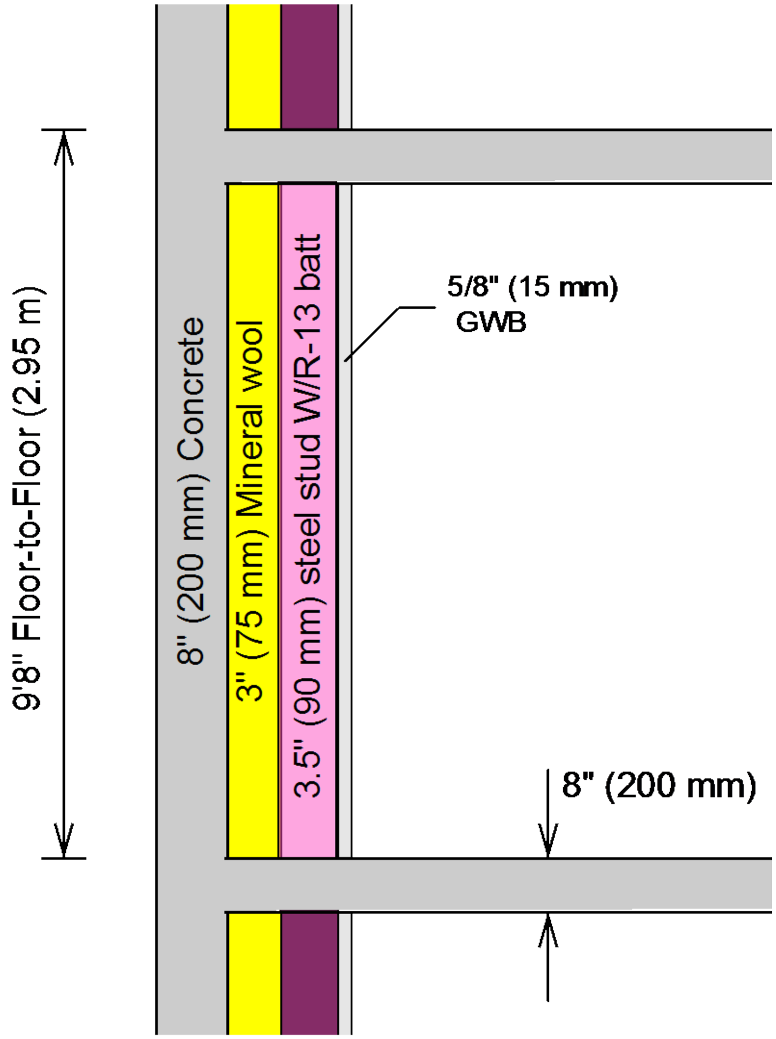
Note: "ccSPF" is closed-cell Sprayed Polyurethane Foam insulation

Whole-wall R-value (R_{ww})

→ Will be shown later how to estimate thermal bridge at floor

→ Floor slabs/balcony can *double* heat flow

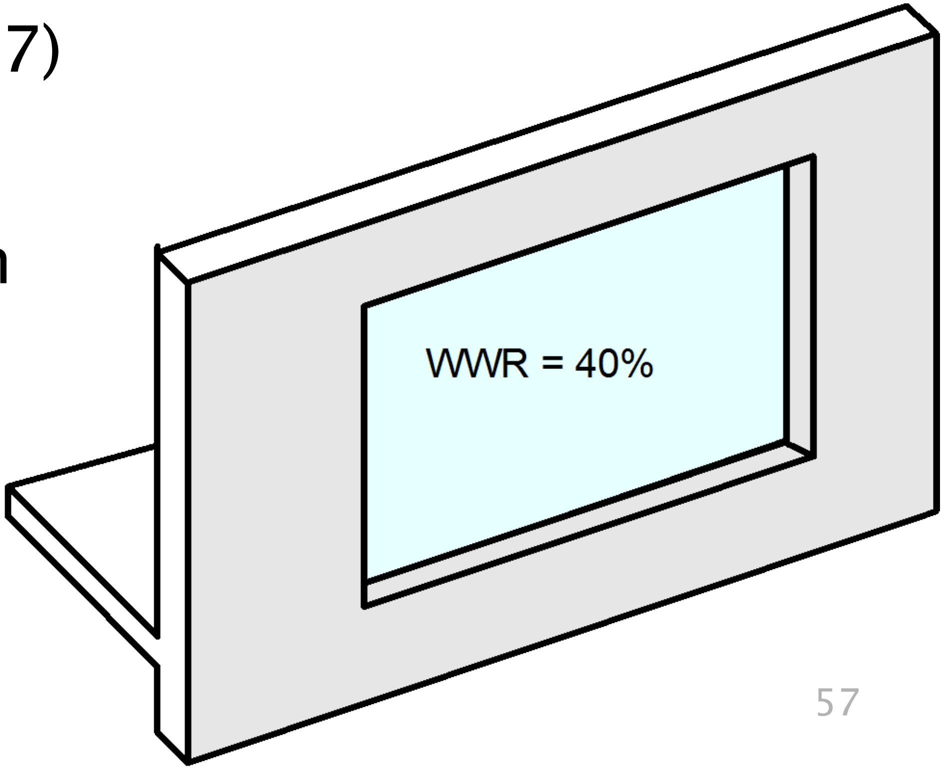
Includes framing and floor slab



Overall R-value ($R_{overall}$)

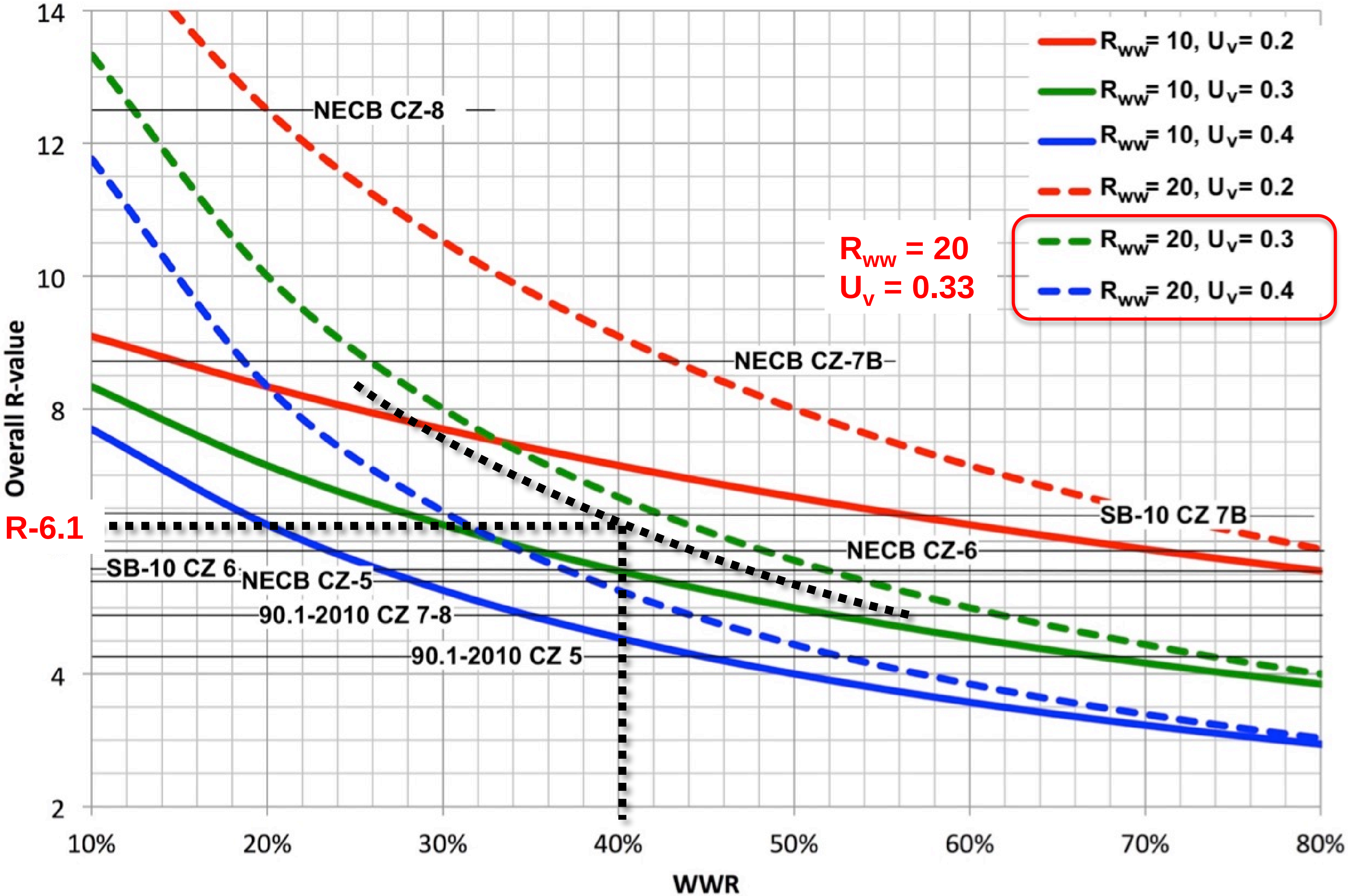
- *Example:*
  - Whole-wall R_{ww}-value = R-20 (U-0.050)
    - R_{SI}3.5, U_{SI}0.29
  - Window R-value= 3 (U-0.33)
- Result **$R_{overall}$-6.1** (RSI 1.07)

- Calculation will be shown later

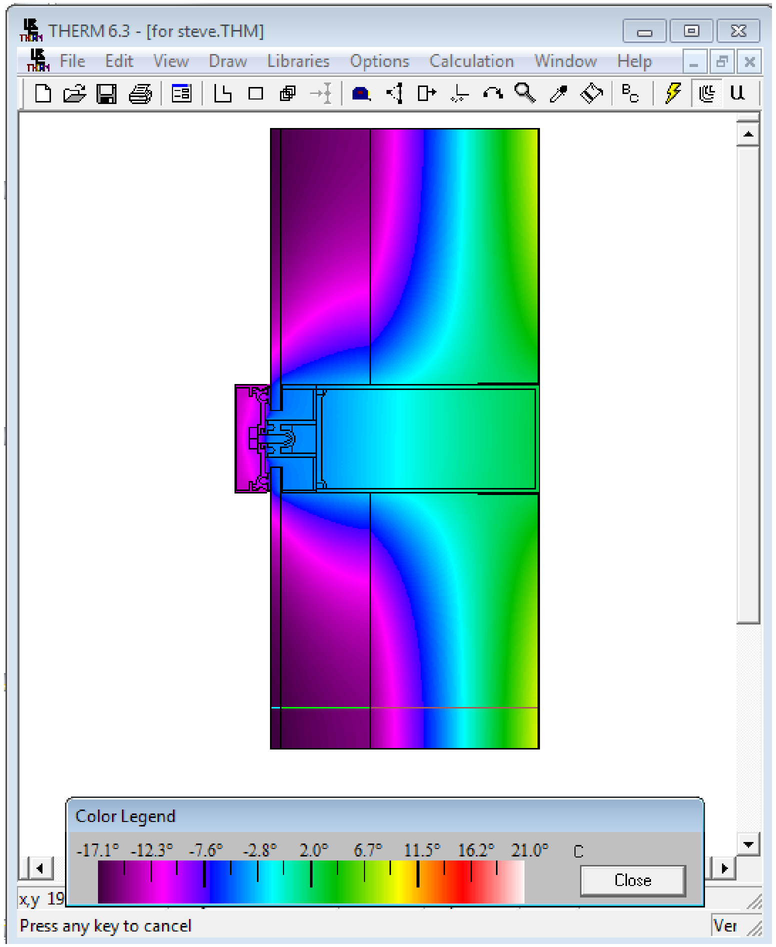


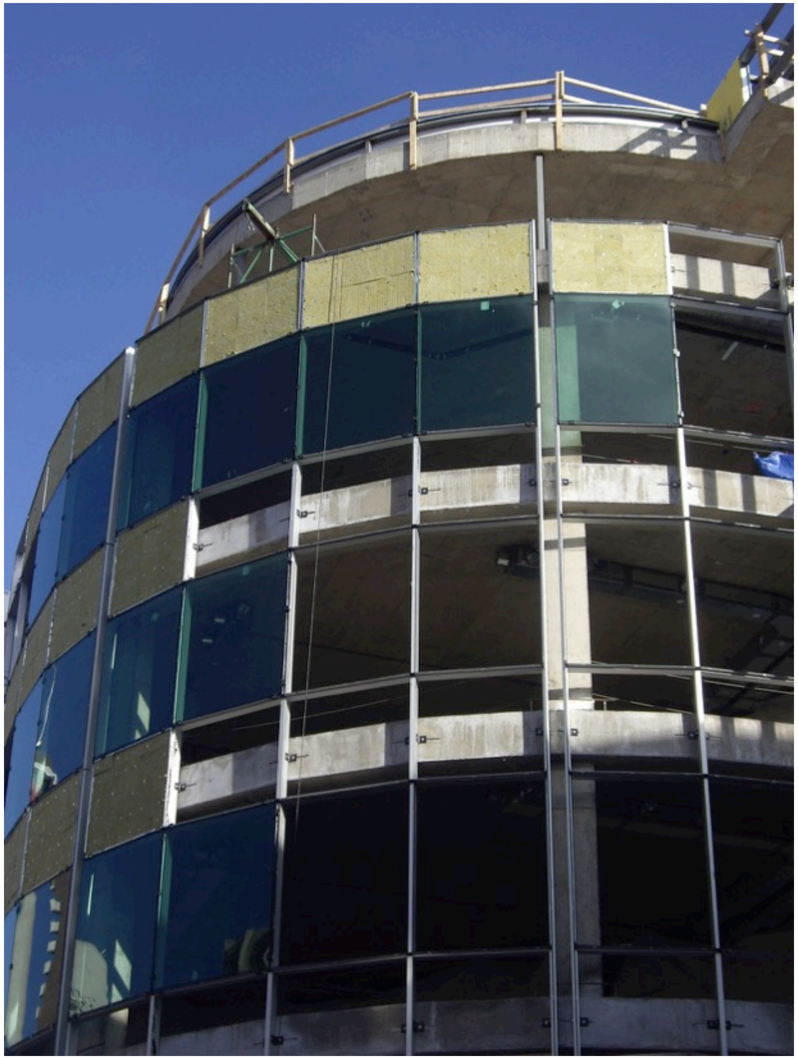
Includes framing, floor slabs *and* windows

Overall R-value vs some codes



Spandrel ??

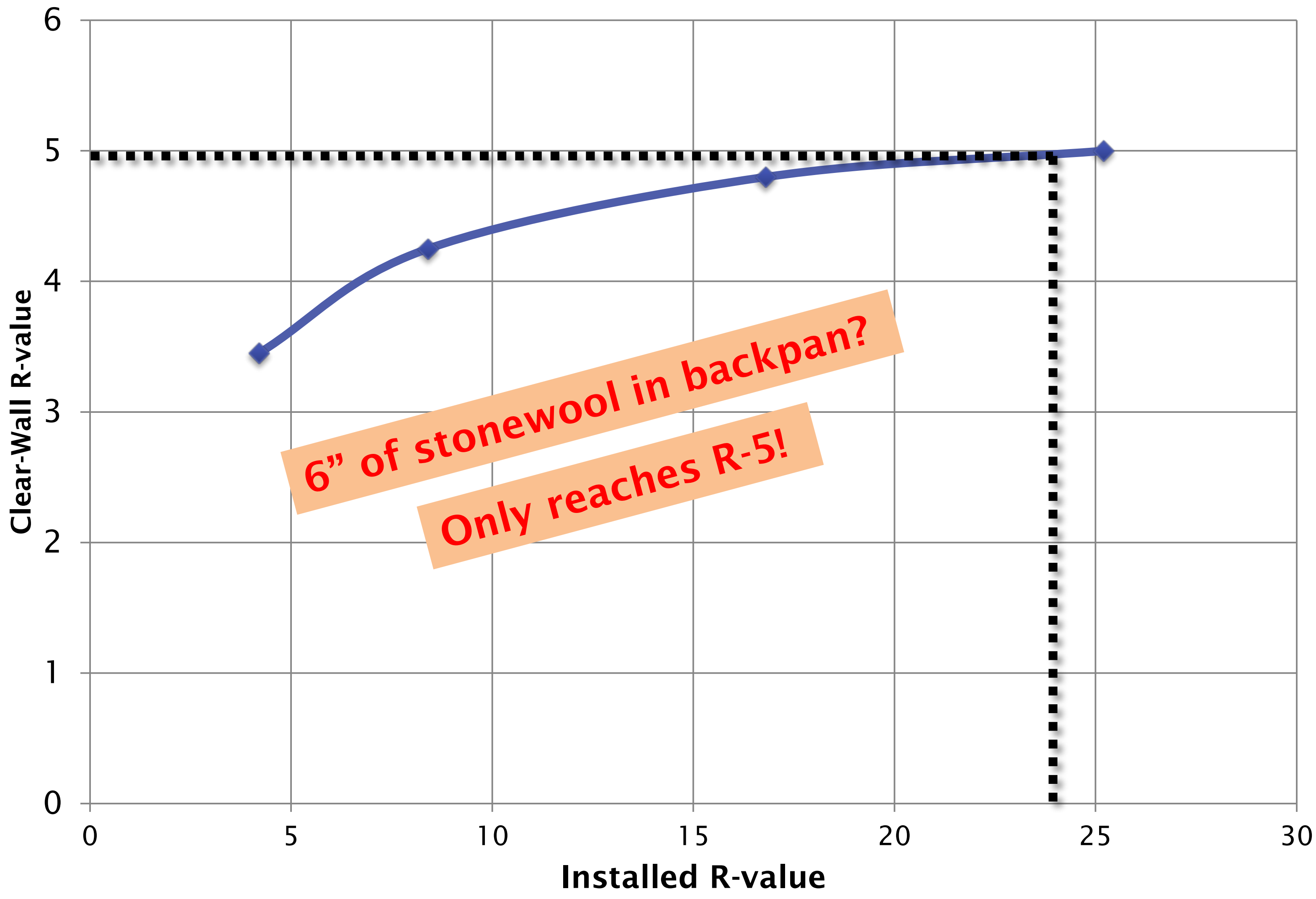




Nominal R-14 (3 in stonewool)

- Actual R-4.0 Assembly: U-0.250 BTU/hr-ft²-°F

Curtainwall spandrel: thermal bridges

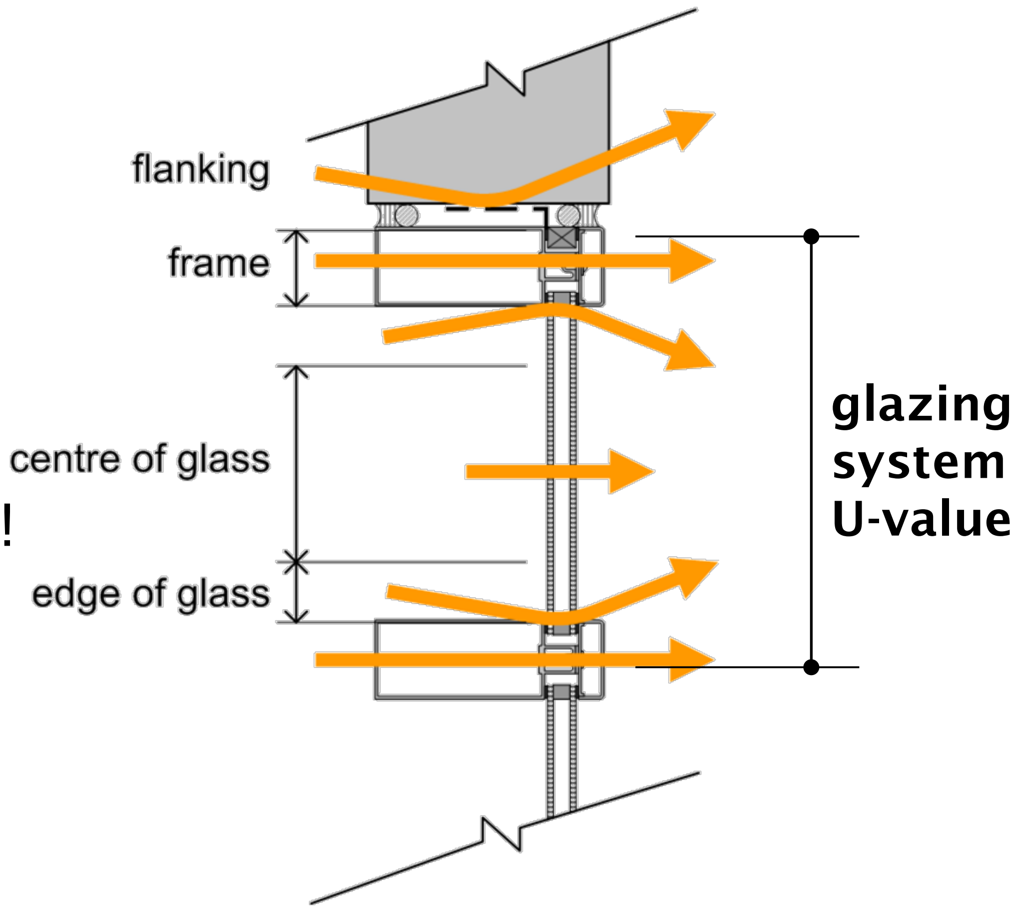


Reference: *ASHRAE 1365-RP Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings*. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc., 2012.

Window heat loss

- → There paths to consider for the vision assembly:
  - → Frame
  - → Edge of Glass
  - → Centre of Glass
- → Heat loss is more than through the glazing units!
- → Consider Flanking (installation)

Curtain Wall Plan View



Thermal Bridging and Codes

- Most require **steel studs** to be **accounted for** (often using tables and "ci")
- NECB "the thermal bridging effect of closely spaced **repetitive structural members**, such as studs and joists, … **shall be accounted for**"
  - the thermal bridging effect of major structural members, such as columns and spandrel beams,… that partly penetrate that *building envelope* assembly need not be taken into account, provided they **do not increase the *overall thermal transmittance*** at the projected area of the member to **more than twice**
- Ontario SB-10: intermediate structural connections of **continuous steel shelf angles** (or similar structural element) used to support the building façade **not counted provided there is a thermal break** between the remaining contact surface of the supporting element and the building structure "

Thermal Bridging and Standards

→ LEED "… energy modeling submittal pathways referenced by the LEED Canada rating systems require that thermal bridging in envelope assemblies (e.g. fenestration, opaque walls, roofs, etc.) be **reasonably accounted for** …"

→ Passive House, Net Zero, etc.
One **needs to account** for any thermal bridges that **materially impact energy consumption**.

Calculating Thermal Bridge Impacts

→ Several methods available

1. **Parallel Path Method**
   → Easiest, simple. Works well for concrete slabs

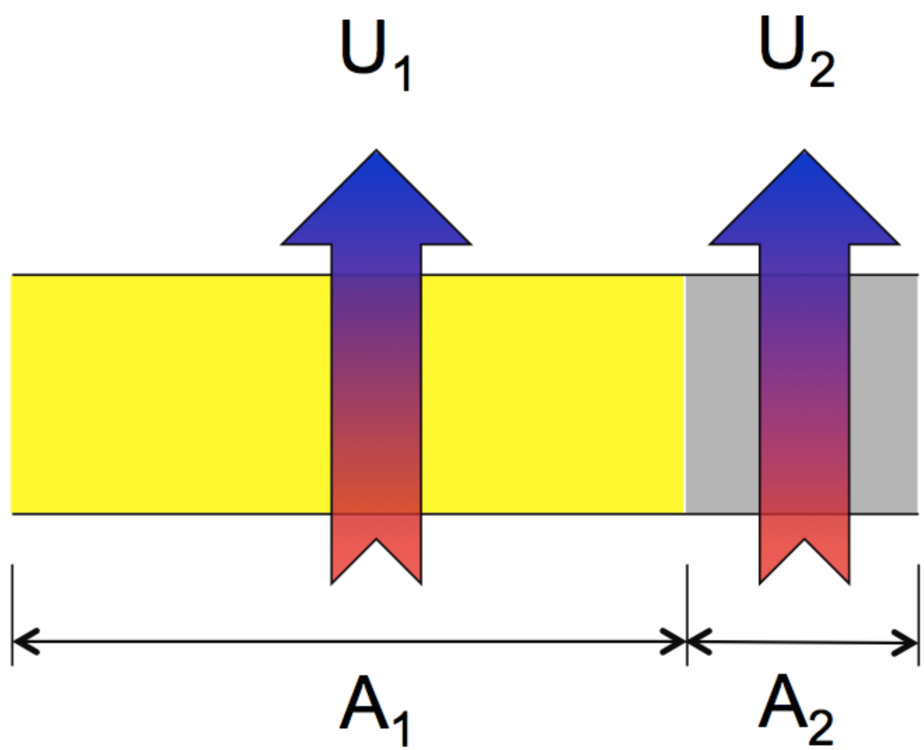
2. **ISO Coefficient Method**
   → Relatively easy. Requires coefficients for each scenario
   → Best simple method for 3-D steel connections

3. **Computer modeling**
   → Requires a trained specialist, but most flexible

1. Parallel Path Method

→ A simpler method, common in the past

$$R_{avg} = \frac{1}{R_1} \cdot \%A_1 + \frac{1}{R_2} \cdot \%A_2$$



$$U_{avg} = \frac{U_1 \times A_1 + U_2 \times A_2}{A_{total}}$$

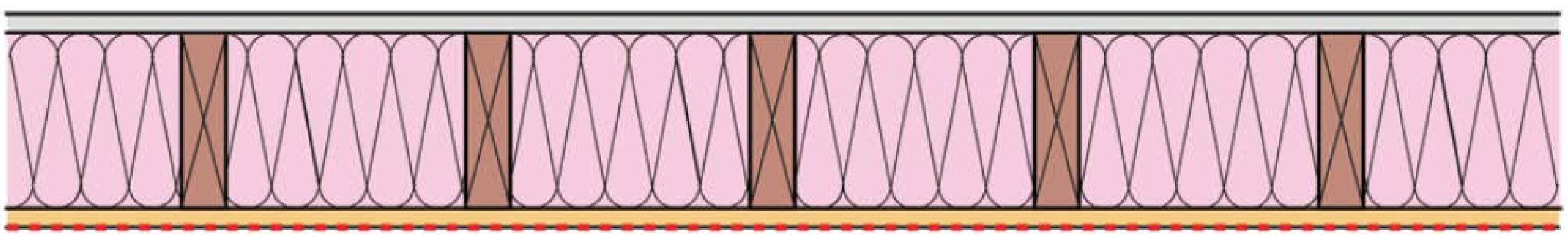
Parallel Path: Example

→ Used for wood framing in NBC 9.36

Parallel Path Method

In wall systems with relatively large components (wood framing) that are moderately conductive (wood is at least R1/ inch), the parallel **path method** has been found to be **quite accurate** (within a few % of measured data).

In this method, heat is assumed to flow from inside to outside in **parallel lines**: one through the wood framing, and another through the insulated portions.

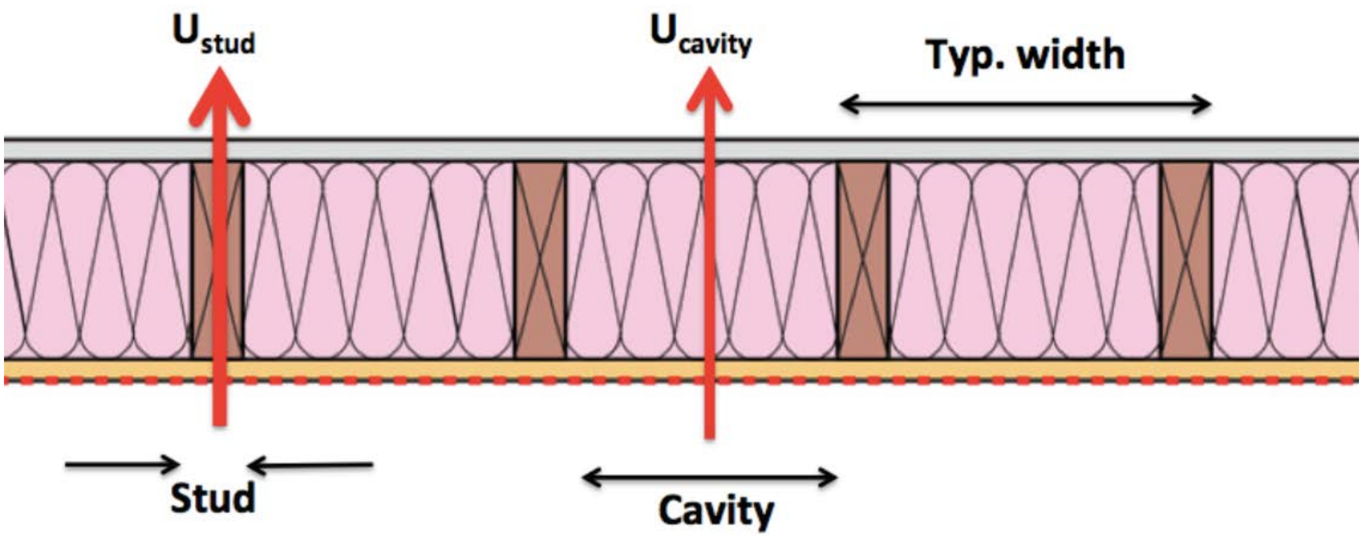


Plan section through wood framed wall

Parallel Path Method

First, conductance or overall **thermal transmittance through each of the paths** that constitute the total envelope section (eg., wood studs and batt insulation, or concrete column) is calculated.

Then the total heat flow is calculated, based on a **weighted average of the areas each path** comprises



Two Distinct Parallel Heat Flow Paths

$$U_{AVG} = U_{Stud} \cdot \frac{A_1}{A_1 + A_2} + U_{batt} \cdot \frac{A_2}{A_1 + A_2}$$

Parallel Path Method - Example

R-value is 22.7 through the insulation and R-8.4 through the stud

For a wall with studs 16” on centre, real world data suggests that studs comprise between 20% and 25% of wall section.

$$U_{AVG} = U_{Stud} \cdot \frac{A_1}{A_1 + A_2} + U_{batt} \cdot \frac{A_2}{A_1 + A_2}$$

$$1 / R_{AVG} = 20\% / R_{Stud} + 80\% / R_{batt}$$

R_{AVG} = 16.9

2. ISO Coefficient Method

- → Thermal bridges divided into two types:
  - → **linear details** that predominately exhibit two-dimensional heat flow, and
  - → **point details** that predominately exhibit three-dimensional heat flow
- → Different symbols used to capture each effect
  - → **ψ** for transmittance of heat in 2-D
  - → **χ** for transmittance of 3-D point details


INTERNATIONAL STANDARD

ISO 6946

Second edition
2007-12-15

Building components and building elements — Thermal resistance and thermal transmittance — Calculation method

Composants et parois de bâtiments — Résistance thermique et coefficient de transmission thermique — Méthode de calcul

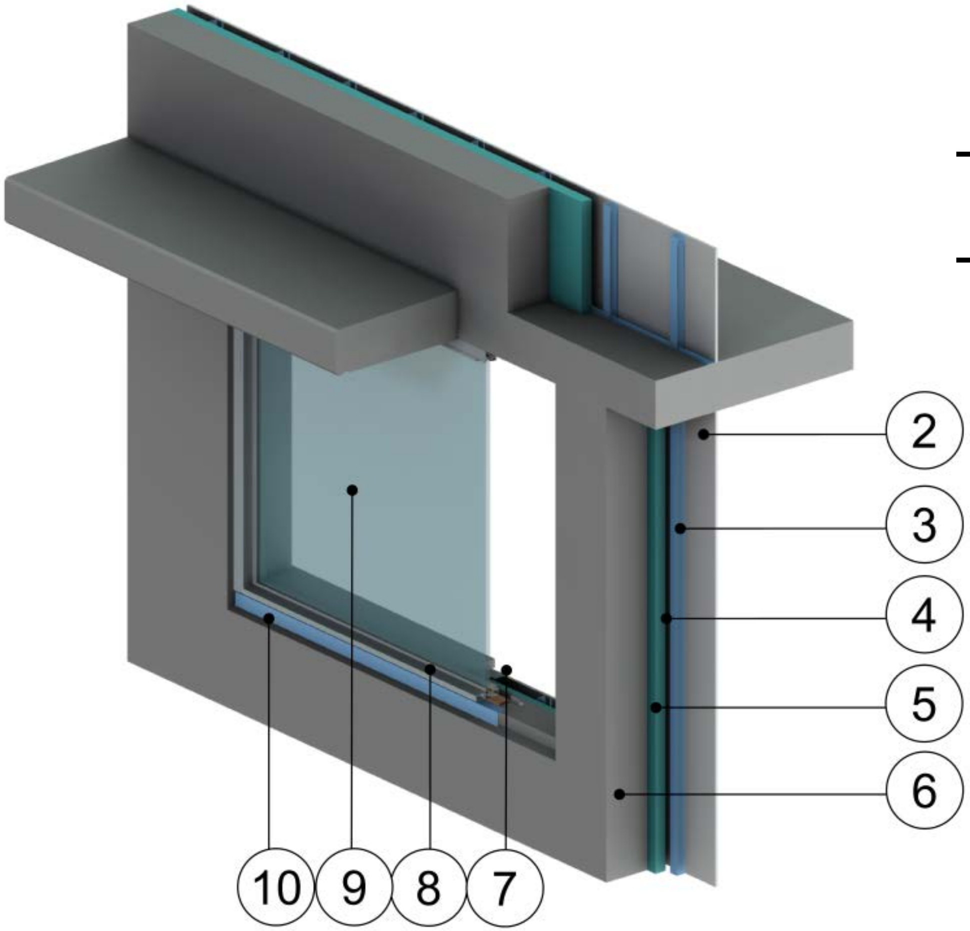
Thermal Bridges – 2/3-D

$$Q = \left[U_o \cdot A + \sum \left(\Psi_i \cdot L_i \right) + \sum \left(\chi_j \cdot n_i \right) \right] \cdot \Delta T$$

- U_o is the "clear field" assembly heat transmittance
- A is the area of the assembly, including all details in the analysis area
- Ψ_i (psi) linear heat transmittance value for detail "i"
- L_i is the total length of the linear detail "i" in the analysis area
- X_j (chi) point heat transmittance value of detail "j"
- N is the number of point thermal bridges of type "j" in the analysis area

Coefficients for some scenarios may be found in ASHRAE 1365 Report, BC Hydro Guide

Example: Balcony /exposed slab edge



- → 8" concrete
- → 3" of continuous XPS insulation on interior
- → 2.5" steel stud
- → drywall

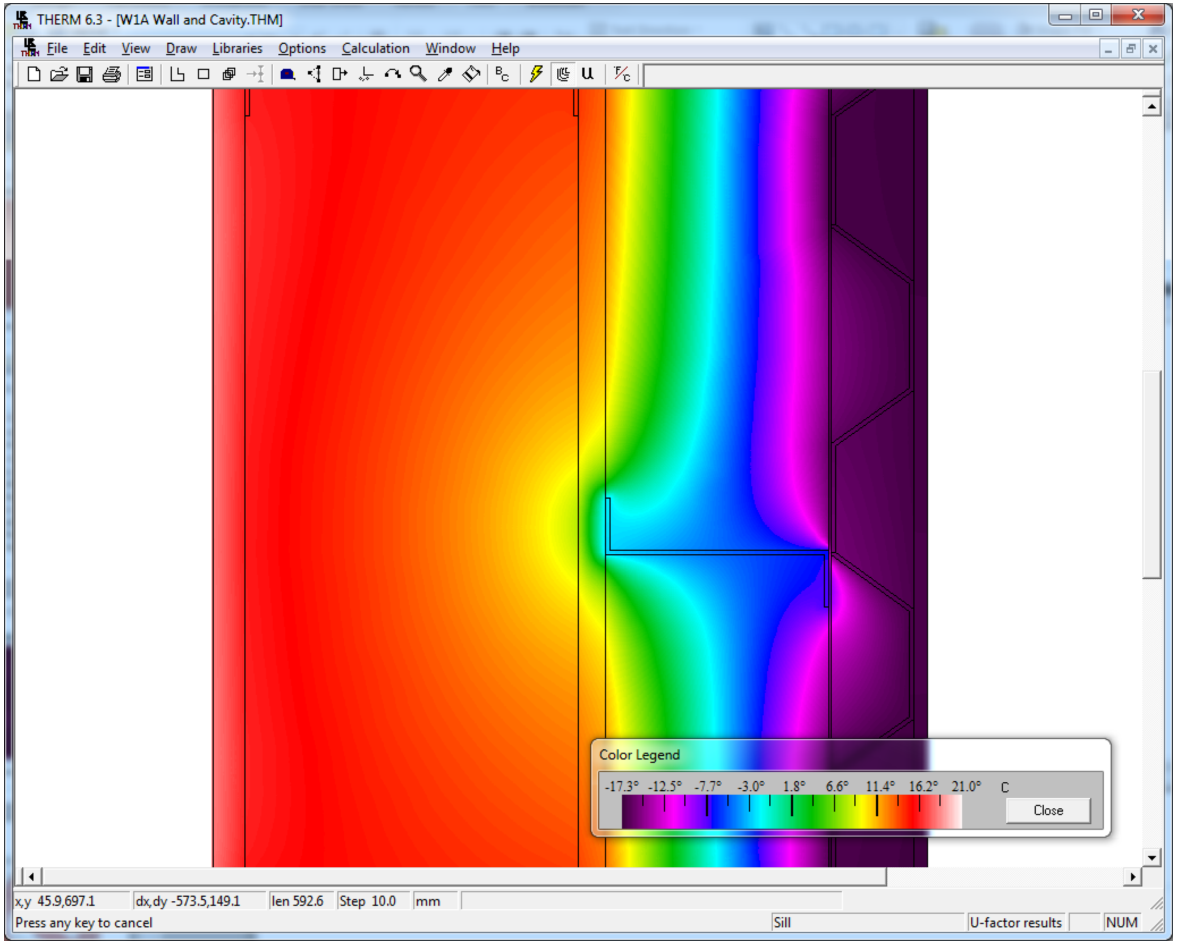
Clear-wall R-17.5
U_{cw}= 0.057 BTU/hr/**ft²**/ ˚F

psi = 0.539 BTU/hr/**ft**/ ˚F

Therefore, one linear foot of this detail is equal to 9.4 square feet of wall above it i.e., 0.539/.057 = 9.4

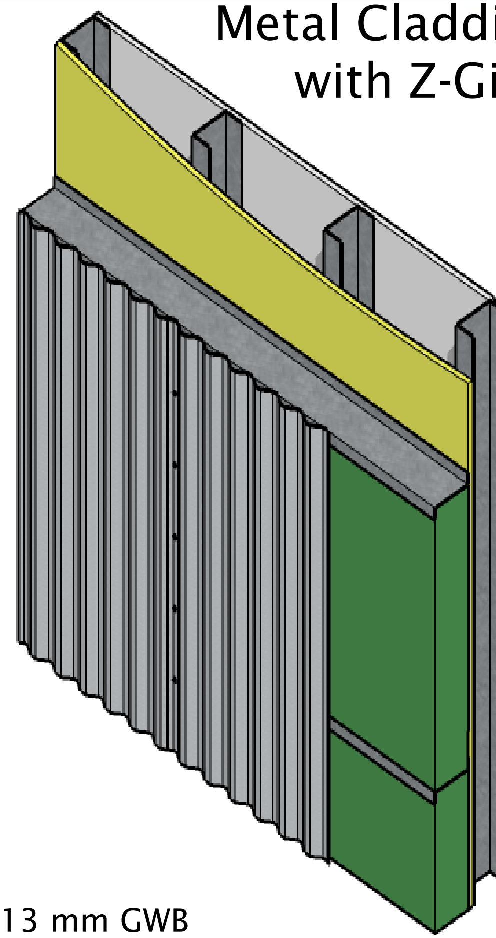
From: *BC Hydro Building Envelope Thermal Bridging Guide*, 2014

3. Computer Modeling



Nominal R-18
Modeled R_{cw}- 8.6

Metal Cladding with Z-Girts



- → ½” 13 mm GWB
- → 4” 102 mm steel stud @ 400 mm oc
- → ½” 13 mm exterior sheathing
- → 4” 102 mm z-girt @ 600 mm oc with R-16.8 semi-rigid
- → Metal siding

Thermal bridging - Windows

$U_{window} = 0.4 = R2.5$

R-20 wall

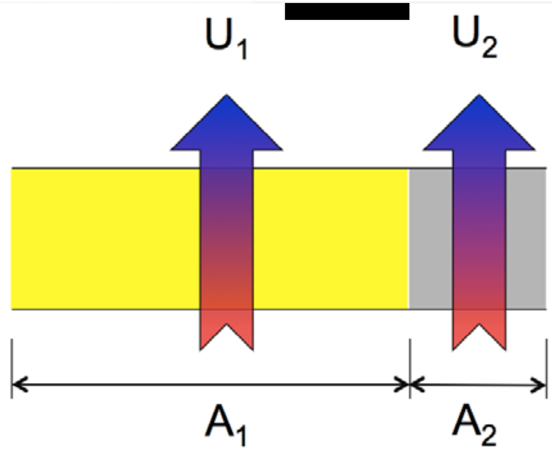
50% of Area

+

R-2.5 window

50% of Area

=



$$U_{avg} = \frac{U_1 \times A_1 + U_2 \times A_2}{A_{total}}$$

Thermal bridging - Windows

R-20 wall

50% of Area

+

R-2.5 window

50% of Area

=

R-4.4

100% of Area

1/20*0.50 + ½* 0.50 = 0.05*.5+0.5*.5 = 0.025+ 0.25 = 0.275, and 1/0.275=3.63

Thermal bridging - Windows

R-20

50% of Area

+

R-4

50% of Area

=

R-6.6

100% of Area

Add R-2 to windows, significantly reduce heat loss/gain from building

Thermal bridging - Windows

R-20

69% of Area

+

R-4

31% of Area

=

R-8.9

100% of Area

Thermal Bridging - Floor Slabs

R-20
8 ft clear

+

8" slab edge
R-1.2

=

R-??

8'8" full-height

Thermal Bridging - Floor Slabs

R-20
8 ft clear

\+

8” slab edge
R-1.2

=

R-9.0

8’8” full-height

4. Concrete Systems

→ Precast

→ Cast-in Place

→ Masonry

Concrete Systems

→ All Concrete systems have **mass-benefit** where allowed codes

→ **Basic principles** of calculating thermal performance are the **same**

→ **Different systems** have slightly **different tips** and tricks to calculate thermal bridges

Precast Concrete

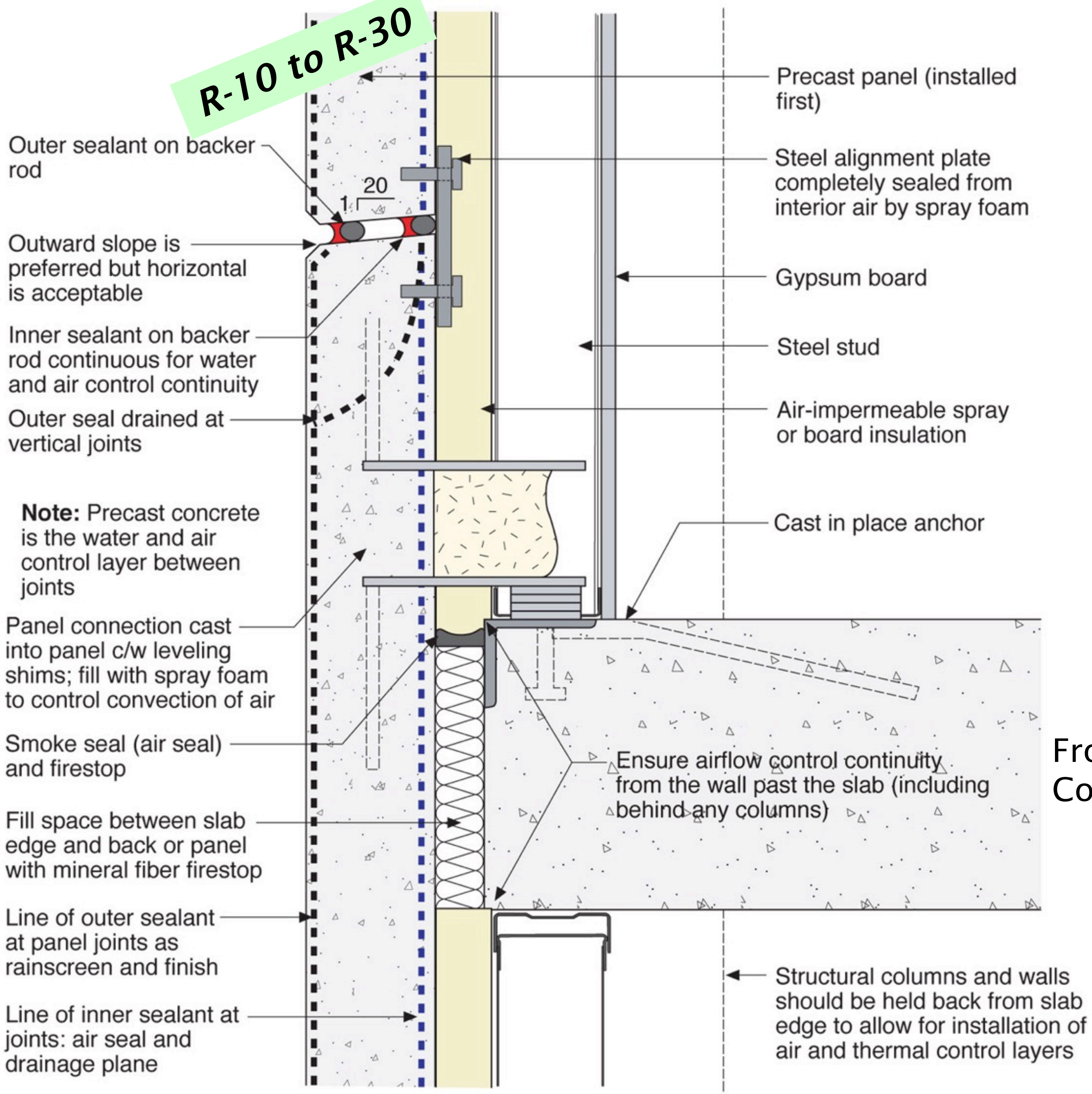
- → Architectural Precast
- → Sandwich panels
- → Total Precast

Architectural
Precast

Architectural Precast

- → Single-wythe hung off building
- → Exterior finish and air-water control
- → Insulation added to the inside
- → Thermal bridge at floor is possible
  - → Easy to minimize with fire stopping insulation

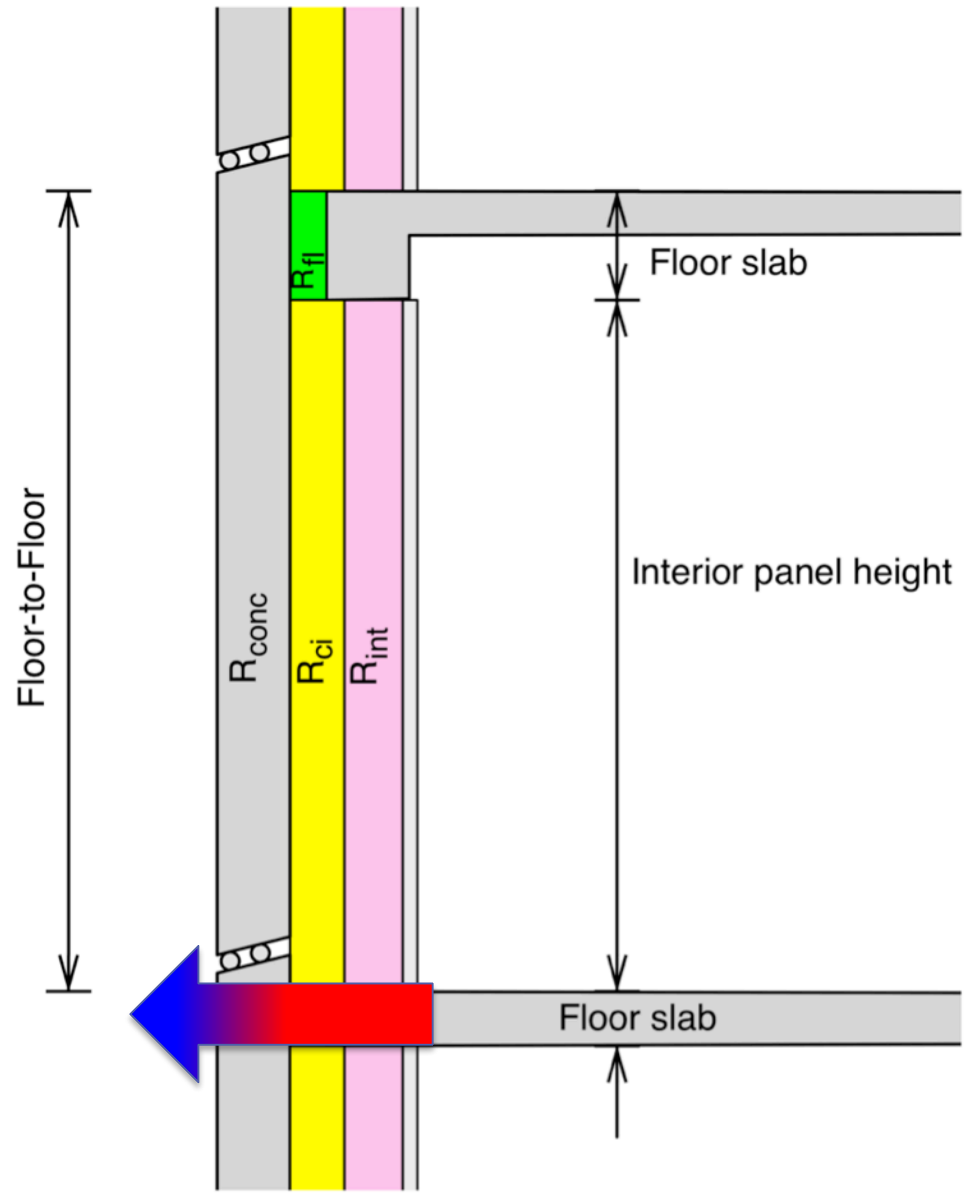
Architectural Precast



From: CPCI Rain Control Guide, 2013

Architectural Precast

- → Floor slab-edge insulation critical

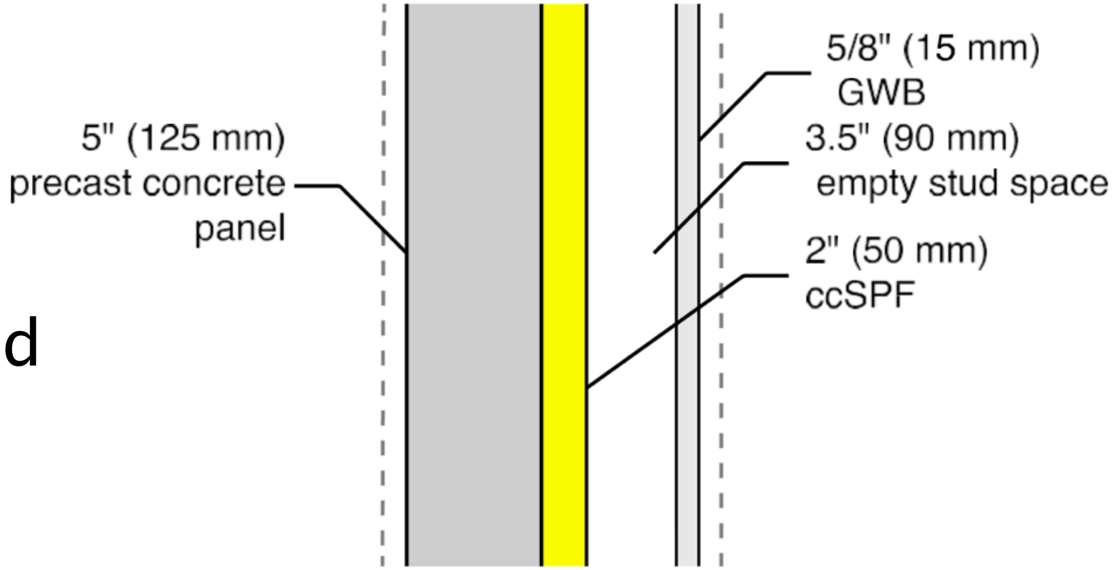


Architectural Precast: Example

→ Clear-wall R-value

→ R-14.5 w/empty stud

→ R-19.7 w/ R-13 batt



Layer	R-value
5" (125 mm) concrete	0.30
2" (51 mm) ccSPF insulation	12.0
3.5" empty stud/films/GWB	2.19
Total	14.5

Supporting tables from Guide

Material	Conductivity (R/inch)	R-value at 2"	R-value at 2.5"	R-value at 3"	R-value at 3.5"	R-value at 4"
Open-cell foam (ocSPF)	3.8	7.6	9.5	11.4	13.3	15.2
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Expanded polystyrene Type 2		same as semi-rigid mineral wool				
Extruded polystyrene	5.0	10.0	12.5	15.0	17.5	20.0
Polyisocyanurate	5.5	11.0	13.8	16.5	19.3	22.0
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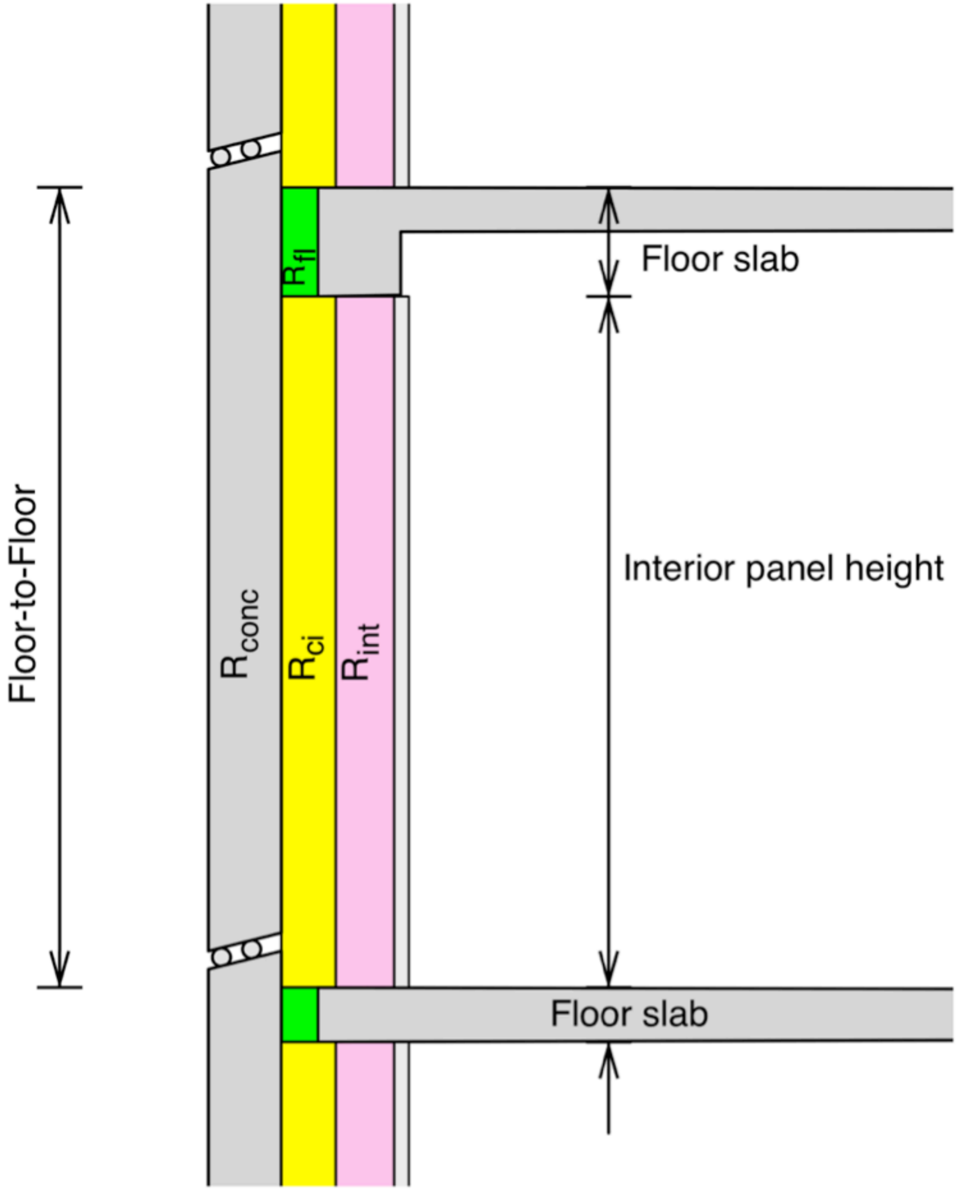
Cavity Depth		Rated Cavity R-value	Layer R_{cw}-value	Layer RSI_{cw}
In	mm		@ 16 inch centres	@ 405 mm centres
2.5	64	Empty	2.15	0.37
3.5	89	Empty	2.19	0.39
		R-13	7.4	1.31
		R-15	7.8	1.38
6.0	152	Empty	2.24	0.39
		R-19	8.5	1.50
		R-21	8.8	1.55
		R-24 (4" ccSPF)	9	1.59

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

Architectural Precast

→ Floor slab-edge insulation critical

Stonewool Firestopping Thickness (in.)	Effective Slab R-value
1	4.75
1.5	6.83
2	8.90
2.5	11.00
3	13.10
3.5	15.15
4	17.20
t>4"	4.0*t+1.2

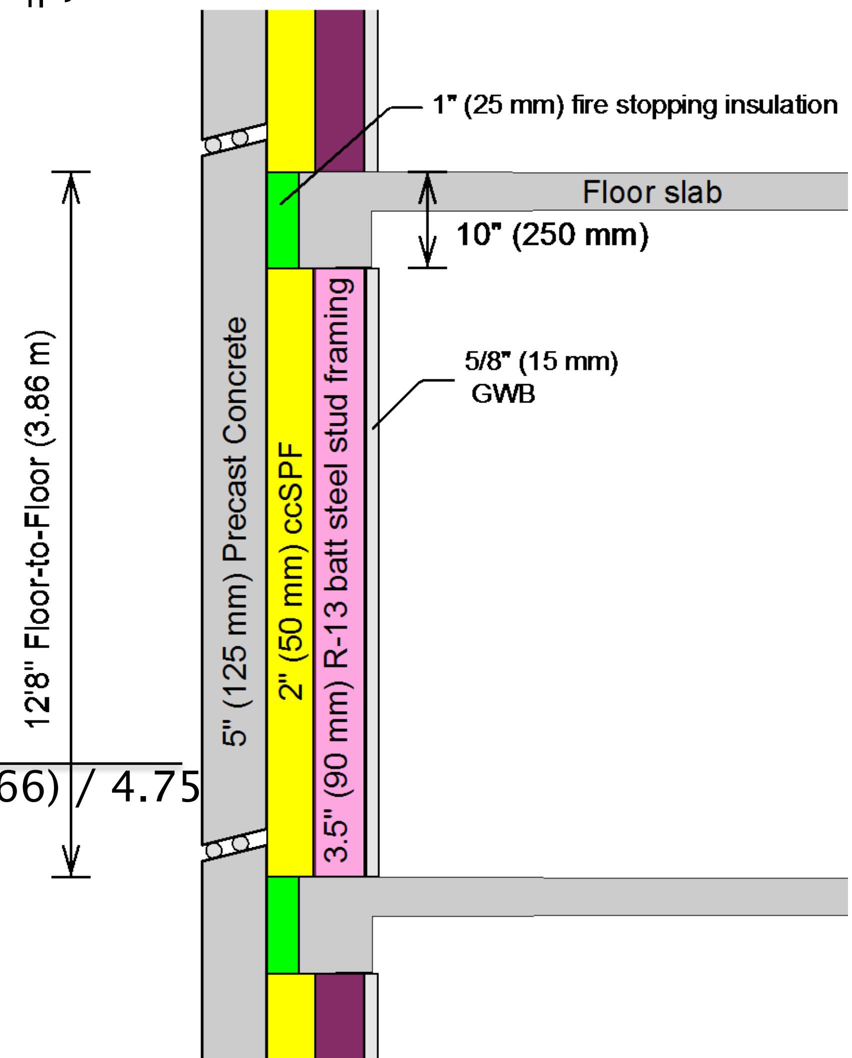


Architectural Precast: Whole-wall Example

$$R_{ww} = 1/\{[(FF-T_{fl})/FF]/R_{cw} + (T_{fl}/FF)/R_{fl}\}$$

where

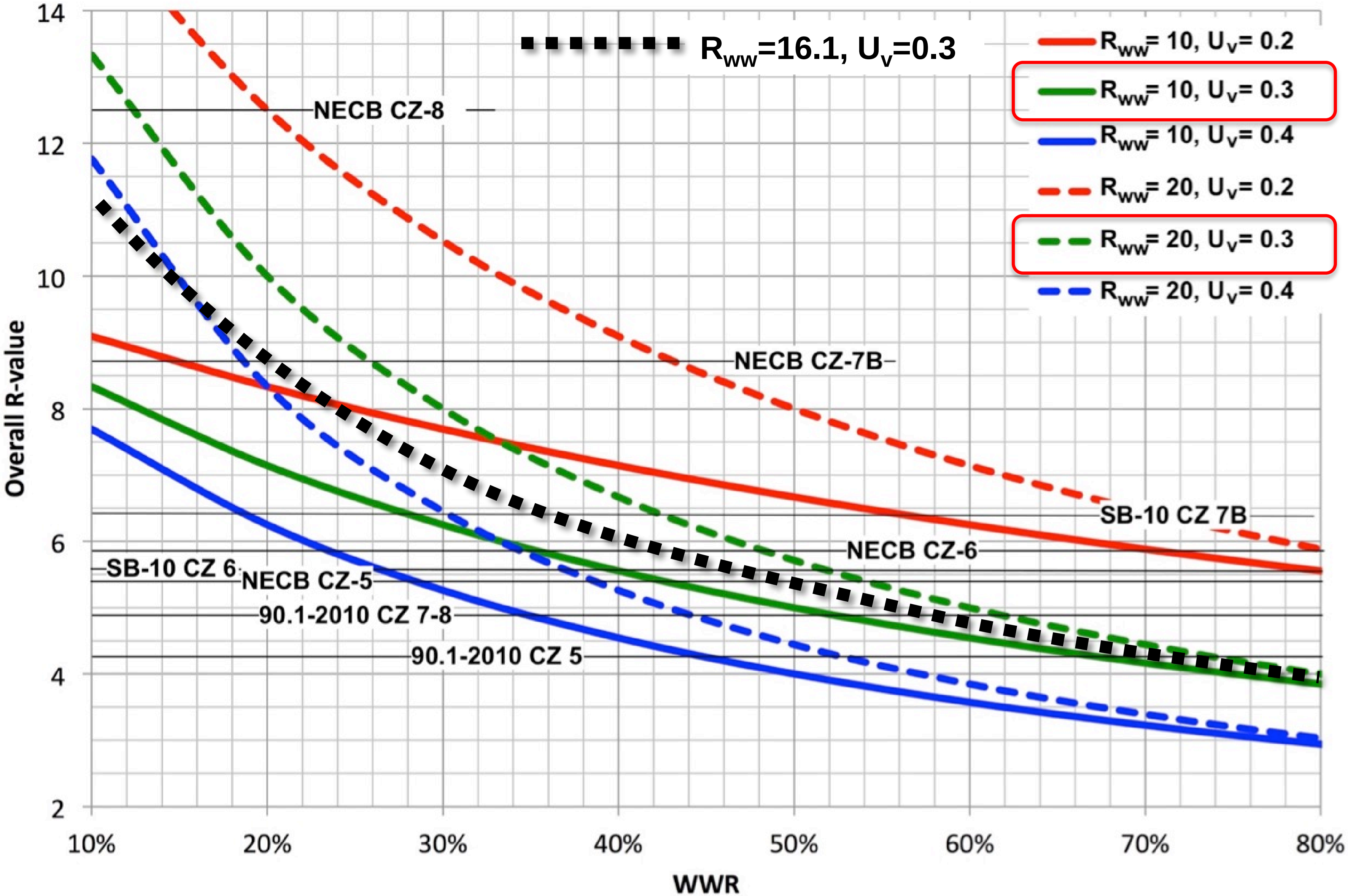
- R_{ww} is the whole-wall R-value (incl. impact of slab)
- FF is the floor-to-floor height
- T_{fl} is the floor slab thickness
- R_{fl} is R-value of the floor-wall assembly (from table)
- Clear-wall R-19.7 (from before)



$$R_{ww} = \frac{1}{[(12.66-0.83)/12.66]/19.7 + (0.83/12.66)/4.75}$$

- R_{ww}-16.1
- R_{ww}-18.0 if gap changed to 2”

Overall R-value vs some codes



Architectural Precast: Tables

→ Whole-wall

8" floor slabs

Rcw	Slab edge (in)	Floor-to-floor height (ft) 9	10	12	14	16	20	24
2.1	1	2.2	2.2	2.2	2.2	2.2	2.2	2.1
	2	2.3	2.3	2.2	2.2	2.2	2.2	2.2
7.4	1	7.0	7.0	7.1	7.1	7.2	7.2	7.2
	2	7.5	7.5	7.5	7.5	7.5	7.5	7.5
8.5	1	7.8	7.9	8.0	8.0	8.1	8.2	8.2
	2	8.5	8.5	8.5	8.5	8.5	8.5	8.5
10	1	8.9	9.0	9.2	9.3	9.4	9.5	9.6
	2	9.9	9.9	9.9	9.9	9.9	9.9	9.9
12	1	10.3	10.4	10.6	10.8	11.0	11.1	11.3
	2	11.6	11.6	11.7	11.7	11.7	11.8	11.8
14	1	11.5	11.7	12.0	12.3	12.5	12.8	12.9
	2	13.2	13.2	13.4	13.4	13.5	13.6	13.7
16	1	12.7	12.9	13.4	13.7	13.9	14.3	14.6
	2	14.7	14.8	15.0	15.1	15.2	15.4	15.5
18	1	13.7	14.1	14.6	15.0	15.3	15.8	16.1
	2	16.2	16.3	16.6	16.8	16.9	17.1	17.3
20	1	14.7	15.1	15.8	16.3	16.7	17.2	17.6
	2	17.6	17.8	18.1	18.4	18.6	18.8	19.0
24	1	16.5	17.1	17.9	18.6	19.1	20.0	20.5
	2	20.2	20.5	21.0	21.4	21.7	22.1	22.4
28	1	18.1	18.8	19.9	20.7	21.4	22.5	23.3
	2	22.6	23.1	23.8	24.3	24.7	25.3	25.7
	3	24.9	25.1	25.6	25.9	26.1	26.5	26.7
32	1	19.5	20.3	21.6	22.7	23.6	24.9	25.8
	2	24.8	25.4	26.3	27.0	27.5	28.3	28.9
	3	27.6	28.0	28.6	29.0	29.4	29.8	30.2

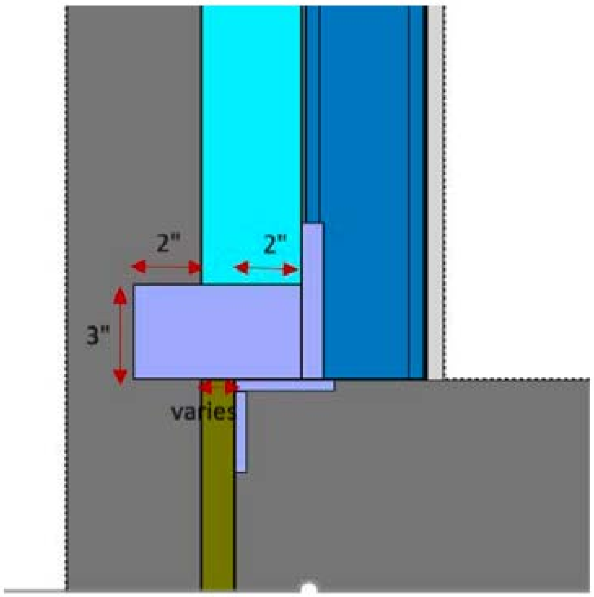
Architectural Precast: Anchors

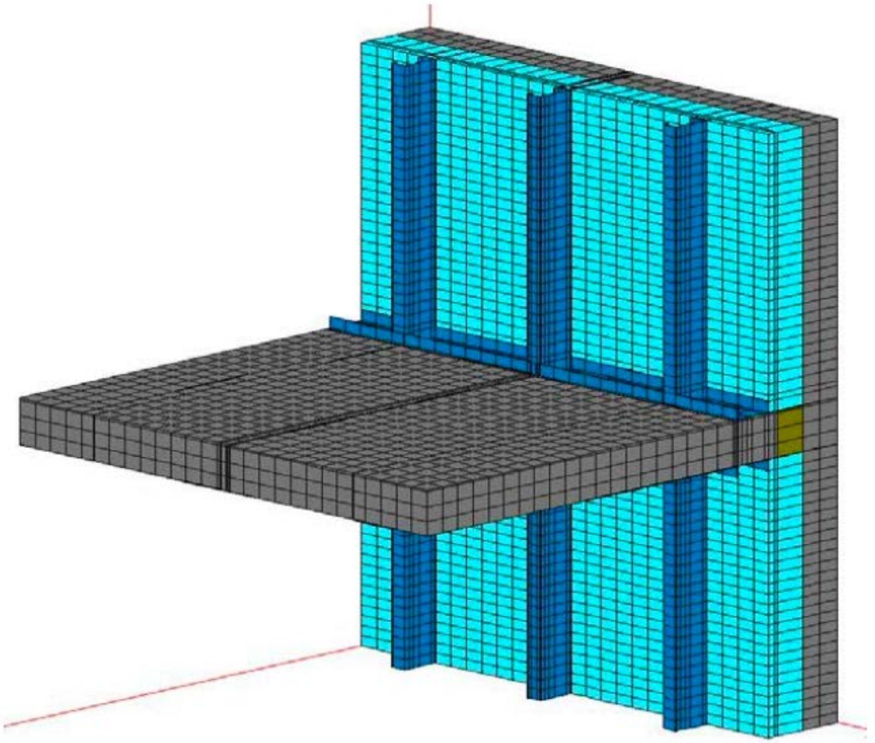
→ Modest thermal bridge in most cases

→ Not required to be accounted for by most codes

→ Data and techniques in Guide

→ Small impact, about 5%-10%

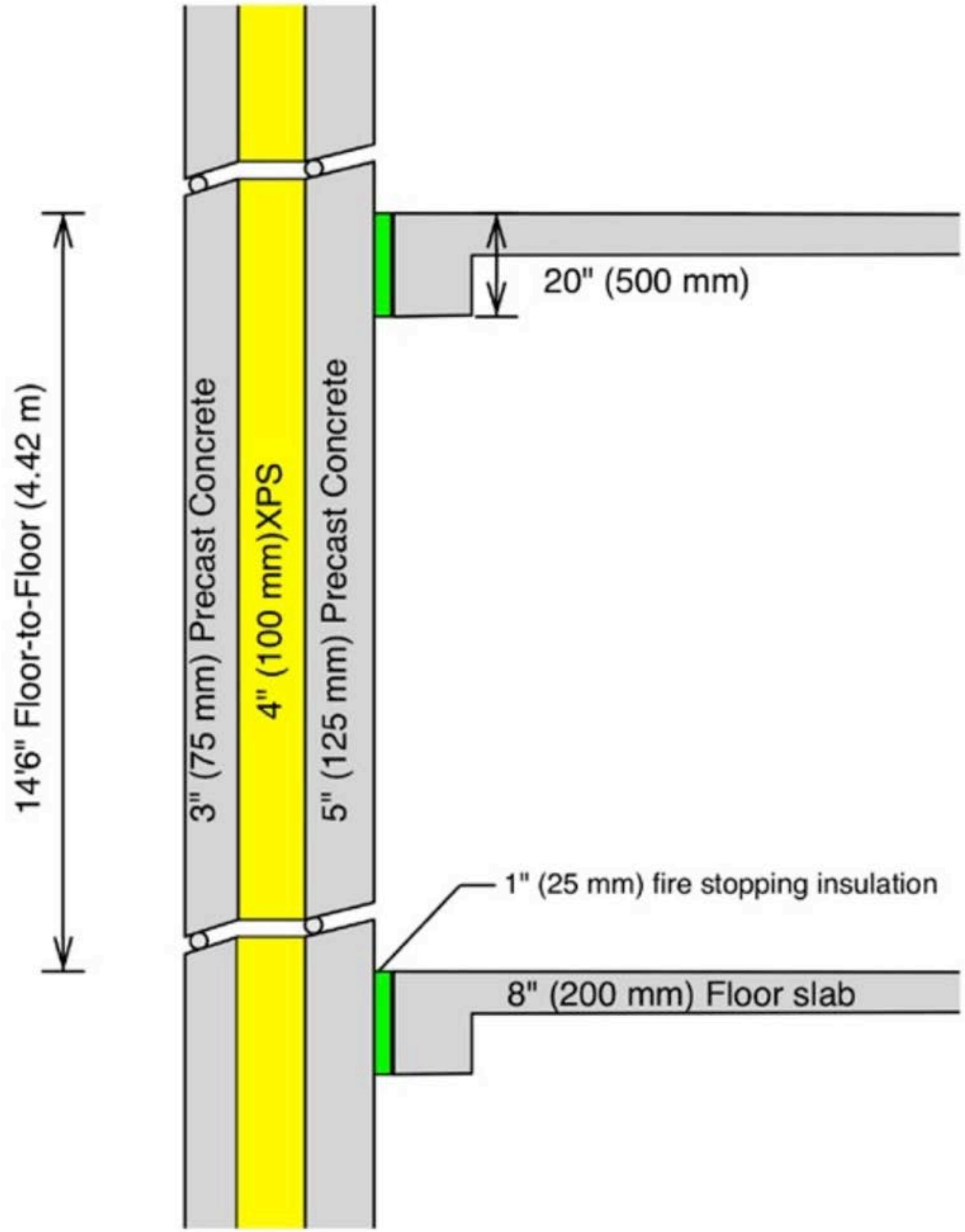




Sandwich (Multi-wythe) Panels

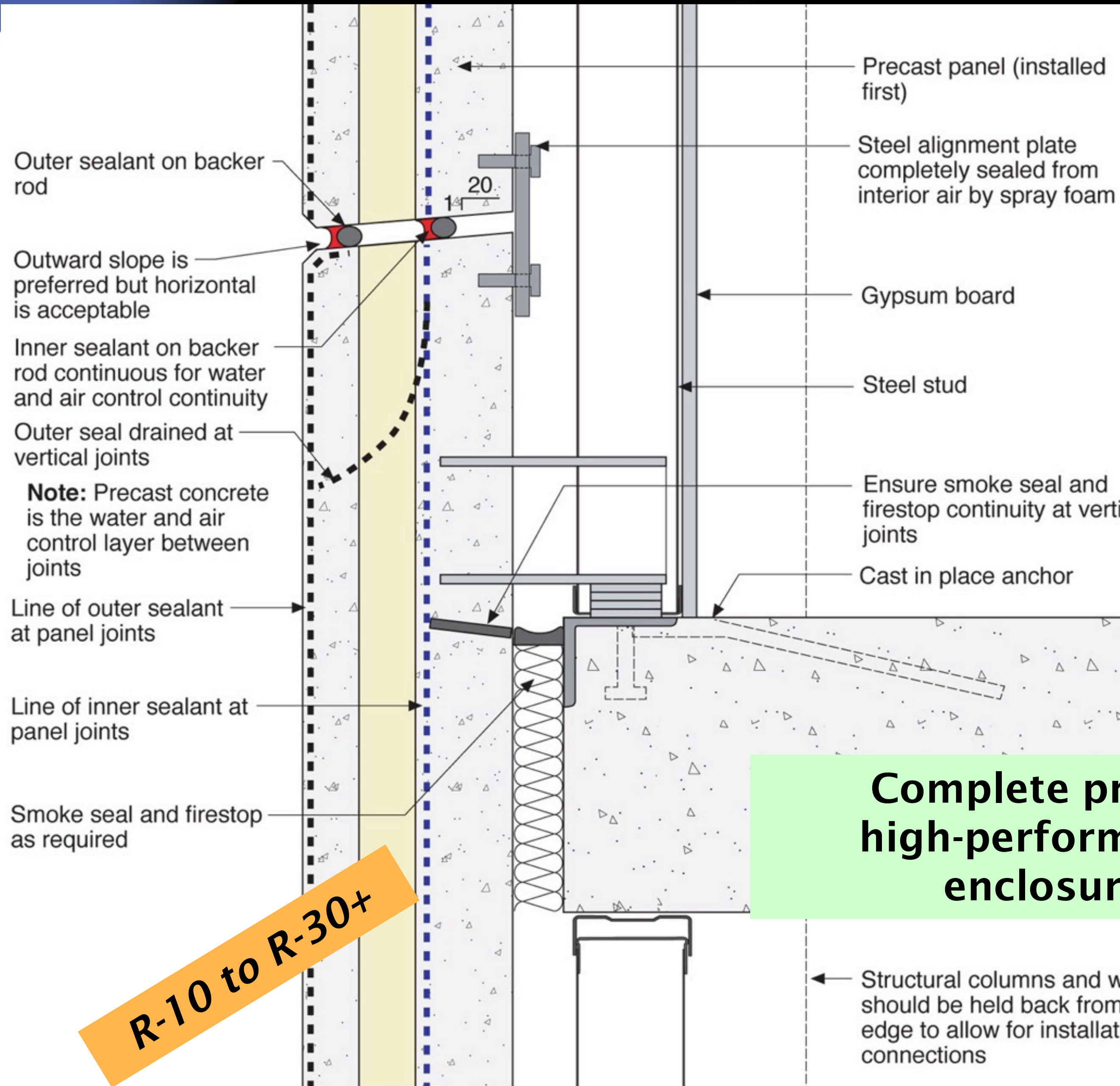
Multi-wythe Sandwich panels

- → Complete system
- → Continuous insulation
  - → Anchors and floors have no impact
- → No need to do complex calculations



Waterloo Region Courthouse
NORR Architects

Multi-wythe Insulated Sandwich panels



Complete prefab high-performance enclosure

Multi-wythe Insulated Sandwich panels

- → E.g. 4” thick XPS insulation between 3” outer wythe and 6” inner wythe
- → Answer… about R21
  - → note: 8” of concrete provides negligible R-value! (relative to insulation) (but mass effect)

Insulation Thickness (in)	Insulation Type		
	R4/in (MW/EPS)	R5/in (XPS)	R5.5/in (PIC)
2	9.4	11.4	12.4
2.5	11.4	13.9	15.1
3	13.4	16.4	17.9
3.5	15.4	18.9	20.6
4	17.4	21.4	23.4
4.5	19.4	23.9	26.1
5	21.4	26.4	28.9
6	25.4	31.4	34.4
8	33.4	41.4	45.4

Note: Insulation values include air films and 7” (178 mm) of concrete, but assume inter-wythe connections have negligible impact on heat flow

Insulation Thickness (mm)	k=0.036 W/mK (MW/EPS)	k=0.029 W/mK (XPS)	k=0.026 W/mK (PIC)
51	1.65	2.00	2.18
64	2.00	2.44	2.66
76	2.35	2.88	3.14
89	2.70	3.32	3.63
102	3.06	3.76	4.11
114	3.41	4.20	4.60
127	3.76	4.64	5.08
152	4.46	5.52	6.05
203	5.87	7.28	7.99

Inter-wythe Connectors

- → Uninsulated panel edges and embeds can be very significant… avoid if at all possible

- → Connectors reduce thermal performance
  - → Typical steel connections around 5-15% heat loss
- → Stainless steel connectors have ¼ the thermal conductivity of steel (so only add 1-5% loss)
- → Composite connectors have low conductivity … but need to be larger in area /more in # for equal strength

**Total
Precast**

Single-wythe Total Precast

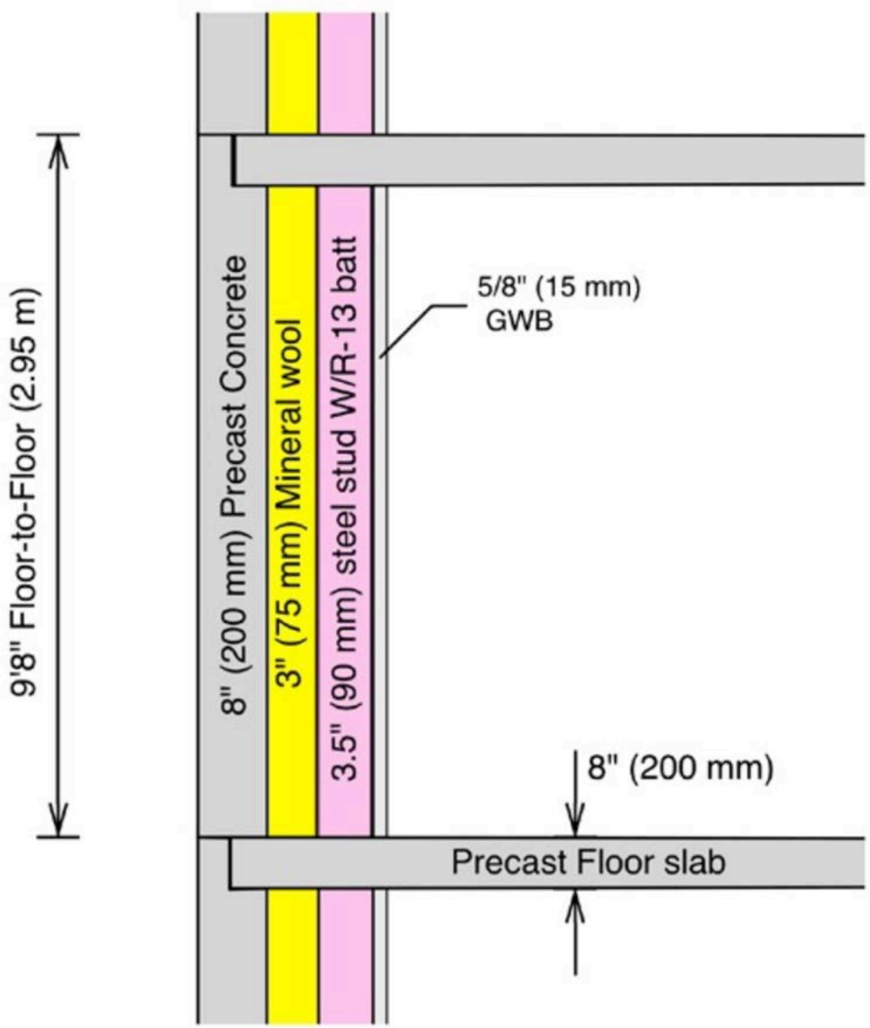
- → Load-bearing structure and exterior finish panels
- → Demising walls, stairwells, elevator core all precast
- → Thermal bridging at floor slab penetrations need to be accounted for
  - → Can be significant heat loss

Total Precast (MURB)

Waterloo, ABA Architects

Total Precast: Example

- Clear-wall R
  - Easy to get high values
- Whole-wall R
  - Floor slabs impact
- Estimate thermal performance with parallel path method
  - *Use R-1.2 for slab*



Total Precast: Whole-wall Example

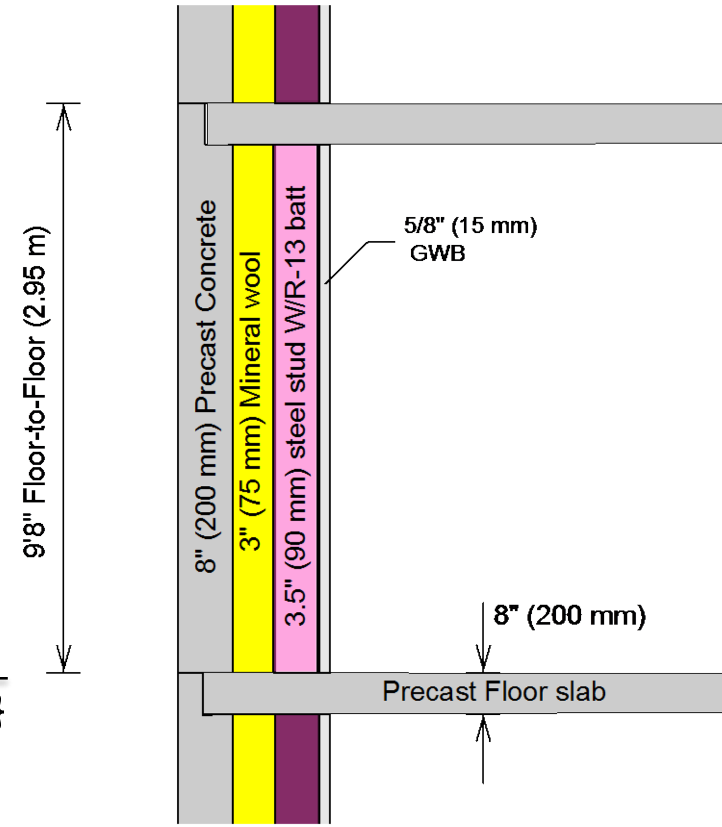
$R_{ww} = 1/ \{ [(FF-T_{fl}) / FF] /R_{cw} + (T_{fl} / FF) / R_{fl} \}$

where

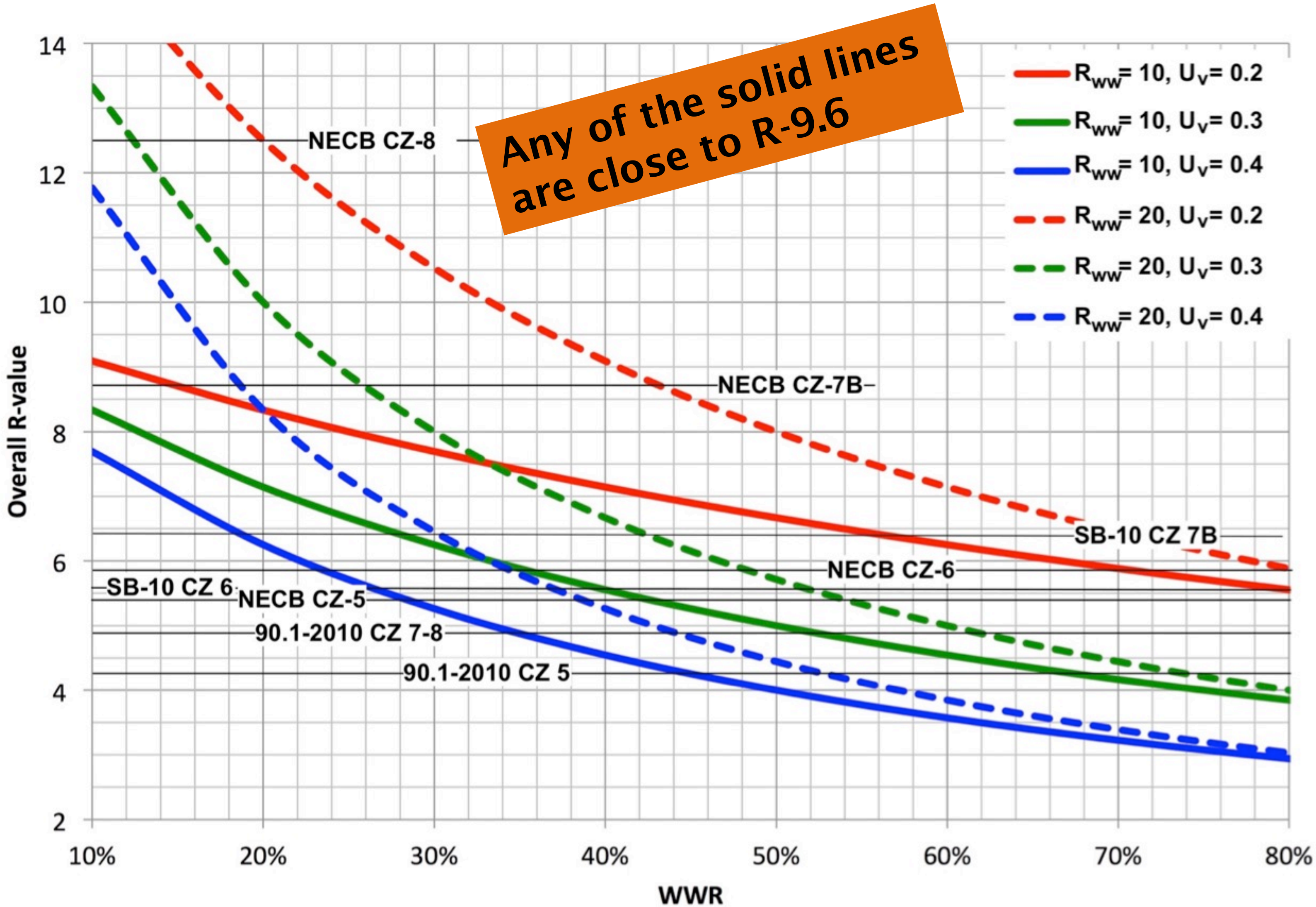
- → R_{ww} is the whole-wall R-value (incl. impact of slab)
- → FF is the floor-to-floor height
- → T_{fl} is the floor slab thickness
- → R_{fl} is R-value of the floor-wall assembly (R-1.2 from Guide)
- → R_{cw} is clear-wall R-20

$$R_{ww} = \frac{1}{[(9.66-0.66) / 9.66] /20 + (0.66/ 9.66) / 1.2\}}$$

→ R_{ww} - 9.6



Overall R-value vs some codes



Total Precast: Table

→ Floor slab penetrations matter!

	floor-to-floor (ft)				
R_{ww}	9	9.66	11	12	16
5	4.0	4.1	4.2	4.3	4.4
7.5	5.4	5.5	5.7	5.8	6.2
10	6.5	6.6	6.9	7.1	7.7
12.5	7.4	7.6	8.0	8.2	9.0
15	8.1	8.4	8.8	9.2	10.1
17.5	8.7	9.0	9.6	10.0	11.2
20	9.3	9.6	10.3	10.7	12.1
25	10.1	10.6	11.4	11.9	13.7
30	10.8	11.3	12.2	12.9	15.0
35	11.3	11.9	12.9	13.6	16.1
40	11.8	12.4	13.5	14.3	17.0

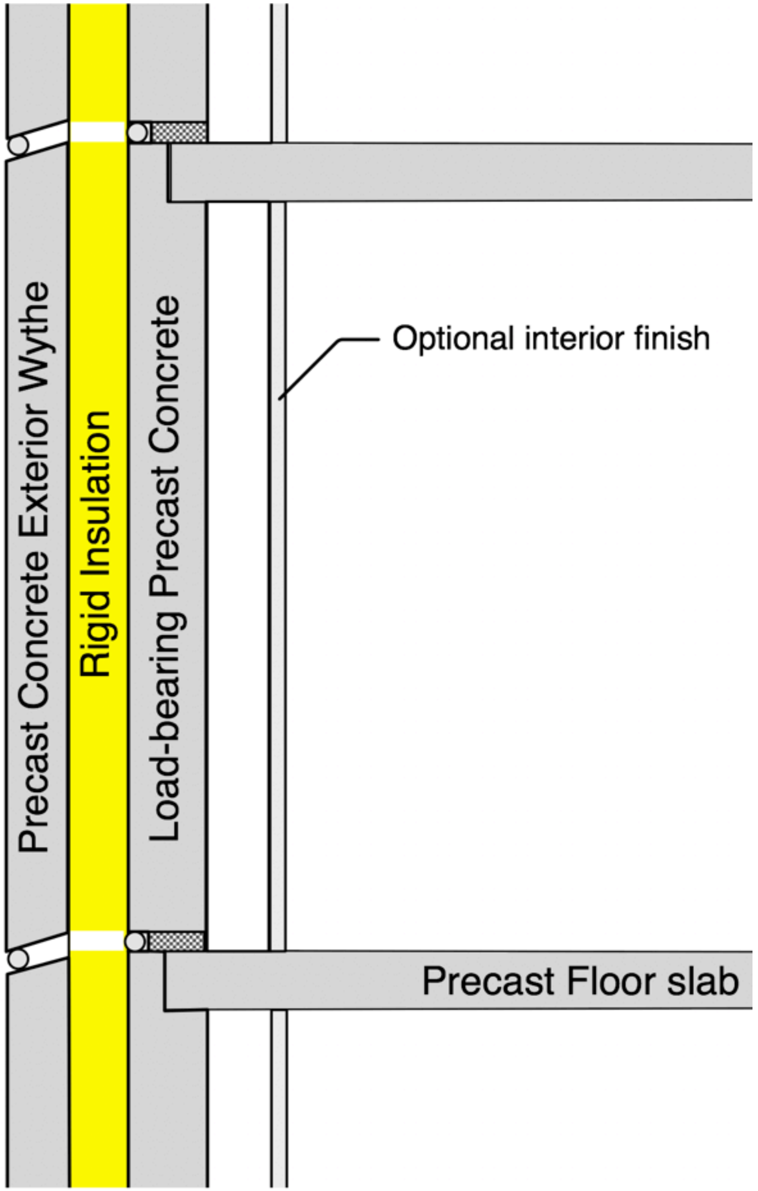
Total Precast : Sandwich panel

→ Total enclosure system

→ Windows can be installed in plant

Total Precast Sandwich

- → No thermal bridges
- → Balconies should be added to the exterior
- → R-value just like non-load-bearing precast sandwich
- → Estimate of performance: Insulation value



Cast-in-Place Systems

- → Conventional CIP
- → Insulated Concrete Forms (ICF)
- → Integrally-Insulated (Sandwich)

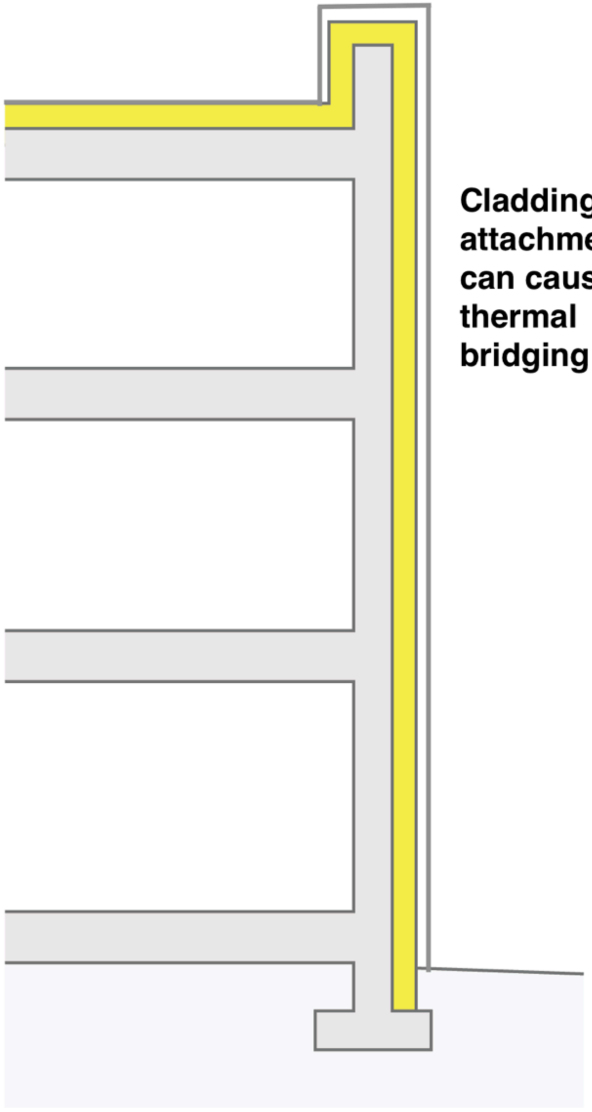
Conventional
CIP

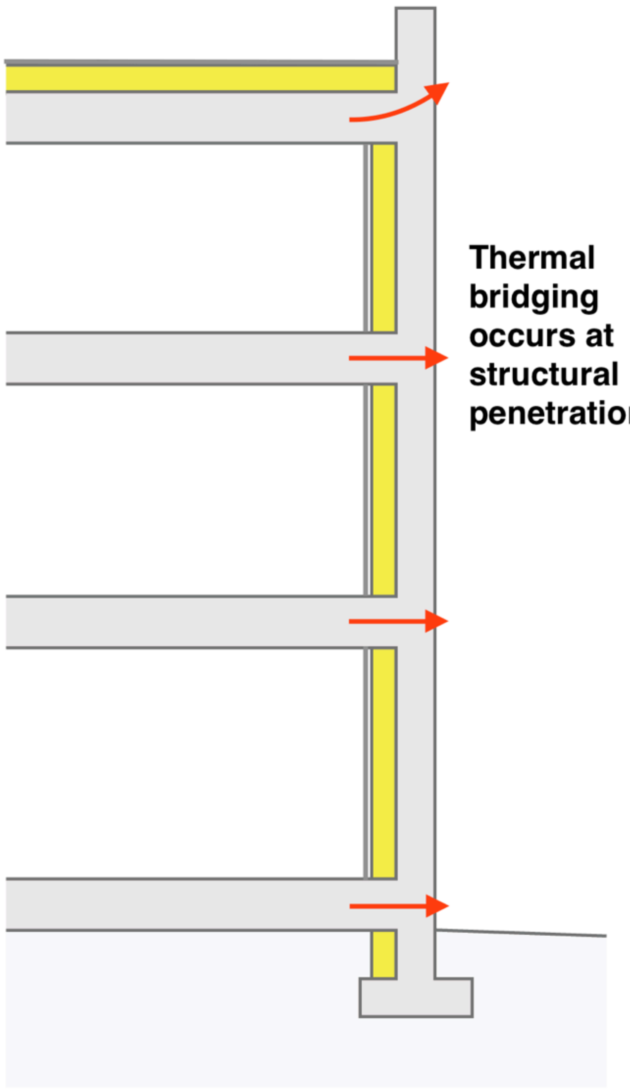
Concrete Structure

→ Any exterior enclosure system may be used

Thermal bridging: structural penetration

→





Cast-in-place

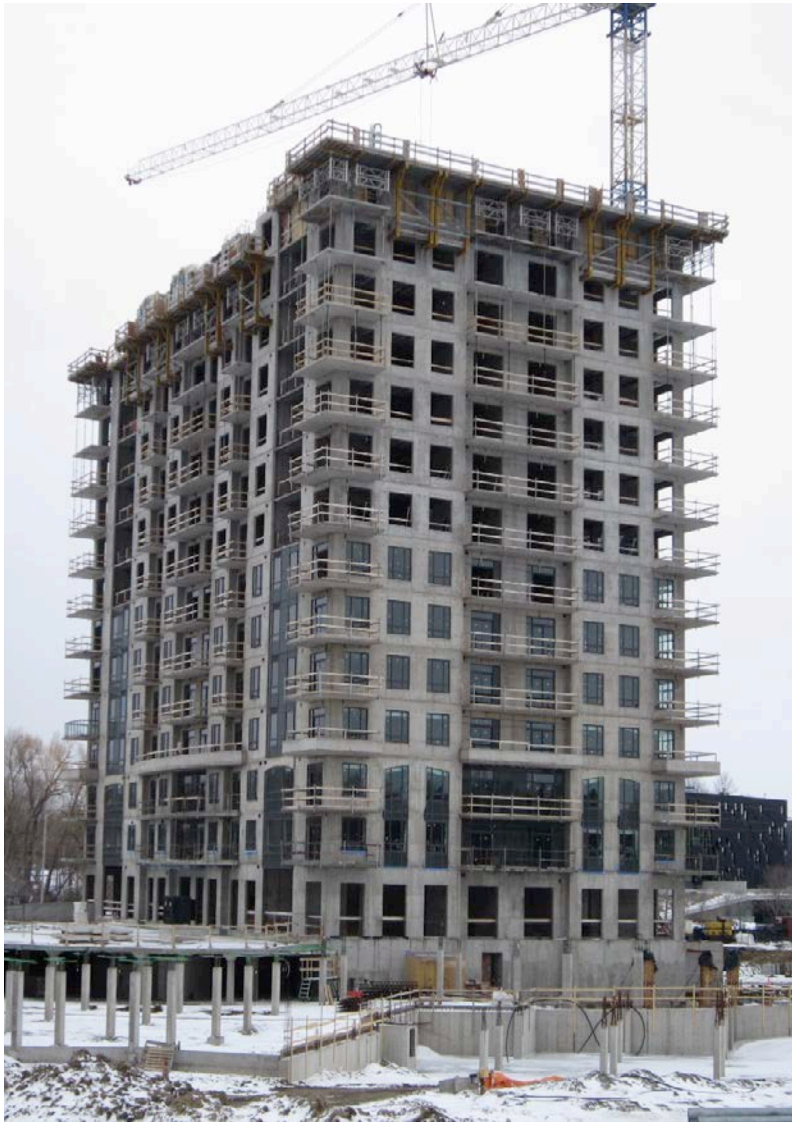
→ Long-used structurally

→ Pierced shear wall can be exterior enclosure support

→ CIP floor slabs tie into walls, interior partitions, elevators

→ Interior or exterior insulation options available

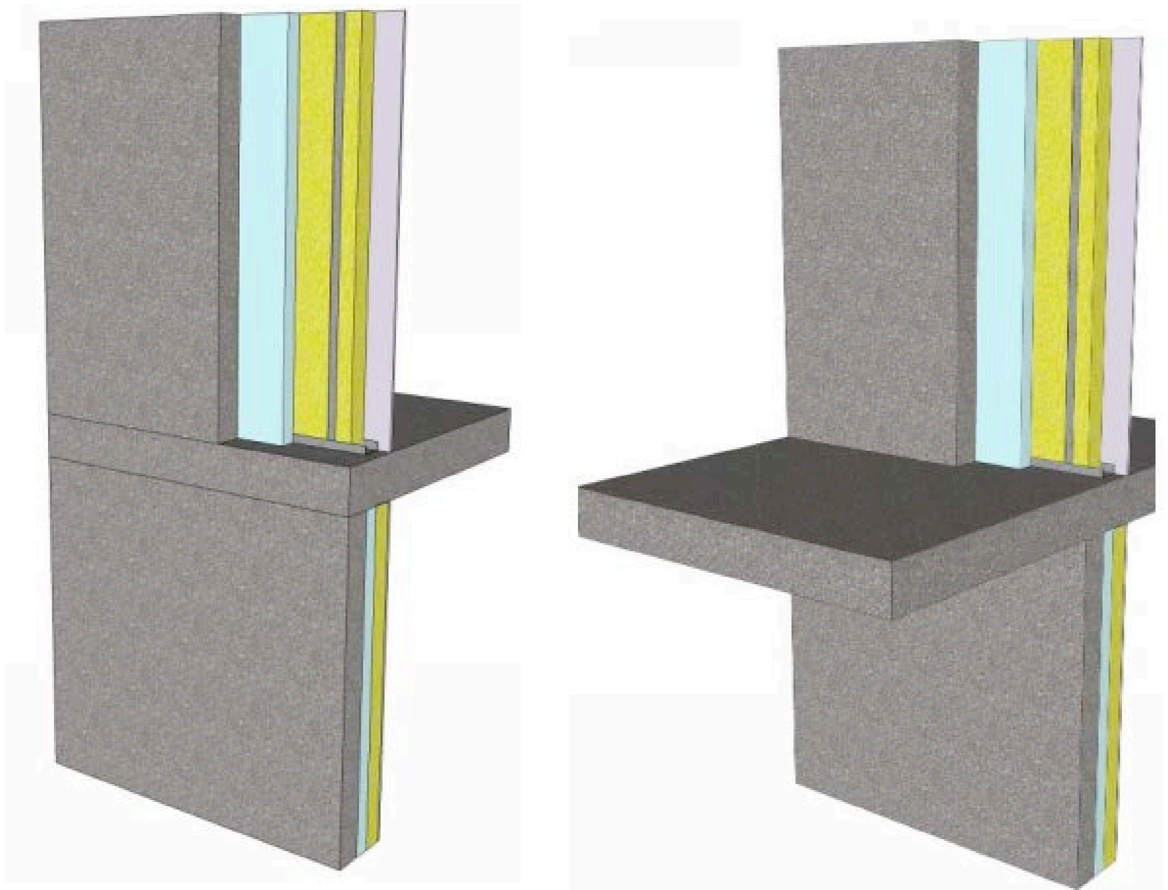
→ Can expose concrete as a finish



CIP with Interior Insulation
(Floor slab penetrating insulation)

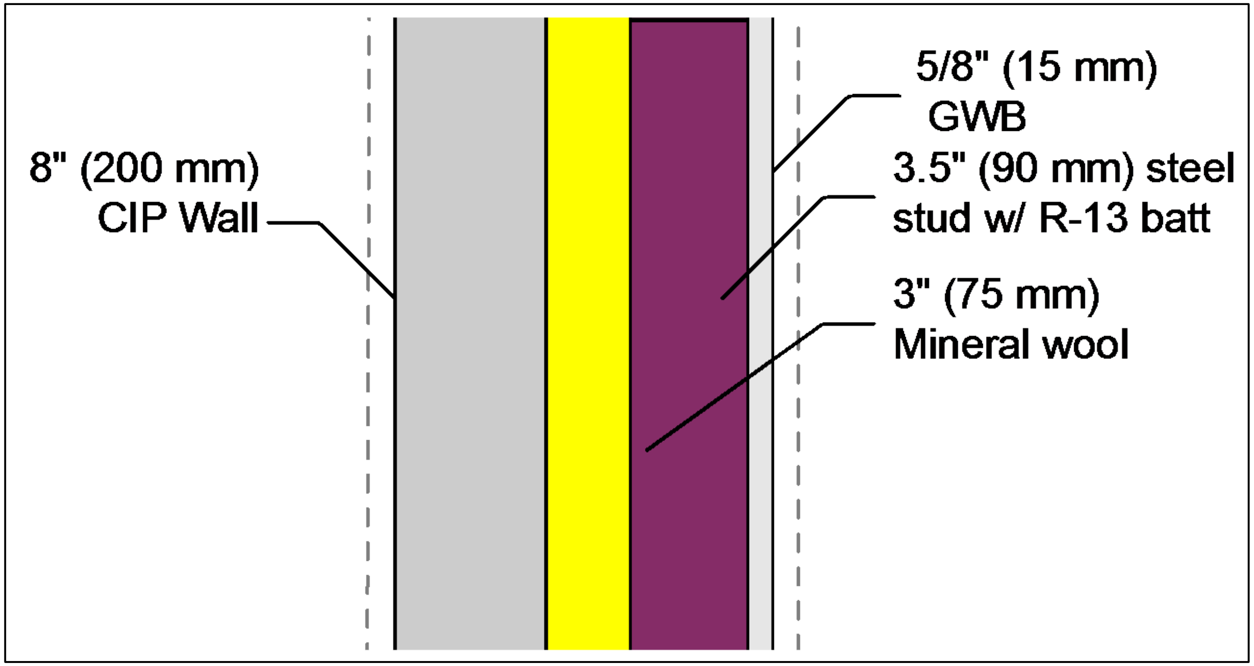
→ Identical to single-wythe total precast

→ Thermal bypass of clear-wall insulation



CIP Interior Insulation Example

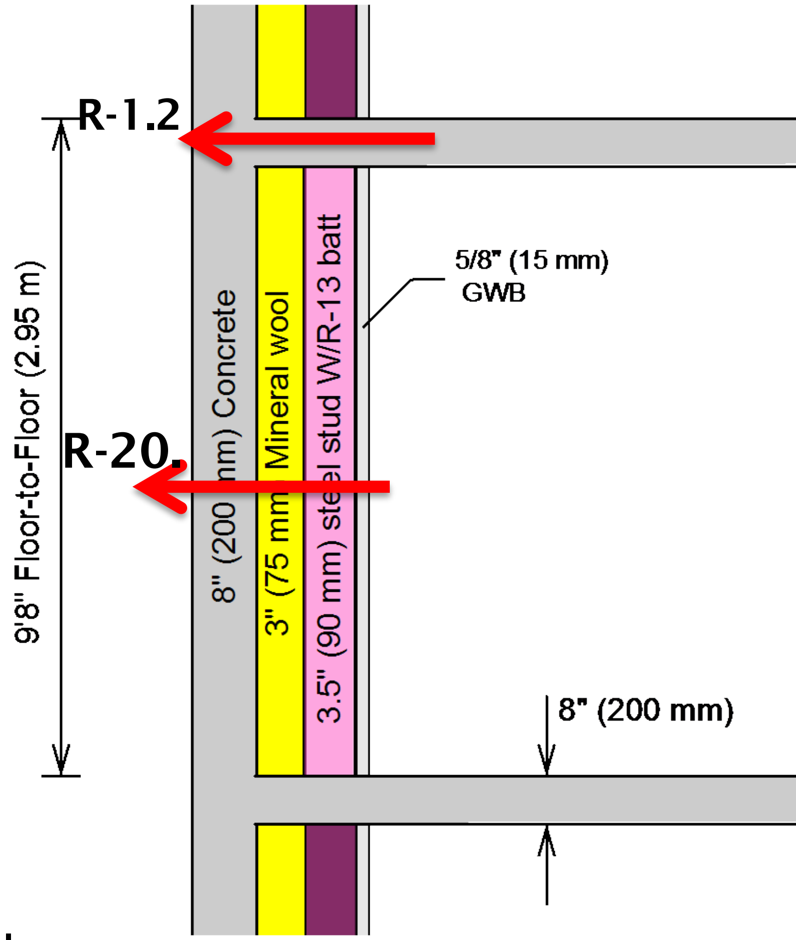
→



Layer	R-value
8” (200 mm) concrete	0.40
3” (76 mm) MW insulation	12.0
3.5” R-13 stud/films/GWB	7.4
Total	**19.8**

CIP Interior Insulation Example @ Floor Slab

- Wall is 9’8” (2.95 m) tall with a 8” (0.2 m) floor penetration
- From Guide, assume slab-edge acts as about R-1.2
- Clear-wall R-19.8
- Using parallel path method, the overall R-value is
  - R-9.6



$R_{ww} = 1/ \{ [(FF-T_{fl}) / FF] /R_{cw} + (T_{fl} / FF) / R_{fl} \}$

where

R_{ww} is the whole-wall R-value of the wall panel

FF is the floor-to-floor height

T_{fl} is the floor slab thickness

R_{fl} is R-value of the concrete floor-to-wall assembly

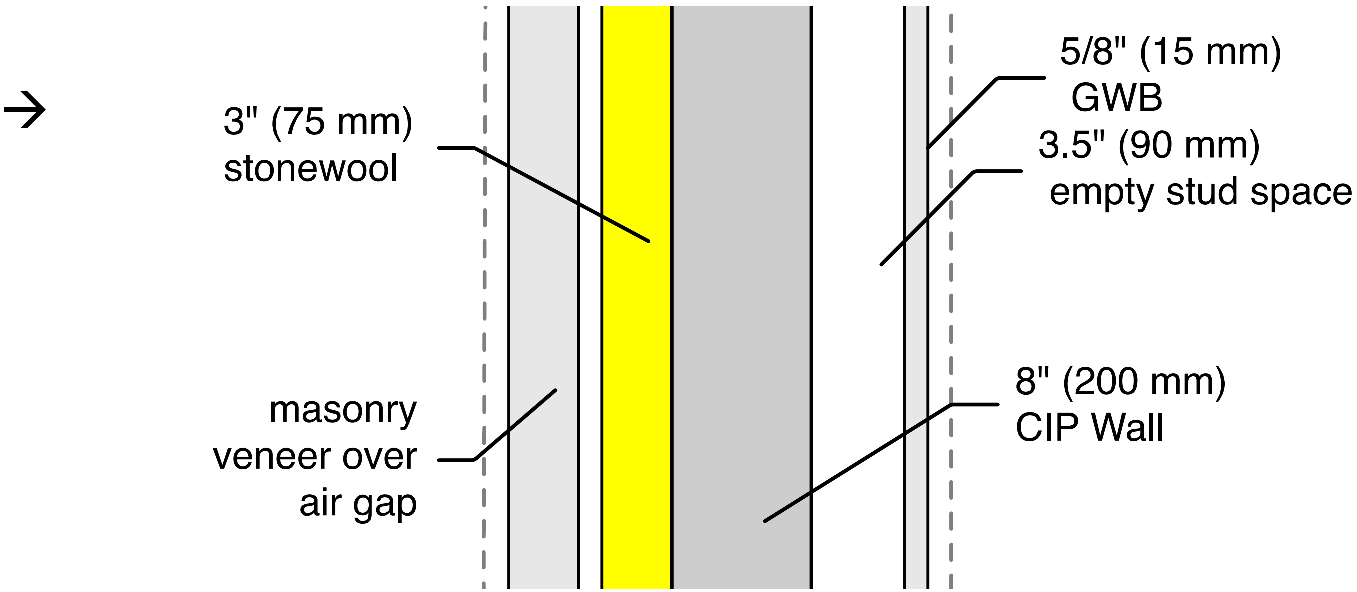
Impact of Floor Slabs (I-P)

	floor-to-floor (ft)				
R_{cw}	9	10	11	12	16
5	4.0	4.1	4.2	4.3	4.4
7.5	5.4	5.6	5.7	5.8	6.2
10	6.5	6.7	6.9	7.1	7.7
12.5	7.4	7.7	8.0	8.2	9.0
15	8.1	8.5	8.8	9.2	10.1
17.5	8.7	9.2	9.6	10.0	11.2
20	9.3	9.8	10.3	10.7	12.1
25	10.1	10.8	11.4	11.9	13.7
30	10.8	11.5	12.2	12.9	15.0
35	11.3	12.2	12.9	13.6	16.1
40	11.8	12.7	13.5	14.3	17.0

Impact of Floor Slabs (SI)

	floor-to-floor (m)				
RSI_{cw}	**2.74**	**3.05**	**3.35**	**3.66**	**4.88**
0.88	0.71	0.73	0.74	0.75	0.78
1.32	0.95	0.98	1.00	1.02	1.08
1.76	1.1	1.2	1.2	1.3	1.3
2.20	1.3	1.4	1.4	1.4	1.6
2.64	1.4	1.5	1.6	1.6	1.8
3.08	1.5	1.6	1.7	1.8	2.0
3.52	1.6	1.7	1.8	1.9	2.1
4.40	1.8	1.9	2.0	2.1	2.4
5.28	1.9	2.0	2.2	2.3	2.6
6.16	2.0	2.1	2.3	2.4	2.8
7.04	2.1	2.2	2.4	2.5	3.0

CIP Exterior Insulation Example



Layer	R-value
3.5” Clay Veneer	0.45
1” Air gap	1.0
3” (76 mm) MW insulation	12.0
8” (200 mm) concrete	0.40
3.5” empty stud/films/GWB	2.19
Total	**16.0**

Supporting tables from Guide

Material	Conductivity (R/inch)	R-value at 2"	R-value at 2.5"	R-value at 3"	R-value at 3.5"	R-value at 4"
Open-cell foam (ocSPF)	3.8	7.6	9.5	11.4	13.3	15.2
Spray Cellulose	3.8	7.6	9.5	11.4	13.3	15.2
Mineral Wool semi-rigid	4.0	8.0	10.0	12.0	14.0	16.0
Expanded polystyrene Type 2		same as semi-rigid mineral wool				
Extruded polystyrene	5.0	10.0	12.5	15.0	17.5	20.0
Polyisocyanurate	5.5	11.0	13.8	16.5	19.3	22.0
ccSPF	6.0	12.0	15.0	18.0	21.0	24.0
Reinforced Concrete	0.06	0.12	0.15	0.18	0.21	0.24
Clay Brick Veneer	0.13				0.45	

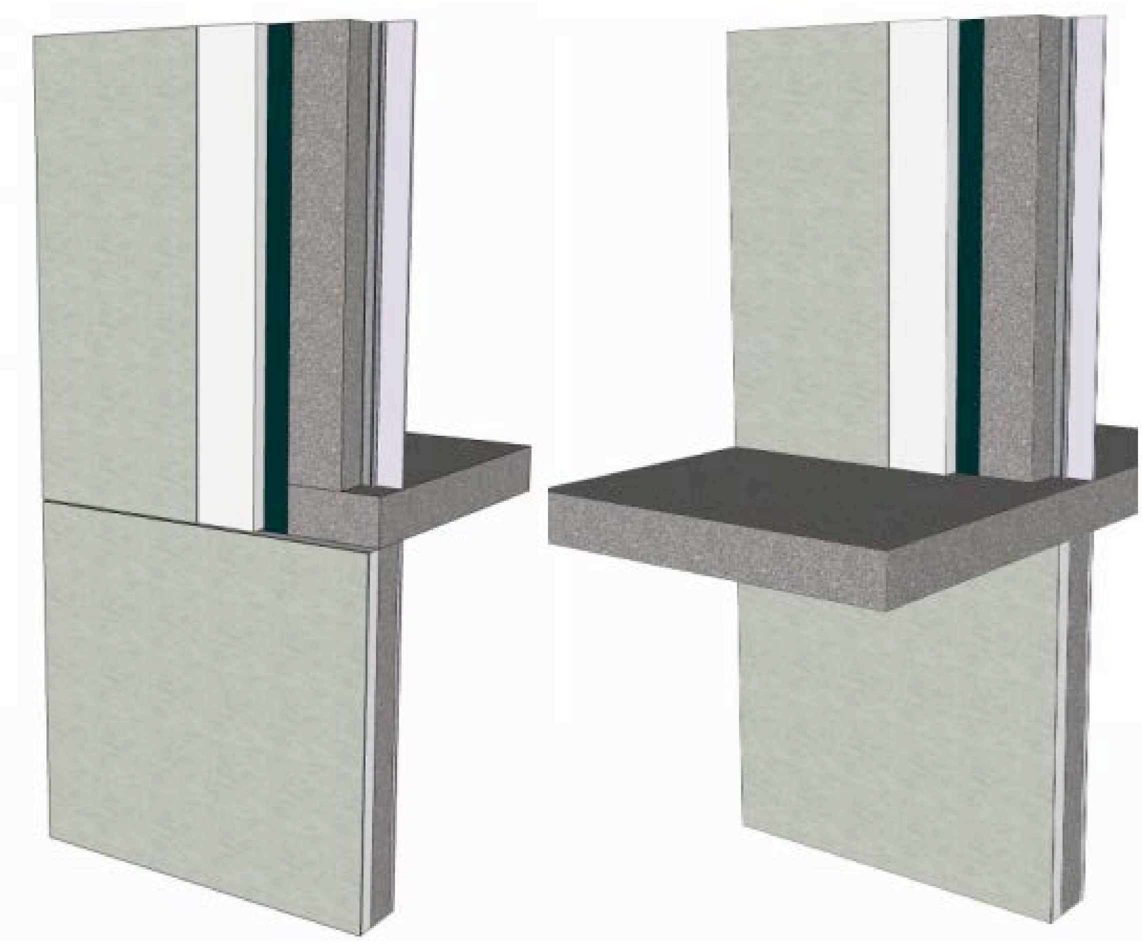
Cavity Depth In	Cavity Depth mm	Rated Cavity R-value	Layer R_{cw}-value @ 16 inch centres	Layer RSI_{cw} @ 405 mm centres
2.5	64	Empty	2.15	0.37
3.5	89	Empty	2.19	0.39
		R-13	7.4	1.31
		R-15	7.8	1.38
6.0	152	Empty	2.24	0.39
		R-19	8.5	1.50
		R-21	8.8	1.55
		R-24 (4" ccSPF)	9	1.59

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

Condition	RSI-value	R-value
Interior Surfaces	0.120	0.68
Exterior Surfaces	0.029	0.16
20 mm (3/4") Air space	0.18	1.0

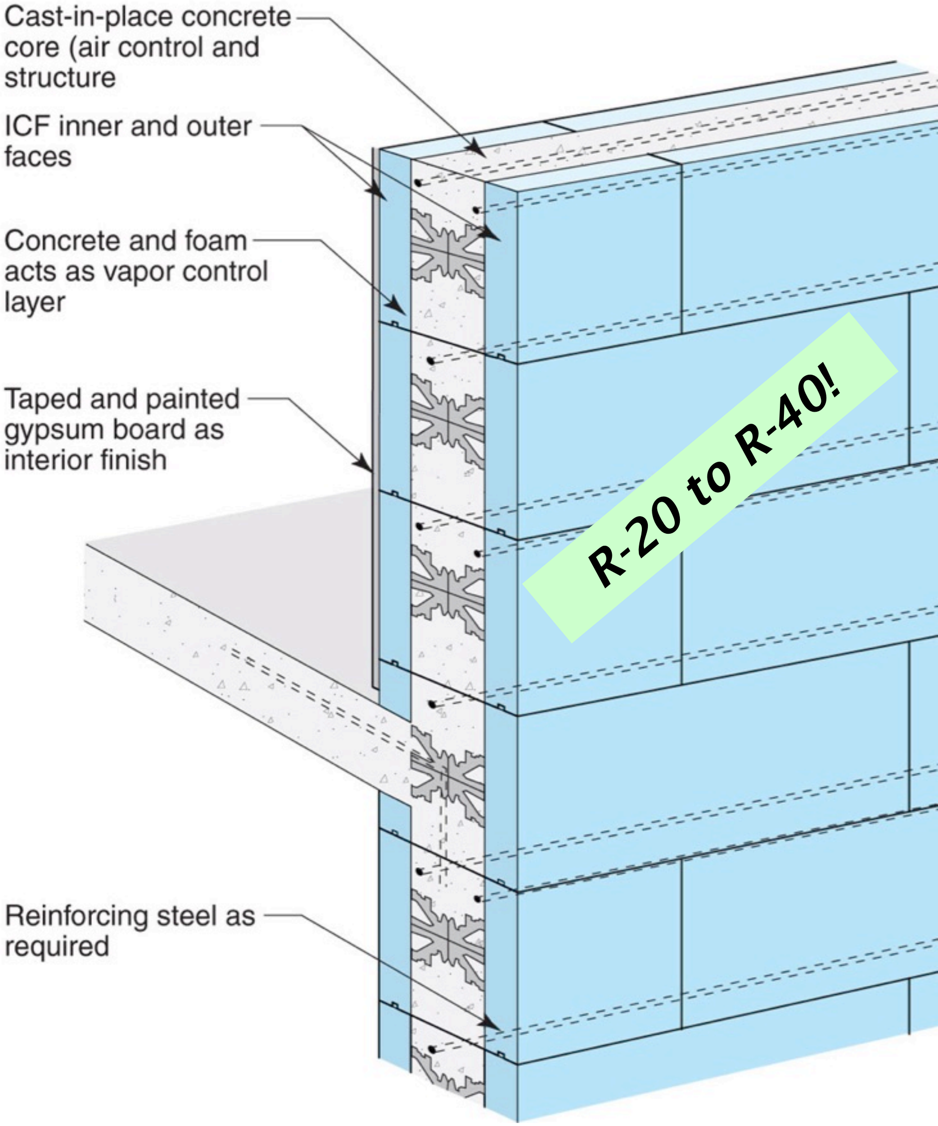
Exterior Insulated at Floor Slabs?

- → Exterior (continuous insulation) is not affected by floor slabs
- → Veneers (and air gap) do add some insulation value
- → Brick ties do reduce performance somewhat



Insulating Concrete Forms

Insulated Concrete Forms



ICF

→ High rise practical – manage window widths

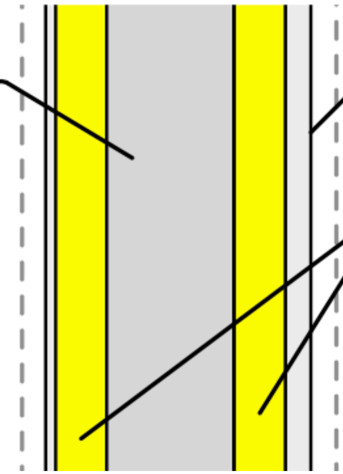
ICF & cladding

- → Many options
- → Drained is best but EIFS is practical
- → Beware: all openings must be drained!

Reference:Straube, J.F., *High Performance Enclosures: Design Guide for Institutional Commercial and Industrial Buildings in Cold Climates*. Building Science Press, Somerville, Massachusetts, 2012.

ICF Example

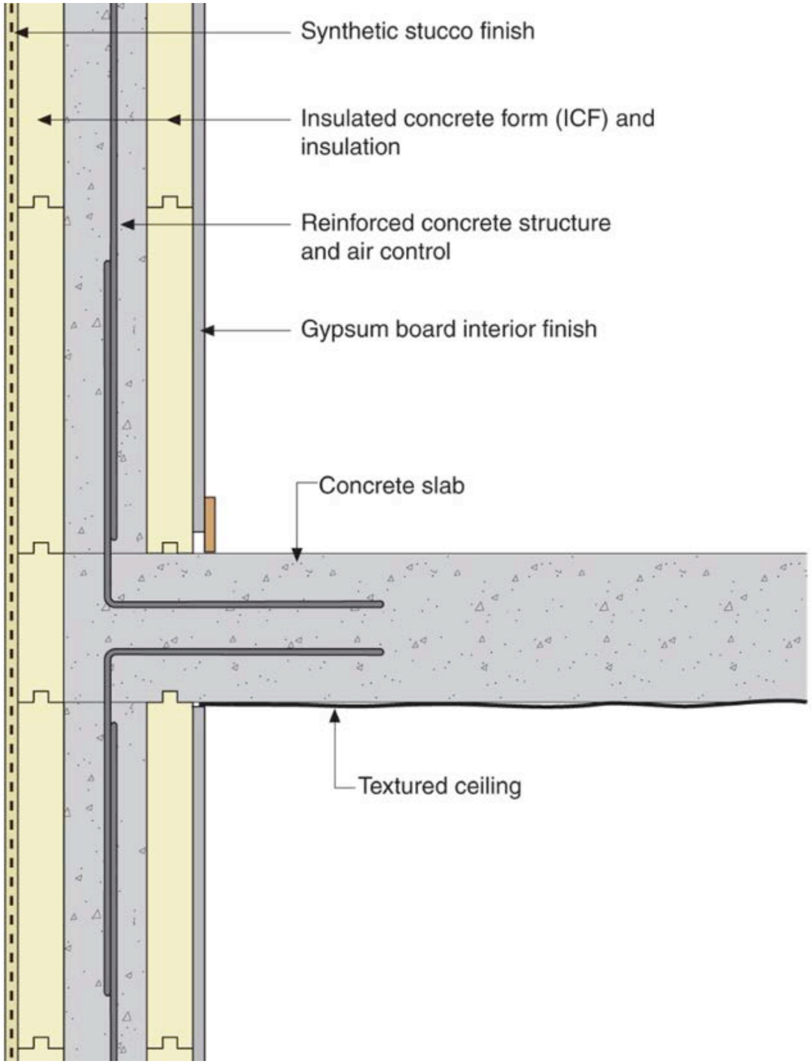
→ Many products now available with range of thicknesses



EPS Type 2	I-P		SI	
Thickness	R_{CW}	U_{CW}	R_{CW}	U_{CW}
100mm (4”)	17.3	0.0579	3.0	0.329
125mm (5”)	21.3	0.0470	3.7	0.267
150mm (6”)	25.3	0.0396	4.5	0.225
175mm (7”)	29.3	0.0342	5.2	0.194
200mm (8”)	33.3	0.0300	5.9	0.171
225mm (9”)	37.3	0.0268	6.6	0.152
250mm (10”)	41.3	0.0242	7.3	0.138

ICF at Floor Slab penetrations?

- → Floor slab penetrates only half of the insulation
- → Impact on whole-wall R-value is modest



Reference:Straube, J.F., *High Performance Enclosures: Design Guide for Institutional Commercial and Industrial Buildings in Cold Climates*. Building Science Press, Somerville, Massachusetts, 2012.

ICF Whole-wall R-value

→ Floors have modest impact

8" floor slabs

Rcw	slab edge insulation (in)	Floor-to-floor height (ft)					
		9	10	12	16	20	24
20	2.5	18.9	19.0	19.1	19.3	19.5	19.6
22	2.5	20.5	20.6	20.8	21.1	21.3	21.4
24	2.5	22.1	22.2	22.5	22.9	23.1	23.2
30	2.5	26.6	26.9	27.4	28.0	28.4	28.6
35	2.5	30.1	30.6	31.2	32.1	32.6	33.0
40	2.5	33.5	34.0	34.9	36.0	36.8	37.3
20	4.0	19.8	19.8	19.8	19.9	19.9	19.9
22	4.0	21.6	21.6	21.7	21.7	21.8	21.8
24	4.0	23.3	23.4	23.5	23.6	23.7	23.7
30	4.0	28.4	28.6	28.8	29.1	29.3	29.4
35	4.0	32.5	32.7	33.1	33.6	33.8	34.0
40	4.0	36.4	36.8	37.3	37.9	38.3	38.6

Integrally-Insulated Sandwich Panels

Integrally-Insulated Sandwich Panels

Masonry

Masonry

- → Non-combustible, impact resistant, flexible format
- → Load-bearing or infill CMU, masonry veneer

Masonry Unit Thermal Performance

R-values

CMU Size [inch] nominal	**4**	**6**	**8**	**10**	**12**
Normal Density (130 pcf) 50% solid					
Ungrouted	0.97	1.08	1.19	1.36	1.48
Fully-grouted	--	0.60	0.81	1.01	1.26
Filled with ccSPF	--	2.31	3.23	3.97	5.01
Low Density (105 pcf) 50% solid					
Ungrouted	1.36	1.70	1.82	1.87	2.33
Fully-grouted	--	0.78	1.05	1.28	1.5
Filled with ccSPF	--	3.95	5.53	6.84	8.62

RSI-values

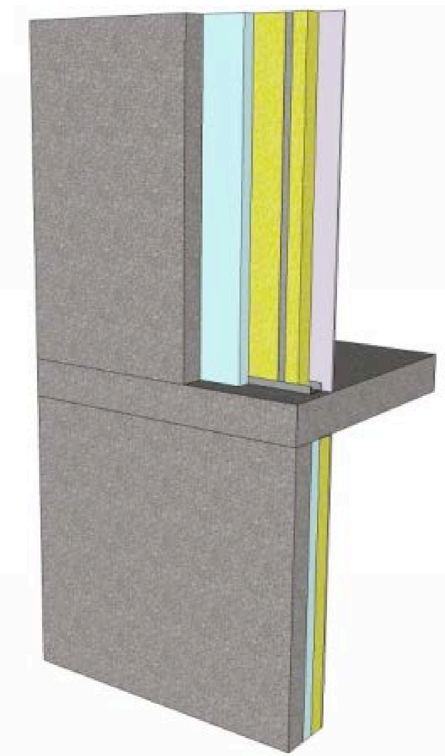
CMU Size [mm] nominal	**100**	**150**	**200**	**250**	**300**
Normal Density (2100 kg/m3)					
Ungrouted	0.17	0.19	0.21	0.24	0.26
Fully-grouted	--	0.11	0.14	0.18	0.22
Filled with ccSPF	--	0.41	0.57	0.70	0.88
Low Density (1700 kg/m3)					
Ungrouted	0.24	0.30	0.32	0.33	0.41
Fully-grouted	--	0.14	0.18	0.23	0.26
Filled with ccSPF	--	0.70	0.97	1.20	1.52

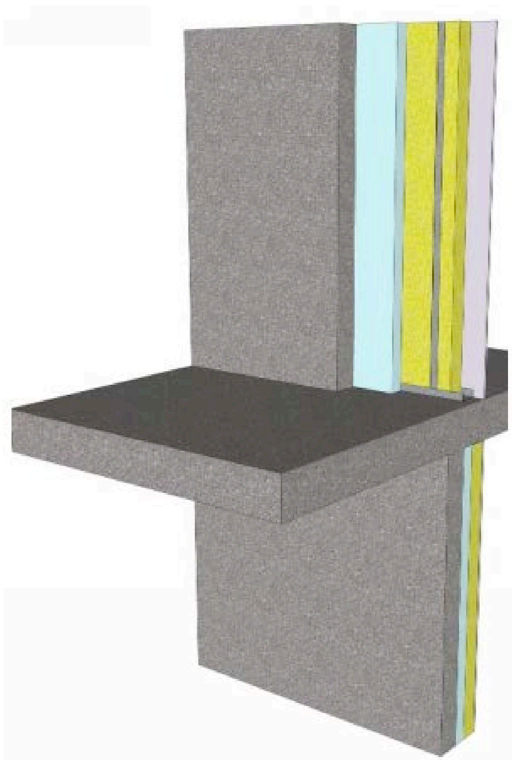
Load-Bearing Masonry

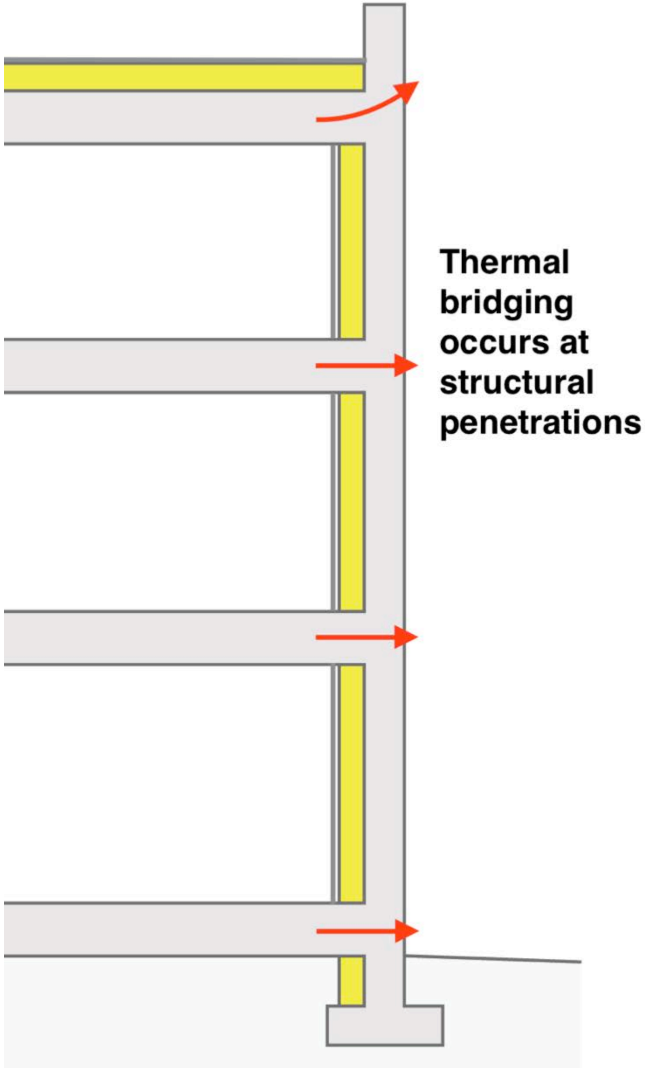
Internally-Insulated Masonry

→ Less effective… account for slabs in thermal bridging

→ Slab edge: approximately R-1.2

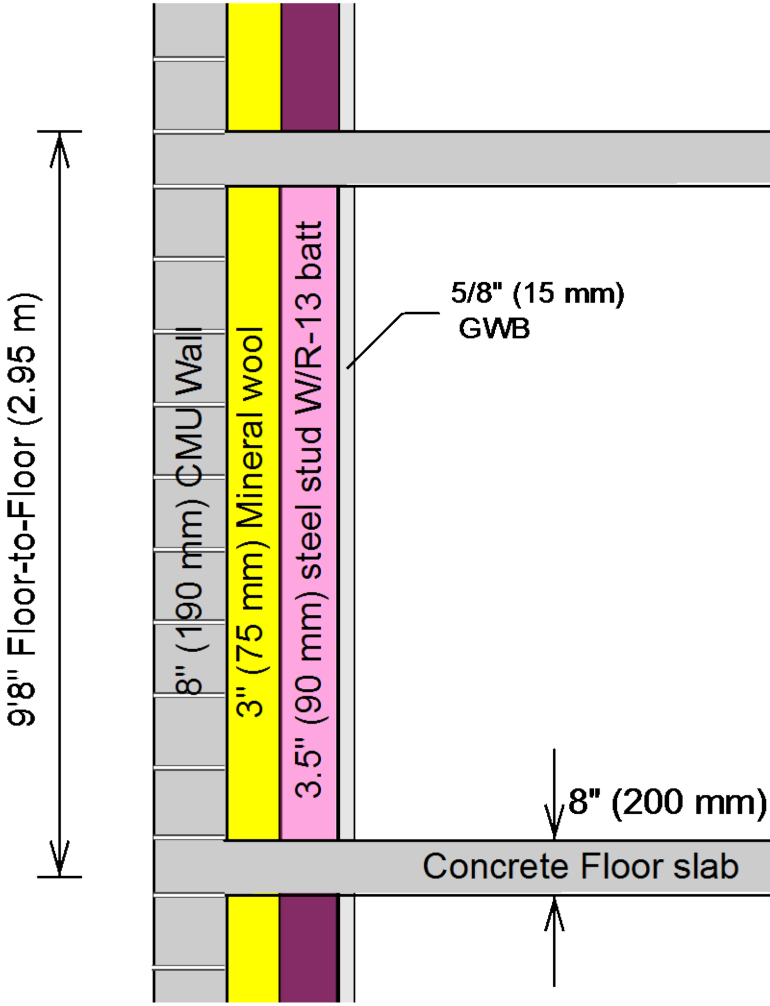




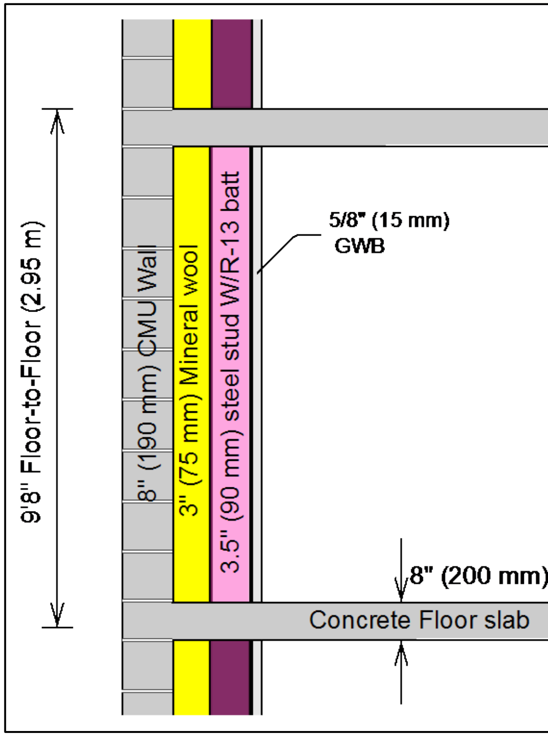


Internally-Insulated: Example

- Calculate the clear-wall R-value and the whole-wall R-value.
  - floor-to-floor height of 9’8” (2.95 m or 9.66 feet)
  - 8” (200 mm or 0.66 foot) thick concrete slab.
  - an 8” (190 mm) CMU wall,
  - 3” (75 mm) of mineral wool,
  - 3.5” (90 mm) steel stud with R-13 batt,
  - 5/8” (15 mm) gypsum



Internally-Insulated Masonry Example



- → Using Tables,
  - → interior layers (batt, GWB, etc.) have an R-value of R-7.4
  - → 3" (76 mm) of mineral wool provide 3 x R-4/inch (from Table 7) = R-12
  - → 8" (190 mm) CMU provides R-1.19
  - → a total clear-wall R-value of 7.4 + 12+ 1.2 = R_{cw}-20.6 (RSI-3.60).
- → Floor slab impact on whole-wall R-value (R_{ww}) estimated using the recommended R-1.2 (RSI 0.21) for the slab, as:
- → $R_{ww} = 1/ \{ [(FF-T_{fl}) / FF] /R_{cw} + (T_{fl} / FF) / R_{fl} \}$
- → $R_{ww} = 1/ \{ [(9.66-0.66) / 9.66] /20.6 + (0.66/ 9.66) / 1.2\}$ = R-9.7
- → Whole wall R drops from R-20.6 to R-9.7

Supporting tables

Material	Conductivity (R/inch)	R-value at 2"	R-value at 2.5"	R-value at 3"	R-value at 3.5"	R-value at 4"
Open-cell foam (ocSPF)	3.8	7.6	9.5	11.4	13.3	15.2
Spray Cellulose	3.8	7.6	9.5	11.4	13.3	15.2
Mineral Wool semi-rigid	4.0	8.0	10.0	12.0	14.0	16.0
Expanded polystyrene Type 2		same as semi-rigid mineral wool				
Extruded polystyrene	5.0	10.0	12.5	15.0	17.5	20.0
Polyisocyanurate	5.5	11.0	13.8	16.5	19.3	22.0
ccSPF	6.0	12.0	15.0	18.0	21.0	24.0

R-values

CMU Size [inch] nominal	4	6	8	10	12
Normal Density (130 pcf)					
Ungrouted	0.97	1.08	1.19	1.36	1.48
Fully-grouted	--	0.60	0.81	1.01	1.26
Filled with ccSPF	--	2.31	3.23	3.97	5.01
Low Density (105 pcf)					
Ungrouted	1.36	1.70	1.82	1.87	2.33
Fully-grouted	--	0.78	1.05	1.28	1.5
Filled with ccSPF	--	3.95	5.53	6.84	8.62

Cavity Depth In	Cavity Depth mm	Rated Cavity R-value	Layer R_{cw}-value @ 16 inch centres
2.5	64	Empty	2.15
3.5	89	Empty	2.19
		R-13	7.4
		R-15	7.8
6.0	152	Empty	2.24
		R-19	8.5
		R-21	8.8
		R-24 (4" ccSPF)	9

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

Interior Insulated Masonry: Tables (I-P)

	floor-to-floor (ft)				
R_{cw}	**9**	**10**	**11**	**12**	**16**
5	4.0	4.1	4.2	4.3	4.4
7.5	5.4	5.6	5.7	5.8	6.2
10	6.5	6.7	6.9	7.1	7.7
12.5	7.4	7.7	8.0	8.2	9.0
15	8.1	8.5	8.8	9.2	10.1
17.5	8.7	9.2	9.6	10.0	11.2
20	9.3	9.8	10.3	10.7	12.1
25	10.1	10.8	11.4	11.9	13.7
30	10.8	11.5	12.2	12.9	15.0
35	11.3	12.2	12.9	13.6	16.1
40	11.8	12.7	13.5	14.3	17.0

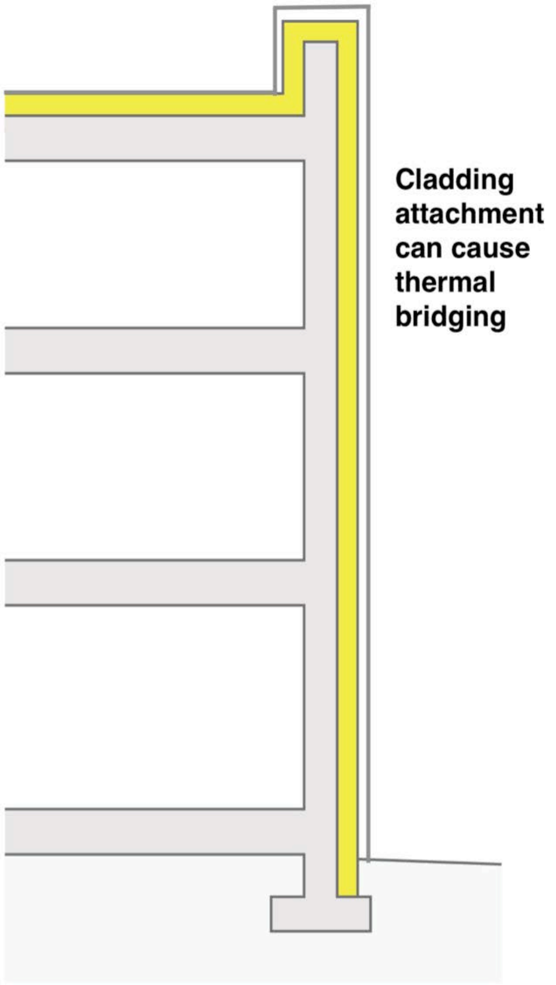
Interpolate for 9'8"

Interior Insulated Masonry: Tables (SI)

	floor-to-floor (m)				
RSI$_{cw}$	**2.74**	**3.05**	**3.35**	**3.66**	**4.88**
0.88	0.71	0.73	0.74	0.75	0.78
1.32	0.95	0.98	1.00	1.02	1.08
1.76	1.1	1.2	1.2	1.3	1.3
2.20	1.3	1.4	1.4	1.4	1.6
2.64	1.4	1.5	1.6	1.6	1.8
3.08	1.5	1.6	1.7	1.8	2.0
3.52	1.6	1.7	1.8	1.9	2.1
4.40	1.8	1.9	2.0	2.1	2.4
5.28	1.9	2.0	2.2	2.3	2.6
6.16	2.0	2.1	2.3	2.4	2.8
7.04	2.1	2.2	2.4	2.5	3.0

Externally-Insulated Masonry

- → Easy to calculate.. can ignore ties and shelf angles by code, but may need to account for other reasons
- → In general, adding insulation "plus a couple R" will be good enough estimate



Steel-Stud
Masonry Veneer

Lots of high performance options

R-value, e.g.

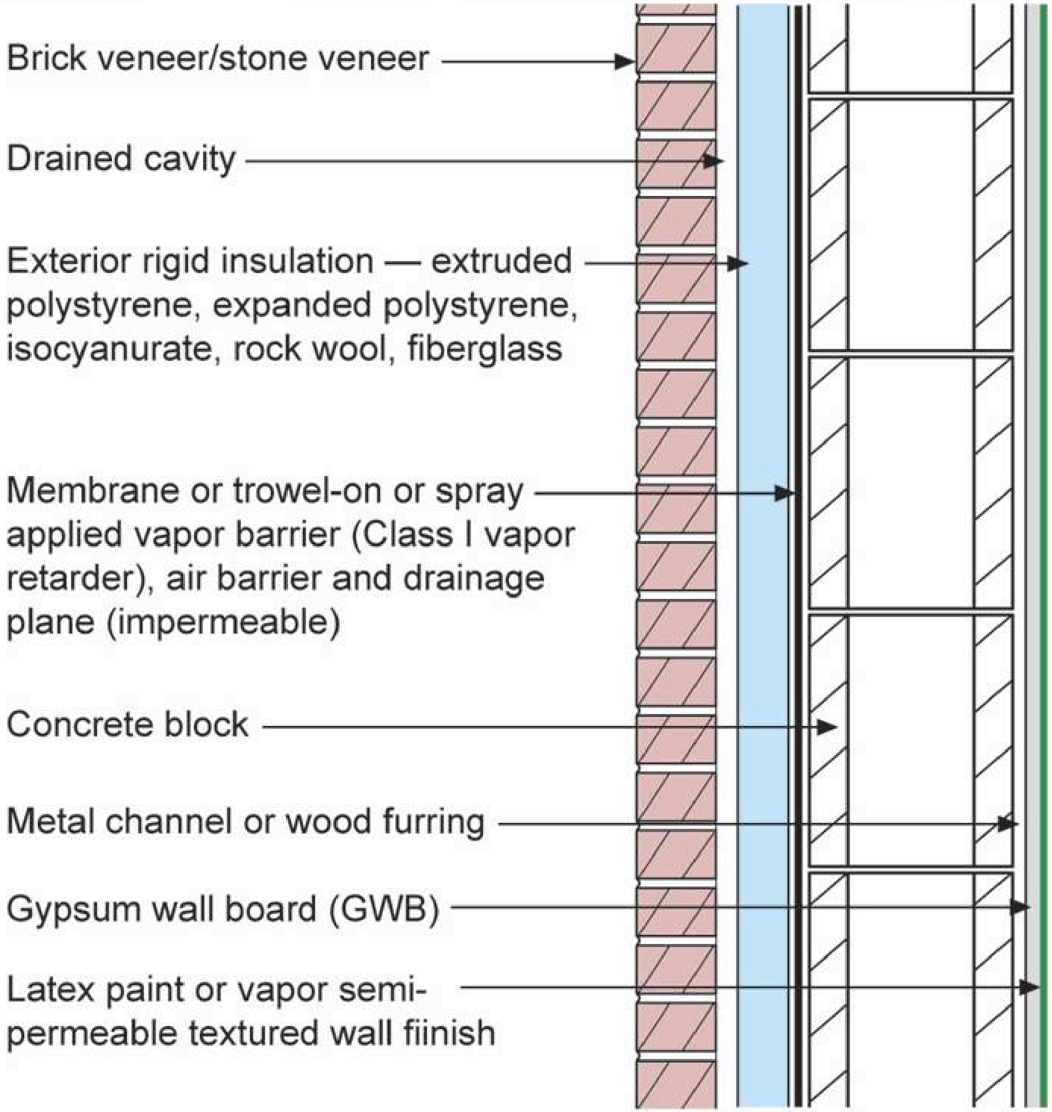
2.5” PIC = R16

3” XPS = R18

3” MFI = R15

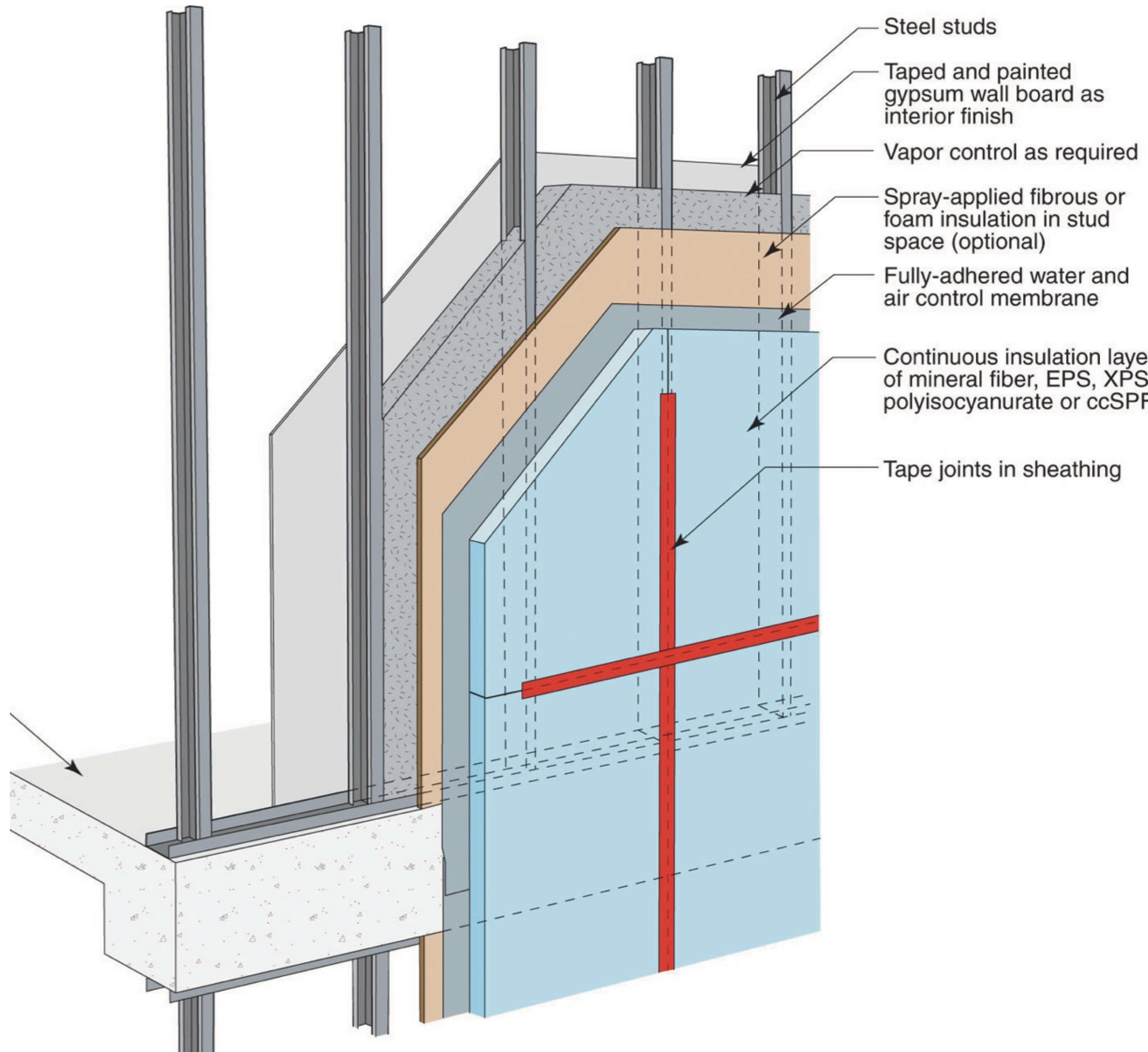
2” MFI = R11

4” ccSPF = R26



Steel-stud / masonry veneer

→ Calculated using same approach



Reference:Straube, J.F., *High Performance Enclosures: Design Guide for Institutional Commercial and Industrial Buildings in Cold Climates*. Building Science Press, Somerville, Massachusetts, 2012.

R-value, e.g.

3” PIC = R20

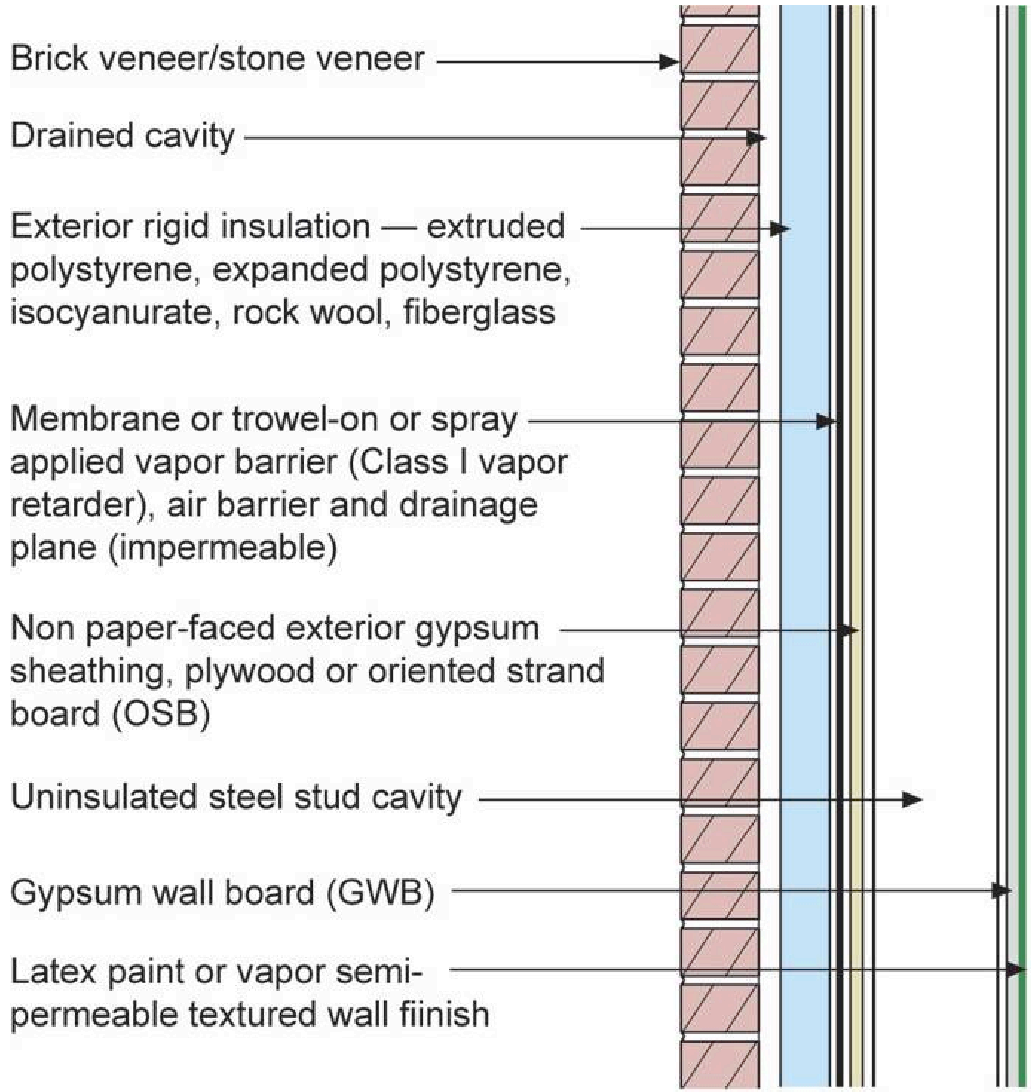
4” XPS = R23

4” MFI = R20

3” MFI = R15

3” EPS = R15

4” ccSPF = R27



Steel-stud / masonry veneer

→

8" (200 mm) slabs		floor-to-floor (ft)				
R_{batt}	R_{ci}	9	10	12	16	24
0	7.5	11.5	11.5	11.5	11.5	11.6
0	10	14.0	14.0	14.0	14.0	14.1
0	15	19.0	19.0	19.0	19.0	19.1
0	20	23.3	23.3	23.3	23.3	23.3
0	25	28.3	28.3	28.3	28.3	28.3
13	5	13.4	13.5	13.6	13.8	14.0
13	7.5	16.0	16.1	16.2	16.4	16.5
13	10	18.6	18.7	18.8	18.9	19.0
13	15	23.6	23.7	23.8	23.9	24.1
15	10	18.9	19.0	19.1	19.3	19.4
15	15	24.0	24.1	24.2	24.3	24.4
15	20	29.0	29.1	29.2	29.3	29.5
19	7.5	16.9	17.0	17.2	17.4	17.5
19	10	19.5	19.6	19.7	19.9	20.1
19	15	24.6	24.7	24.8	25.0	25.1
19	20	29.7	29.7	29.8	30.0	30.1
24	10	19.9	20.0	20.2	20.4	20.5
24	15	25.0	25.1	25.3	25.4	25.6

Note: Rbatt and Rci are the nominal ratings for the insulation installed between metal framing and outside respectively.

Thermal Bridging Solutions

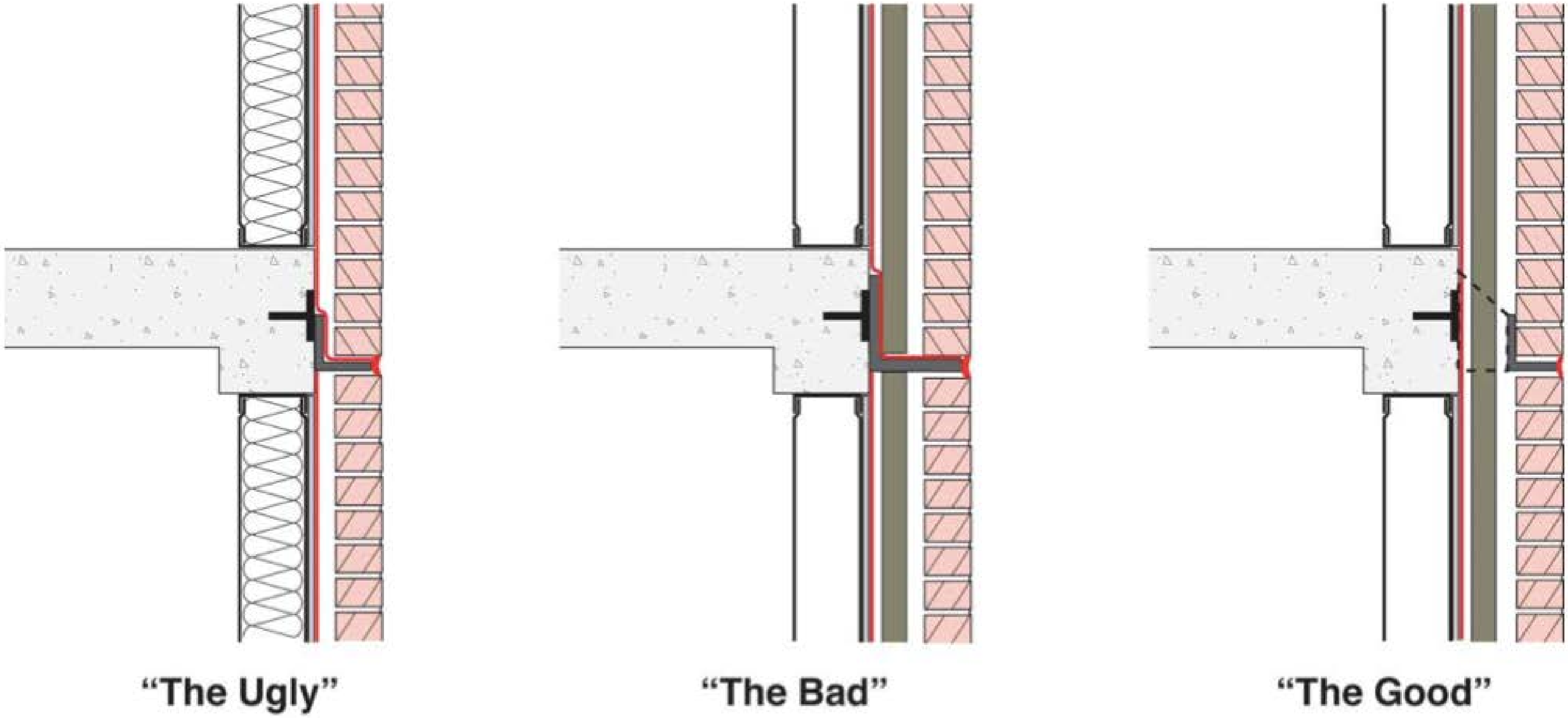
Supporting Masonry Veneer,

Balcony Penetrations,
Cladding Attachment,
etc.

Shelf Angles

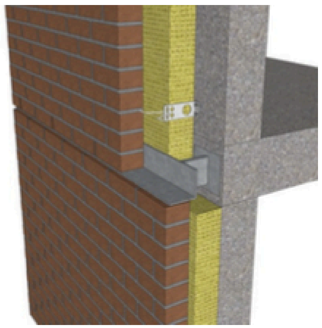
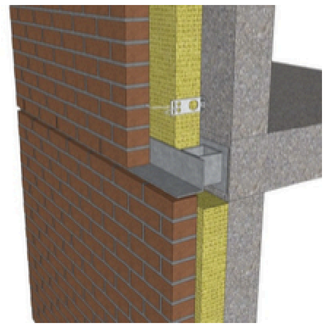
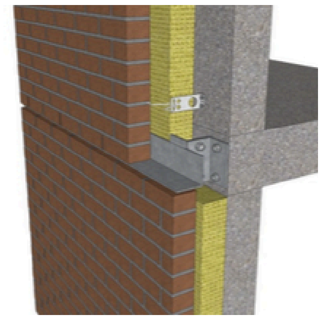
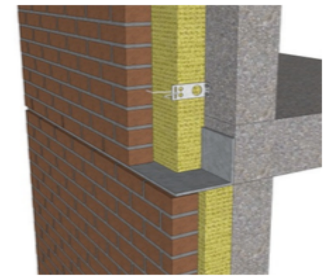
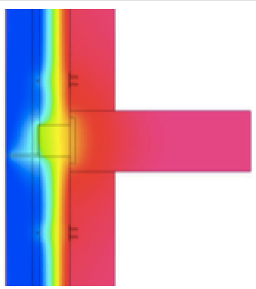
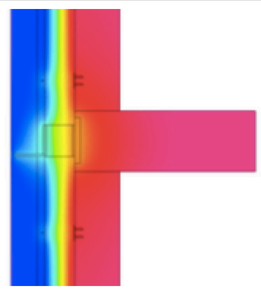
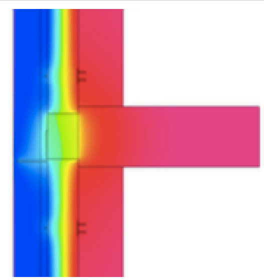
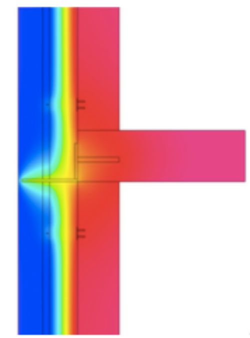
→ Often one per floor

Heavy Cladding Attachment through Exterior Insulation



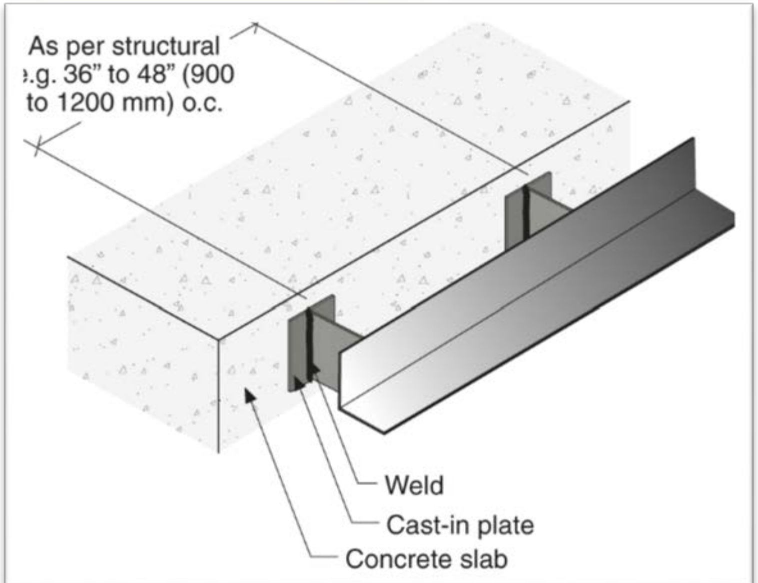
Stupidly large shelf angle
Structural engineers need to be part of the conversation

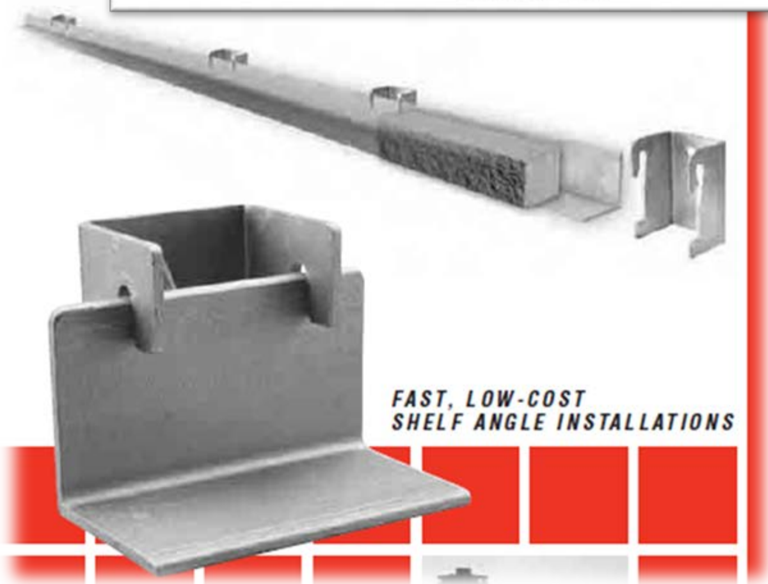
Shelf Angles: Use Stand-offs or better

	Knife Plate	HSS Structural Section	Overlapping Angles	Poured Concrete Backup
				
				
	shelf angle: 4"x4"x1/4" outside of insulation. 4"x4"x3/4" stand-off knife plates welded to embed plates at 48" o.c.	shelf angle 4"x4"x1/4" outside insulation. 4"x4"x1/4" HSS tube welded to embed plates at 48" o.c.	shelf angle 4"x4"x1/4" outside insulation. 2-6"x4"x5/16" angles bolted to slab edge at 48" o.c.	
Nominal Insulation R-Value/U-Value	R-16.8 (RSI 2.95) U-0.060 (USI 0.339)	R-16.8 (RSI 2.95) U-0.060 (USI 0.339)	R-16.8 (RSI 2.95) U-0.060 (USI 0.339)	R-16.8 (RSI 2.95) U-0.060 (USI 0.339)
Effective Assembly R-Value/U-Value	R-14.8 (RSI 2.6) U-0.068 (USI 0.384)	R-14.8 (RSI 2.6) U-0.068 (USI 0.385)	R-15.0 (RSI 2.64) U-0.067 (USI 0.379)	R-10.5 (RSI 1.84) U-0.096 (USI 0.543)
Effective Reduction	16.4%	16.5%	15.3%	37.5%
Linear Transmission	ψ = 0.096 IP (0.166 SI)	ψ = 0.097 IP (0.168 SI)	ψ = 0.089 IP (0.153 SI)	ψ = 0.339 IP (0.586 SI)

Wilson, M., Finch, G., Higgins, J., "Masonry Veneer Support Details: Thermal Bridging", *Proc. of 12th Canadian Masonry Symposium*, Vancouver, British Columbia, June 2-5, 2013.

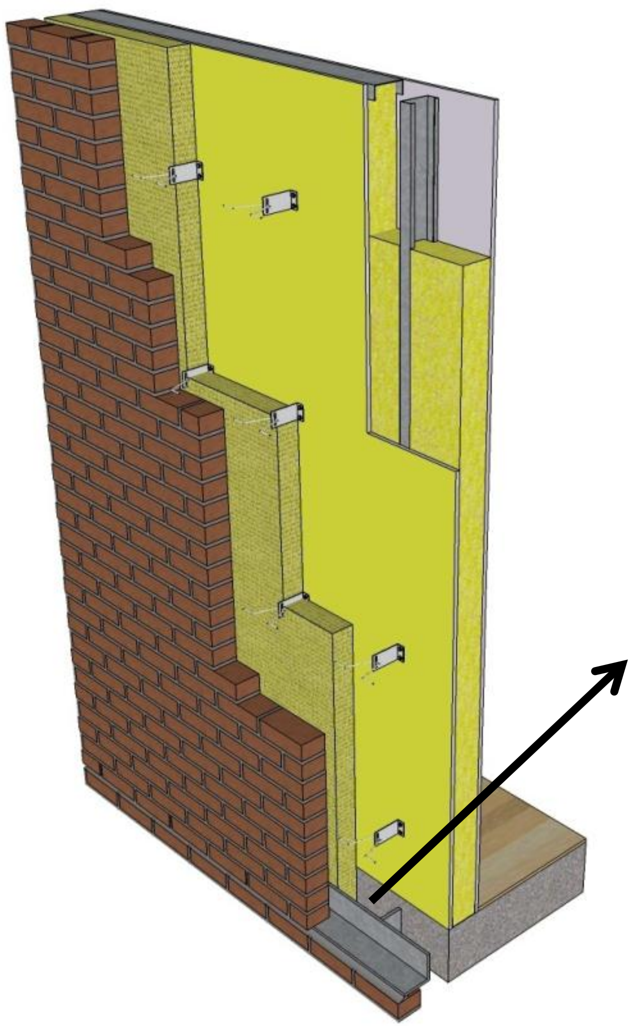
Stand-off Shelf Angle





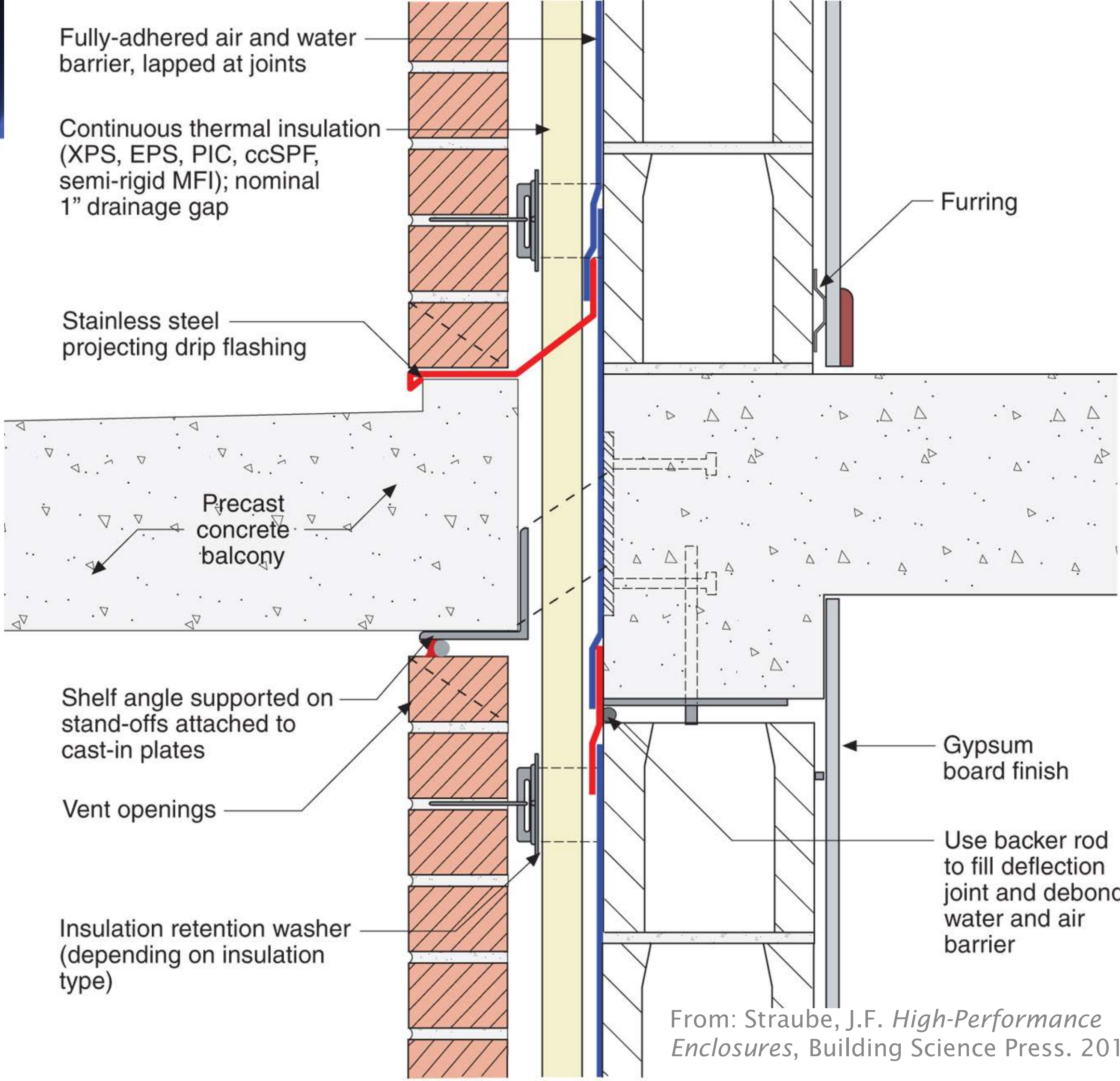
(courtesy of Fero Corp)

Masonry – With Stand-off Shelf Angles



<u>Without</u> Stand-off Plates: **Overall Effective – Including Slab Edges** ***Backup: 3 5/8" Steel Studs , Empty***	
+2" Mineral Wool Exterior (R-8.4)	R-8.6
+3" Mineral Wool Exterior (R-12.6)	R-10.1
+4" Mineral Wool Exterior (R-16.8)	R-11.5

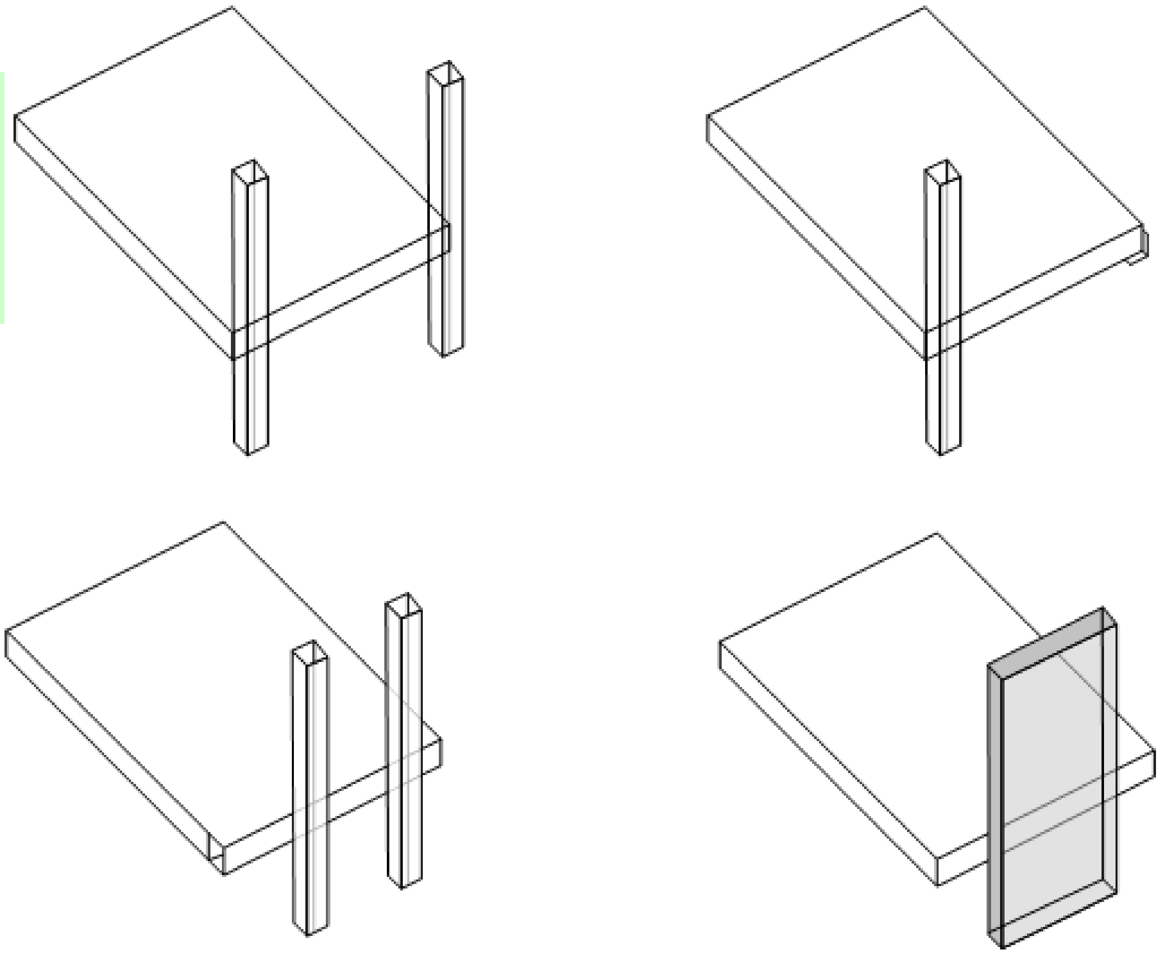
<u>WITH</u> Stand-off Plates: **Overall Effective – Including Slab Edges** ***Backup: 3 5/8" Steel Studs , Empty***	
+2" Mineral Wool Exterior (R-8.4)	R-11.3
+3" Mineral Wool Exterior (R-12.6)	R-14.5
+4" Mineral Wool Exterior (R-16.8)	R-17.7



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

Balcony Design Solutions

Limit attachment to the building

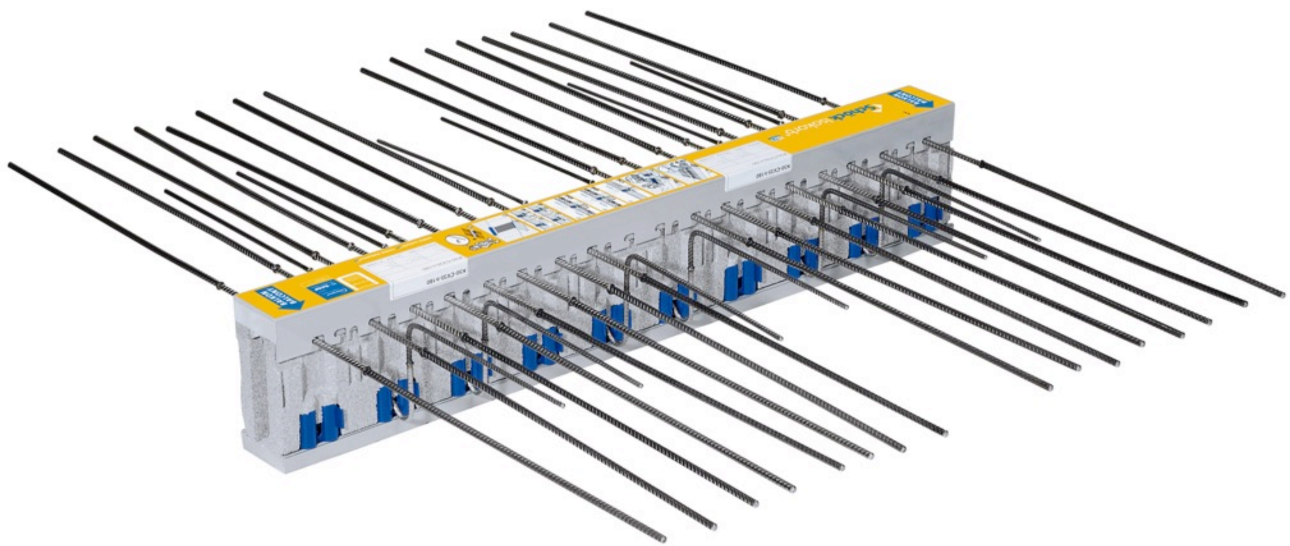



Philly's Best
HOT OVEN


Thermal Bridging Solutions

→ Products are being brought to market

→ Thermally-broken balconies



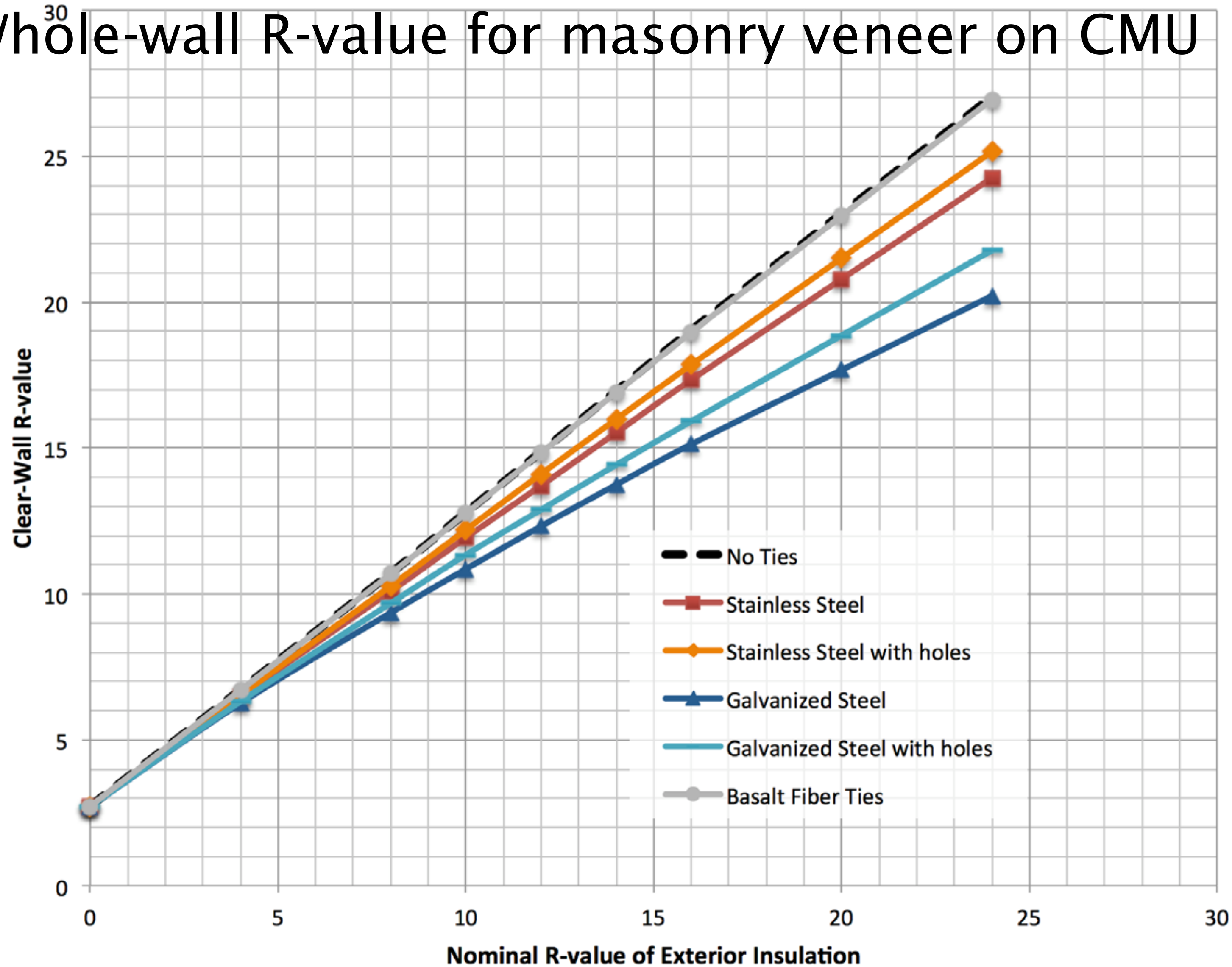
Courtesy: Schoeck



Installation is simple

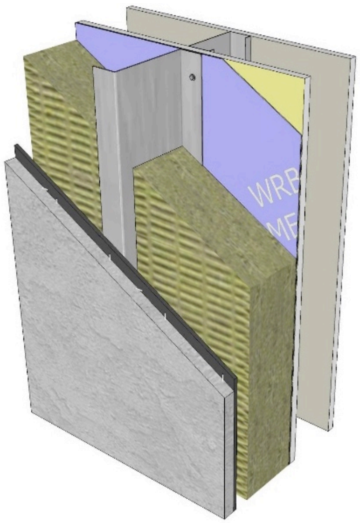
Brick Ties / Cladding Attachment

→ Whole-wall R-value for masonry veneer on CMU

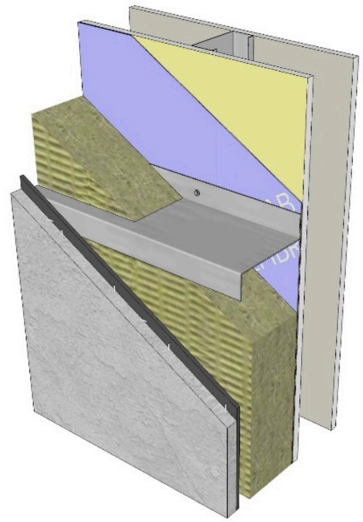


Finch, G, Wilson, M., Higgins, J., "Thermal Bridging of Masonry Veneer Claddings & Energy Code Compliance", *Proc. of 12th Canadian Masonry Symposium*, Vancouver, British Columbia, June 2-5, 2013.

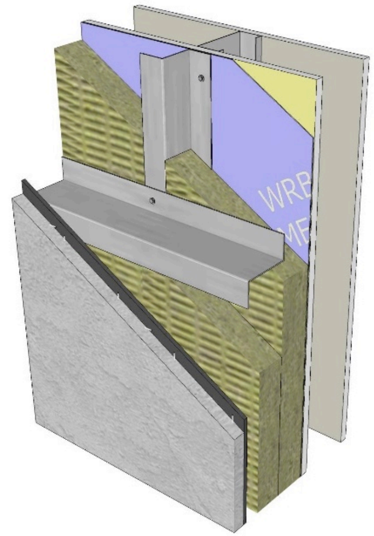
Cladding Attachment Options



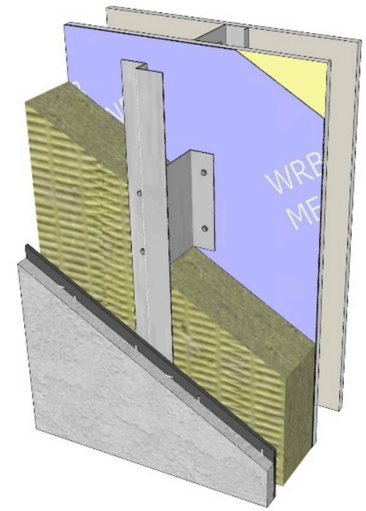
Vertical Z-girts



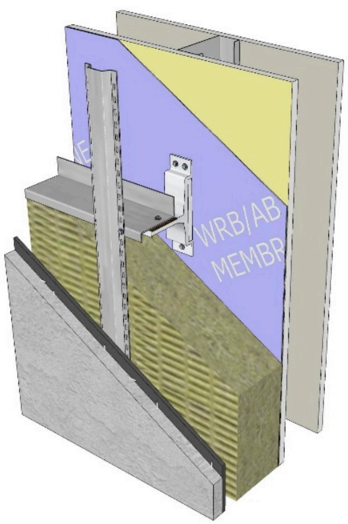
Horizontal Z-girts



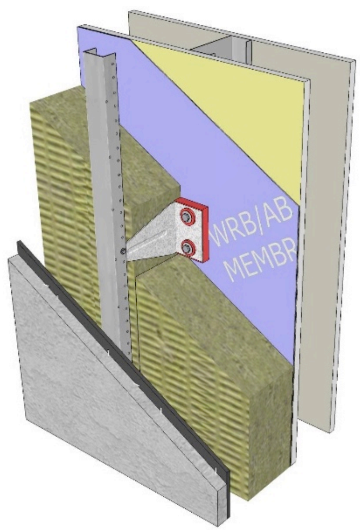
Crossing Z-girts



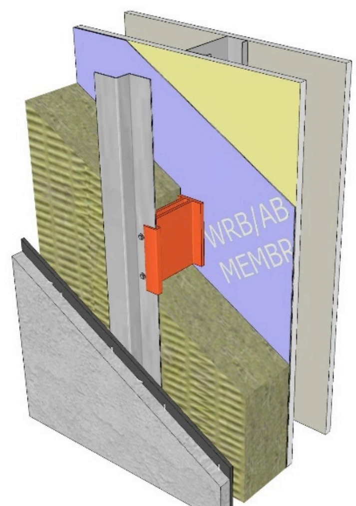
Galvanized/Stainless Clip & Rail



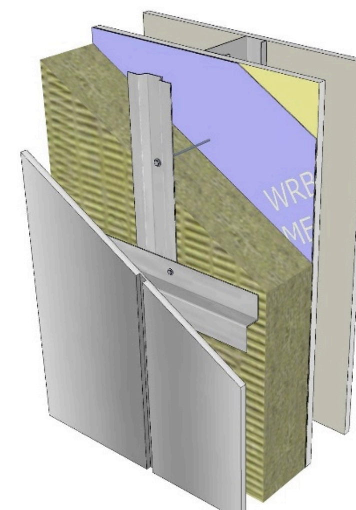
Aluminum Clip & Rail



Thermally Improved Clip & Rail

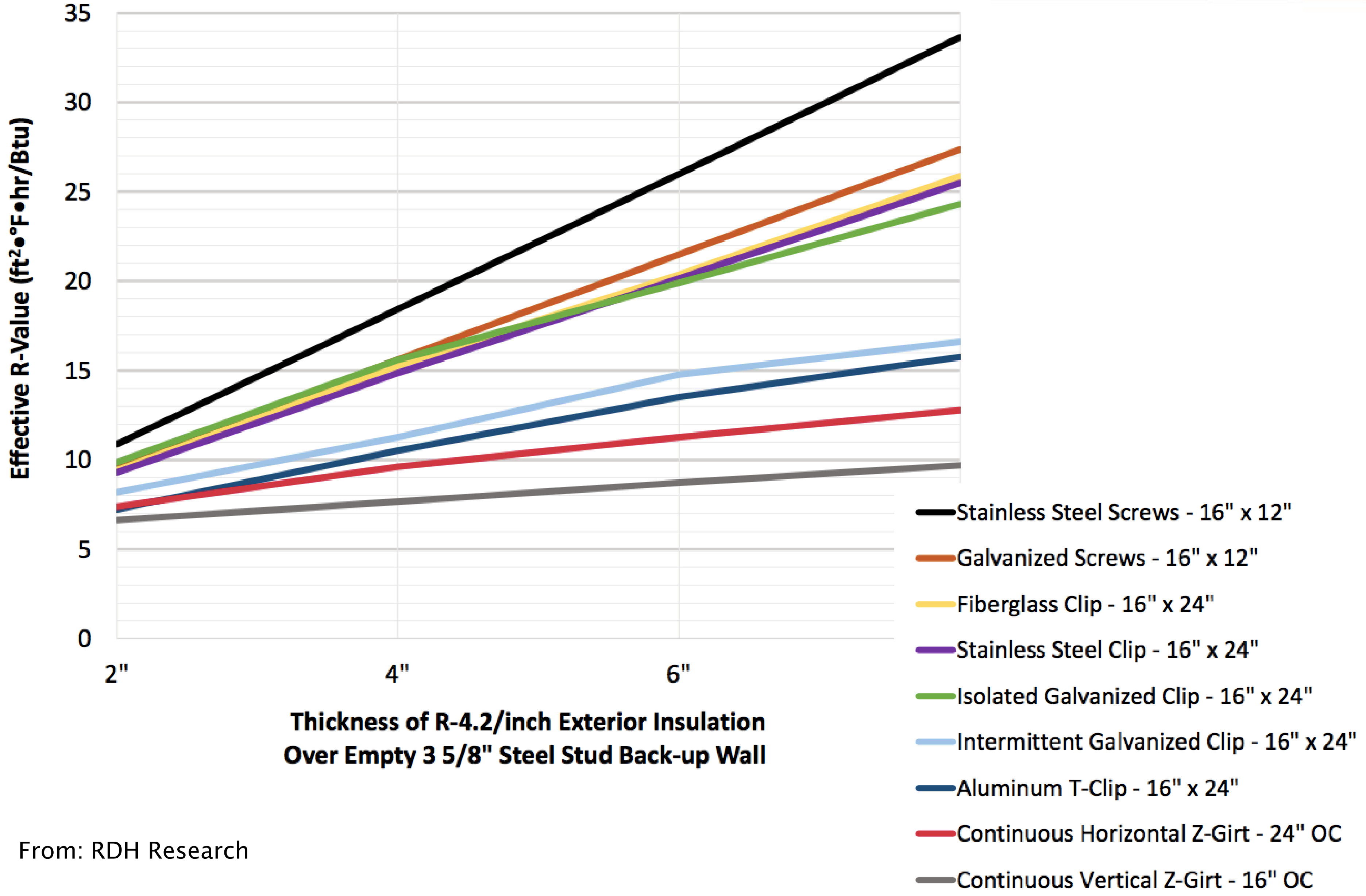


Non-Conductive Clip & Rail



Long Screws through Insulation

Cladding Attachment Thermal Bridging



From: RDH Research

Conclusions

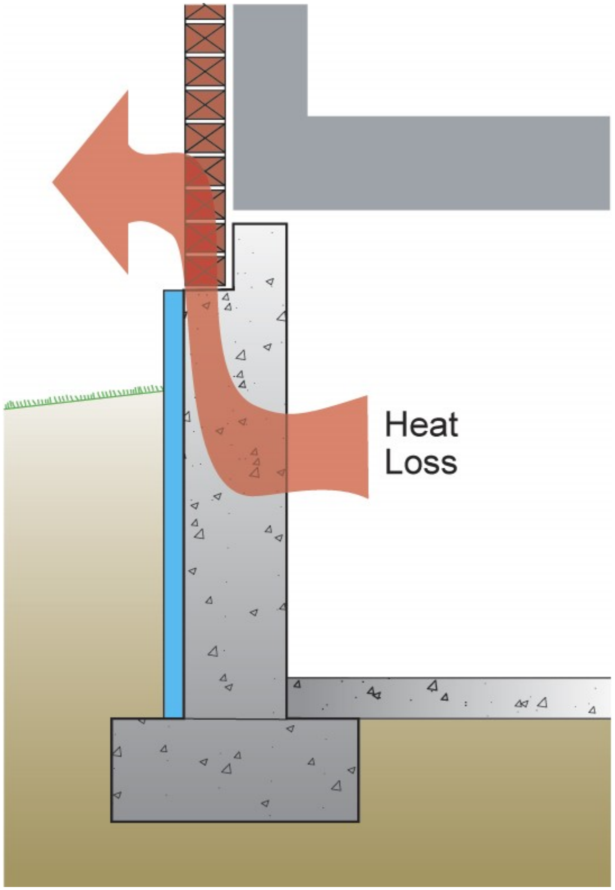
- → Simple calculations suffice for most design
- → Include thermal bridging of framing
  - → Use tabular data
- → Exterior, continuous insulation usually best option
  - → Consider thinner studs, thick continuous insul.
- → Simple trade-off analysis can make a big difference, fewer and/or better windows have a big impact

Roofs and Basements

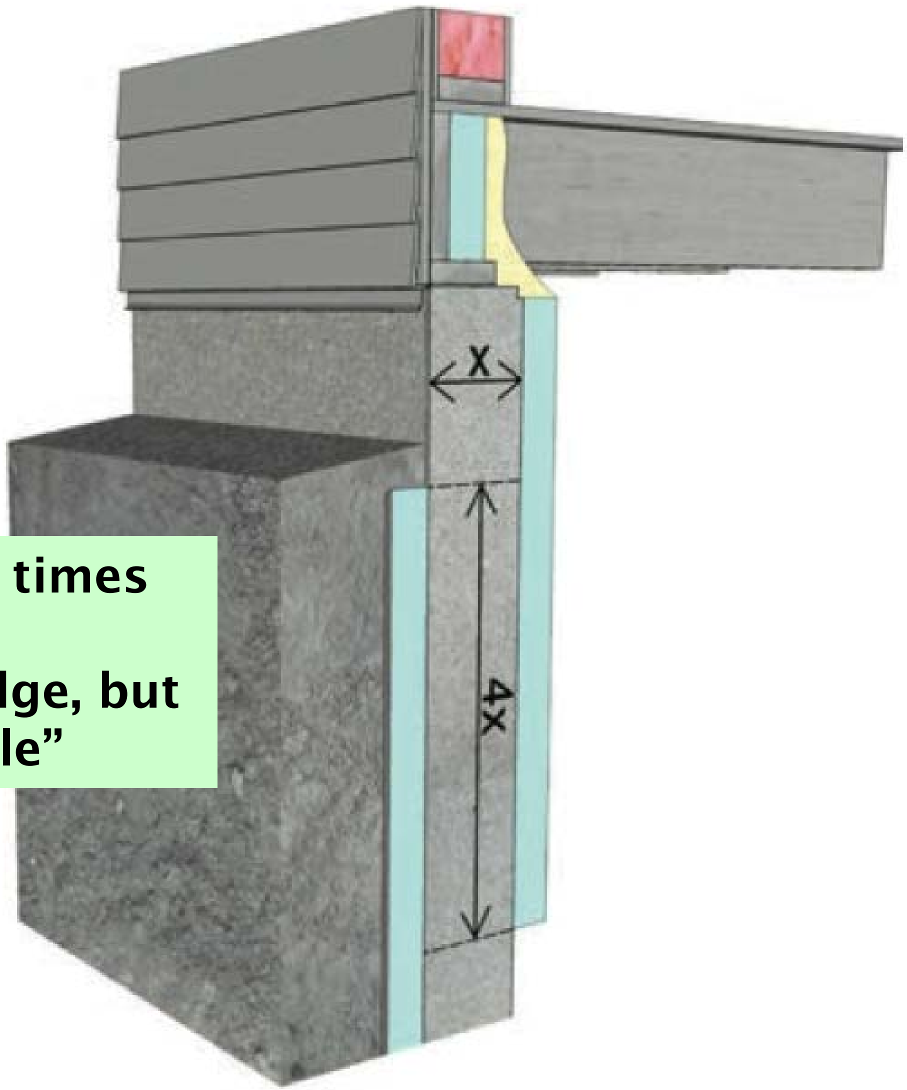
Grade-transition

→ Code exempts specific scenarios

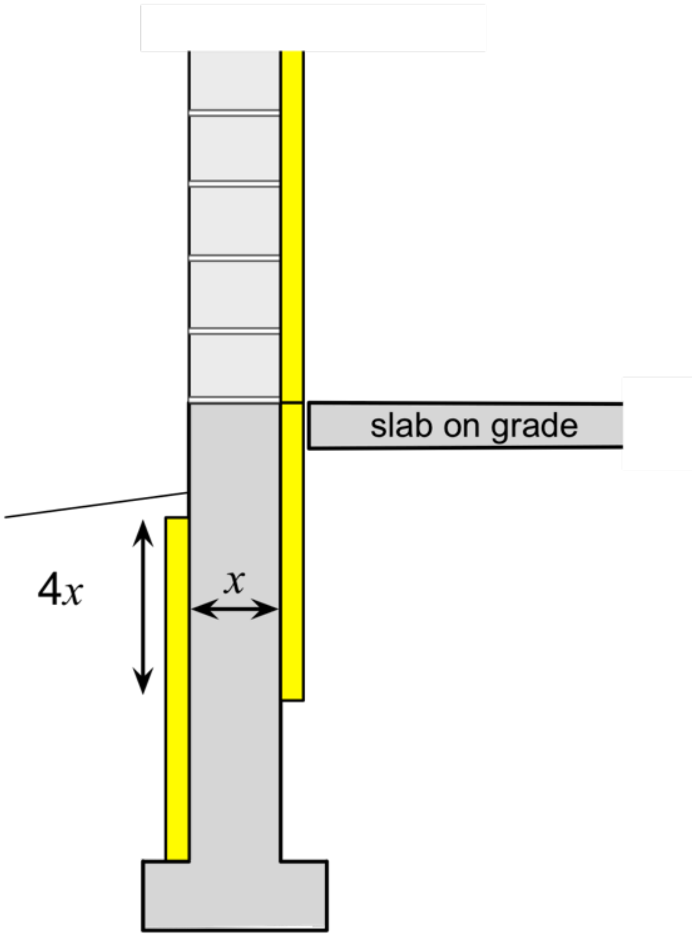
→ Others need to be calculated

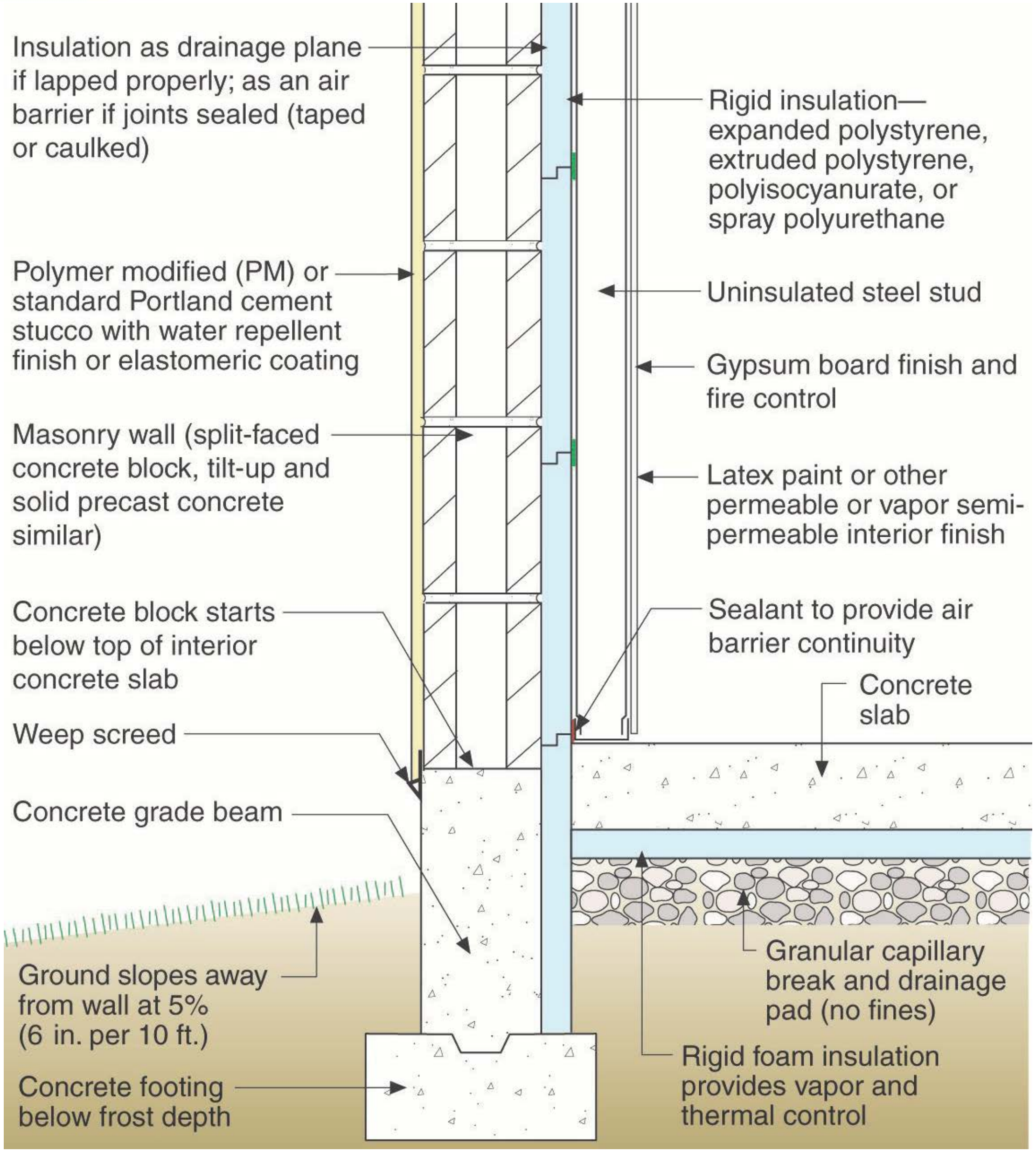


Grade-transition



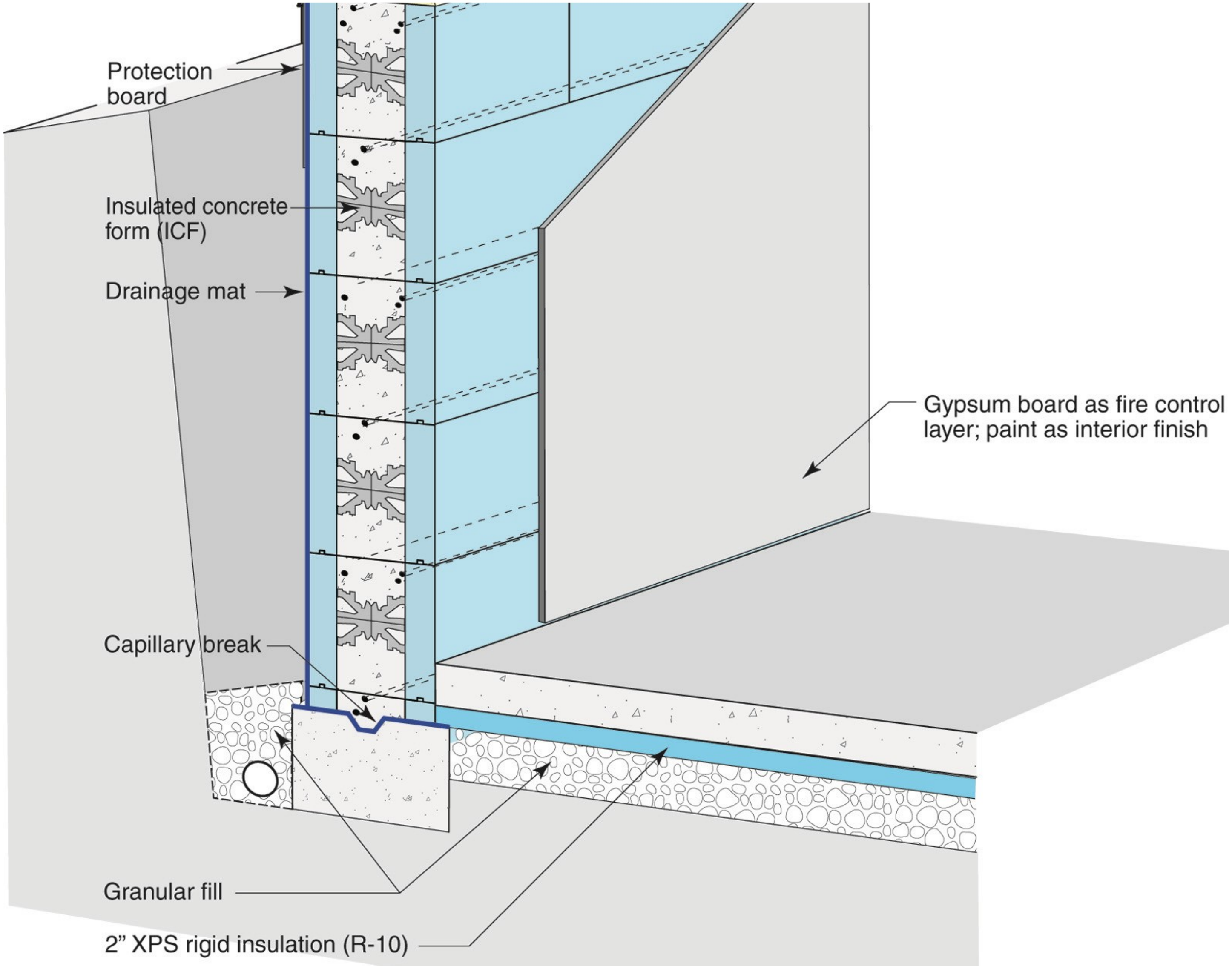
Overlap 4 times thickness
Still a bridge, but "acceptable"



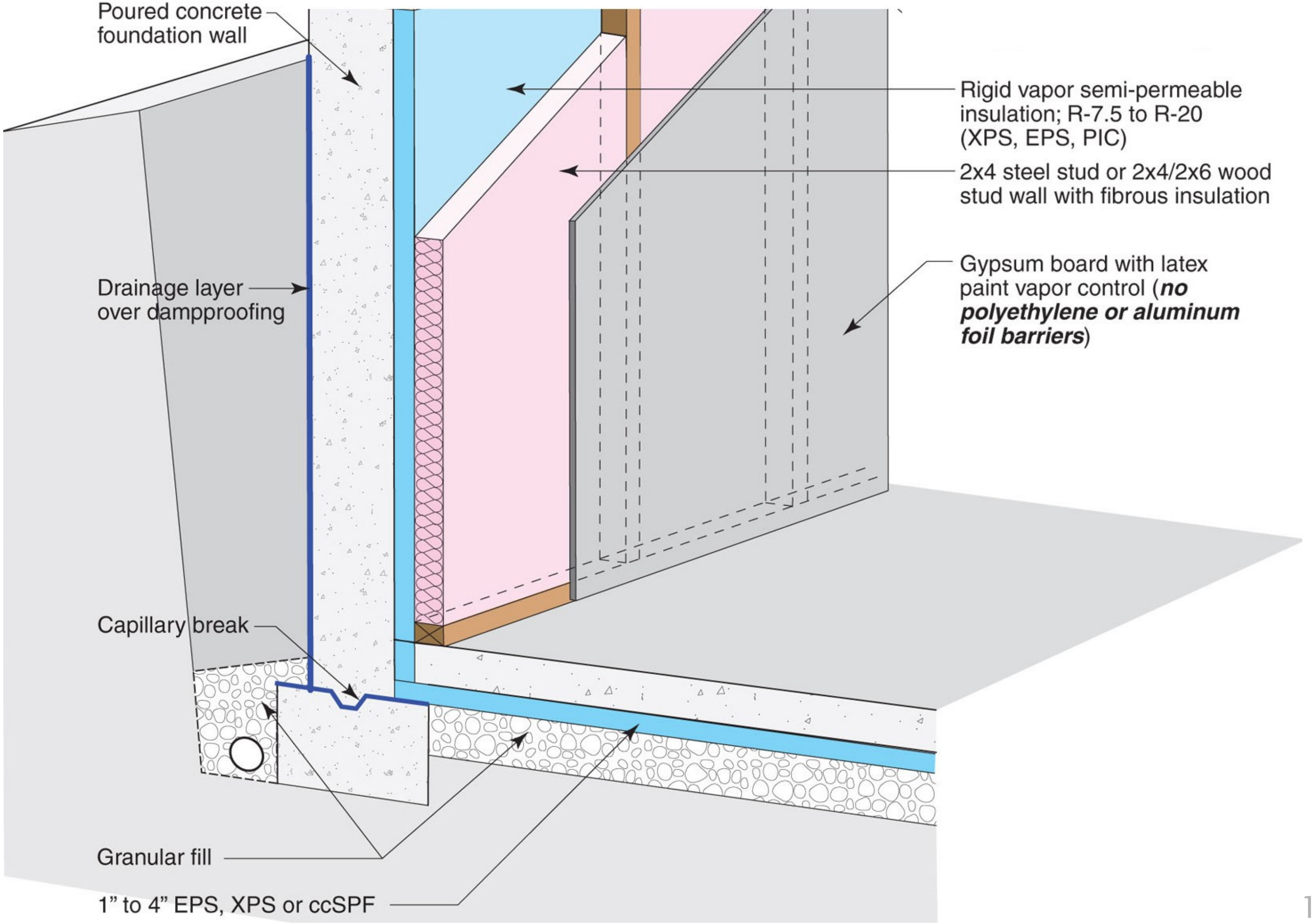


Insulation as drainage plane if lapped properly; as an air barrier if joints sealed (taped or caulked)
Polymer modified (PM) or standard Portland cement stucco with water repellent finish or elastomeric coating
Masonry wall (split-faced concrete block, tilt-up and solid precast concrete similar)
Concrete block starts below top of interior concrete slab
Weep screed
Concrete grade beam
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Concrete footing below frost depth
Rigid insulation—expanded polystyrene, extruded polystyrene, polyisocyanurate, or spray polyurethane
Uninsulated steel stud
Gypsum board finish and fire control
Latex paint or other permeable or vapor semi-permeable interior finish
Sealant to provide air barrier continuity
Concrete slab
Granular capillary break and drainage pad (no fines)
Rigid foam insulation provides vapor and thermal control

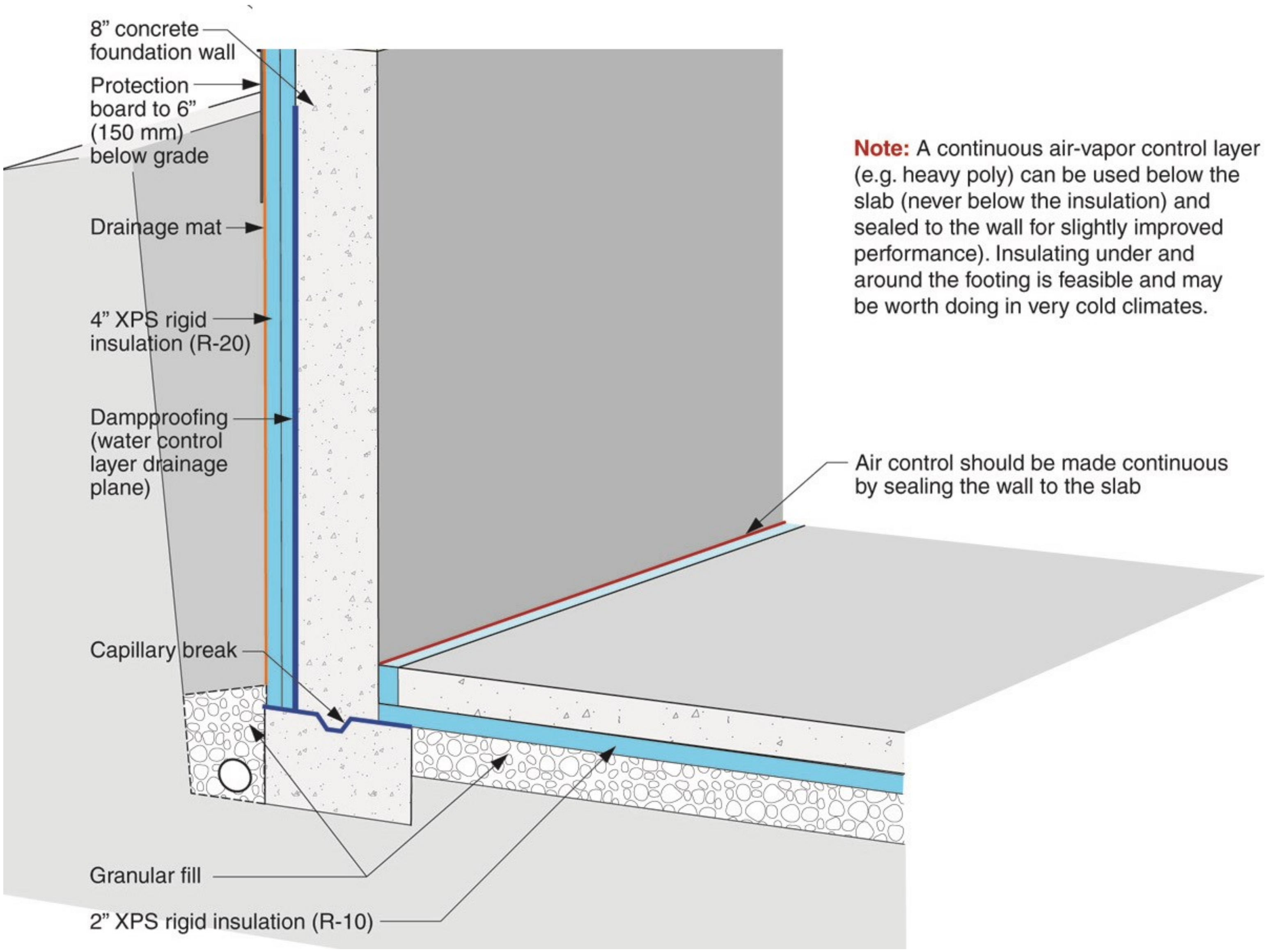
ICF Basement



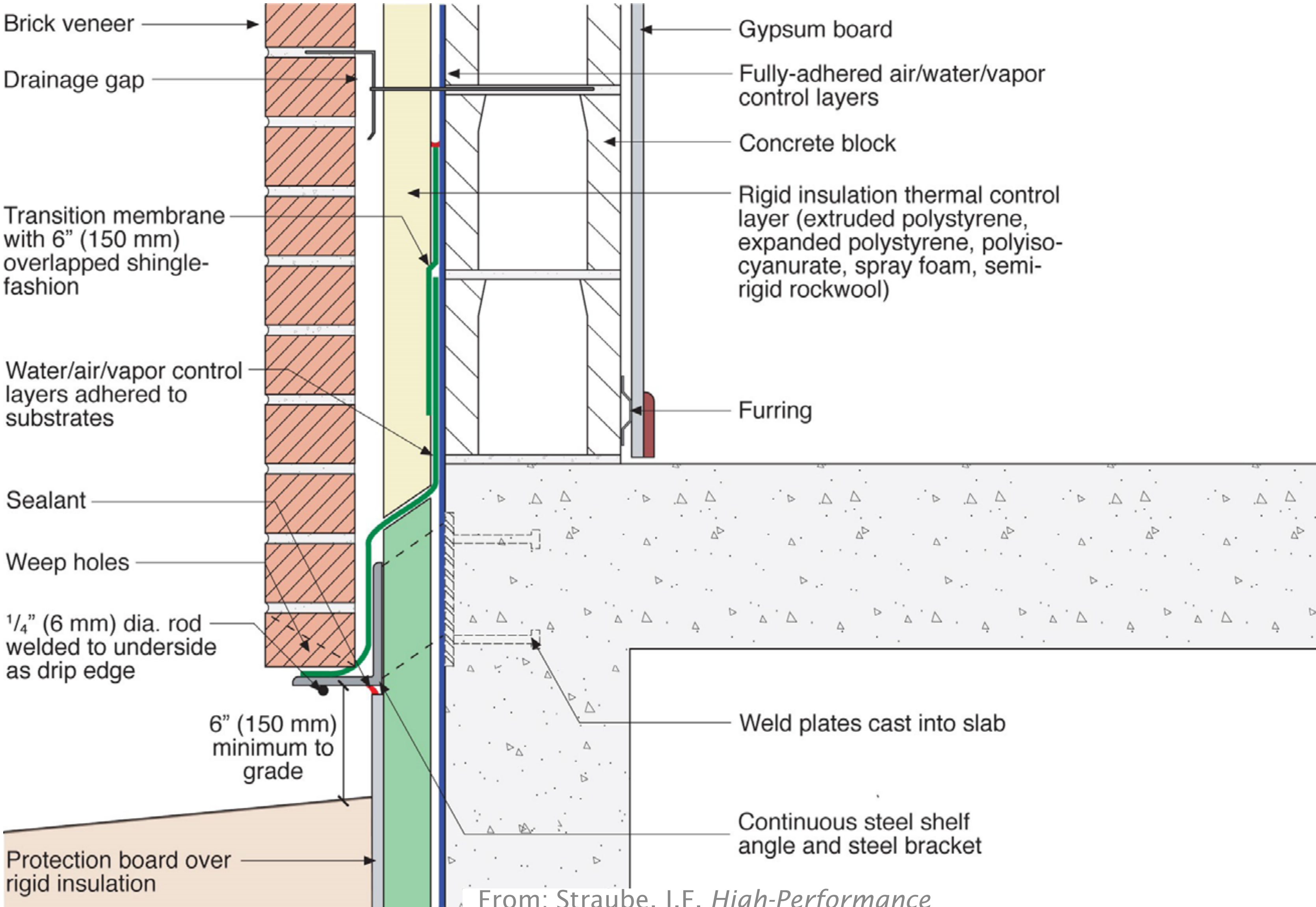
CIP Basement with Interior Insulation



CIP Basement with Exterior Insulation



Stand-off Shelf Angle at Grade



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

Roofs

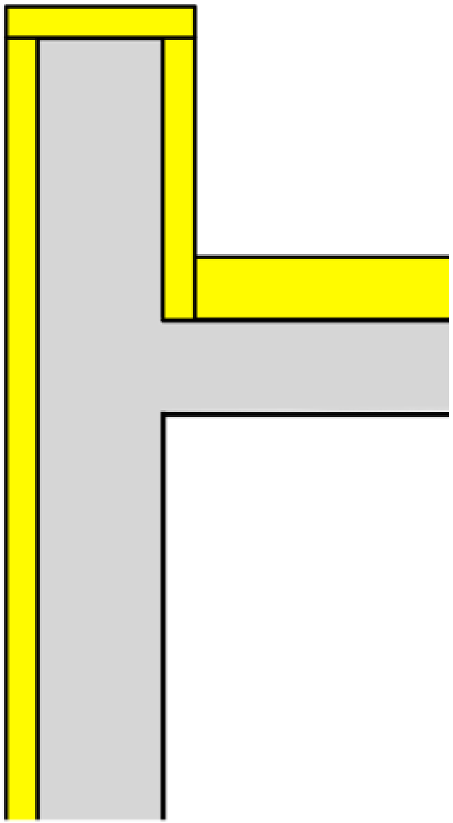
- → Low-slope most common for this segment
- → Account for Screws?
  - → Not code-required
- → Account for HVAC Curbs, HVAC Screen posts, etc.?

Roofs thermal bridges:

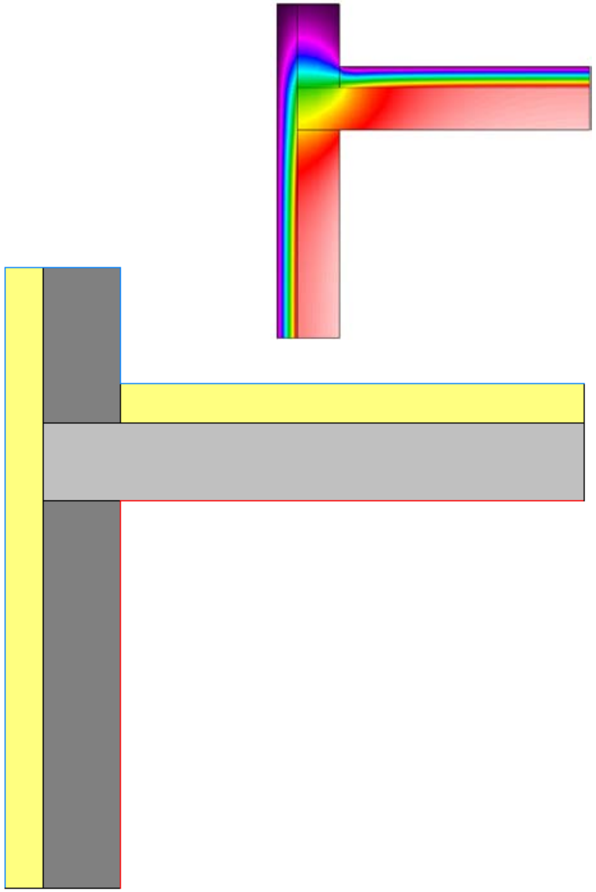
Parapets

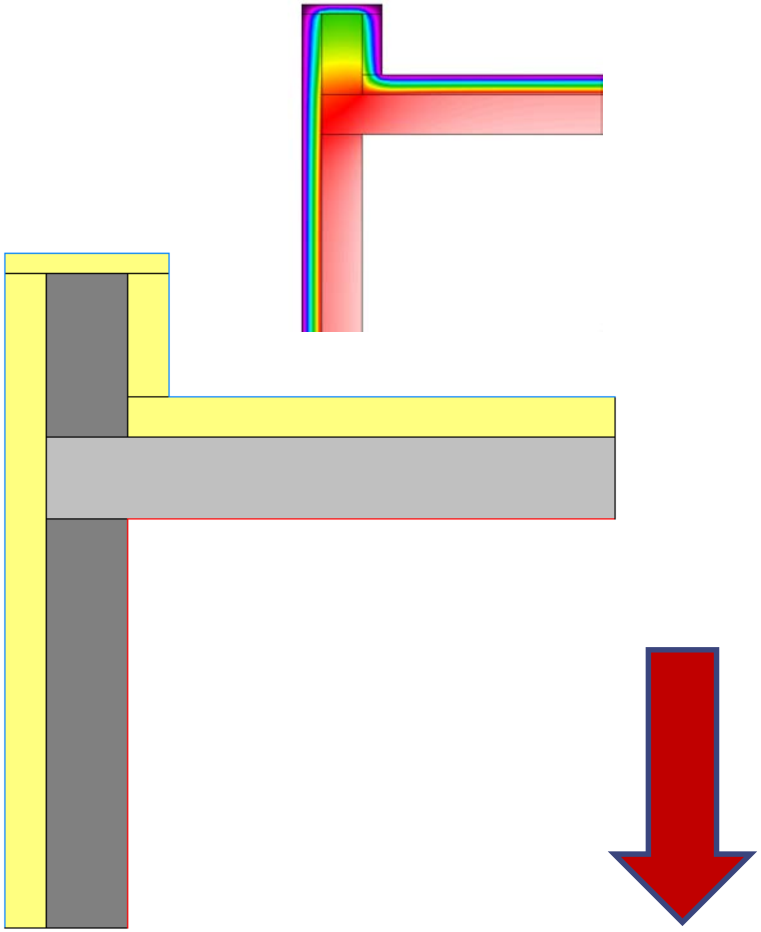
→ Wrap-around insulation

→ Easy to add a little on top



Parapets



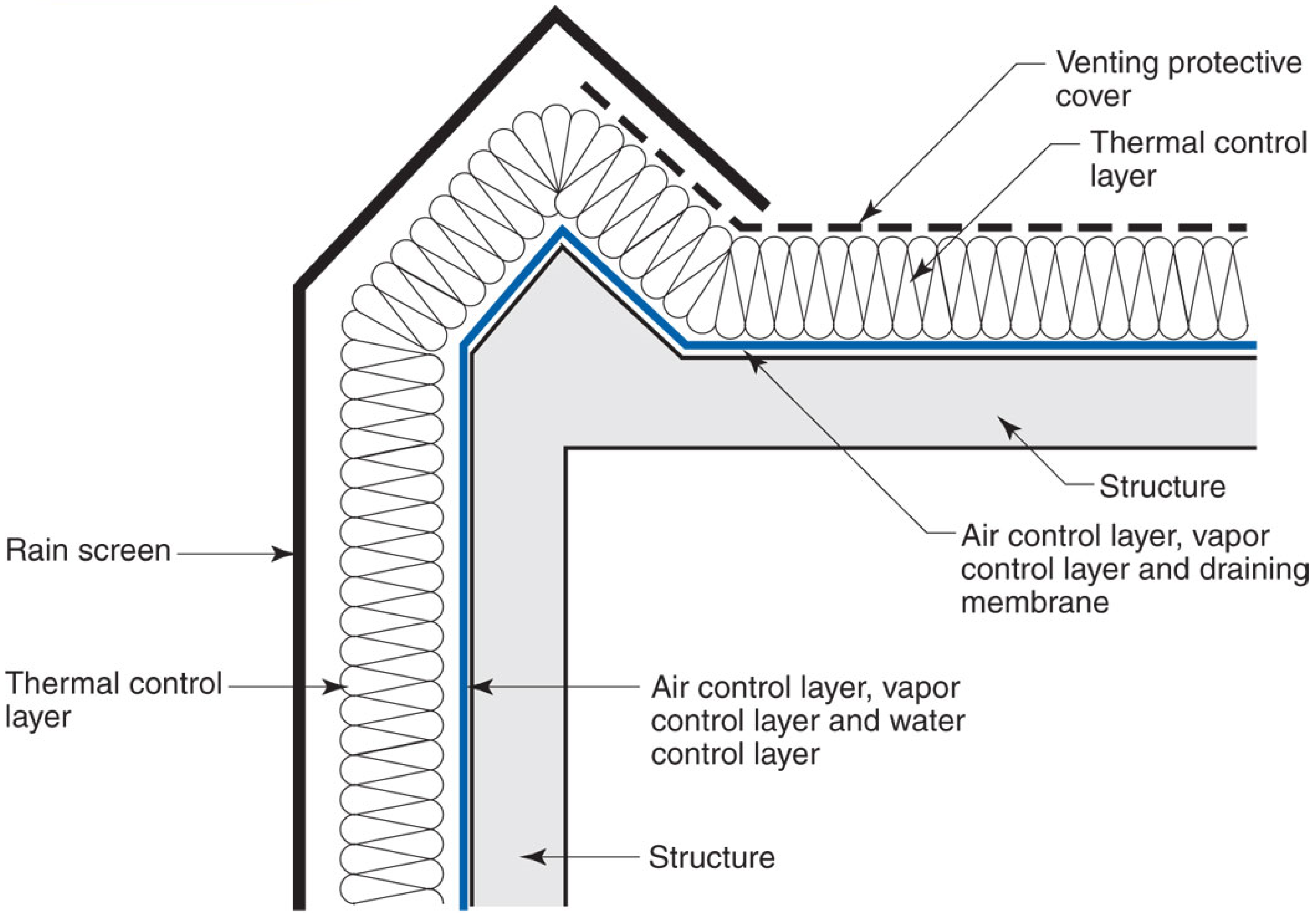


0.428 BTU/hr.ft.F

0.039 BTU/hr.ft.F

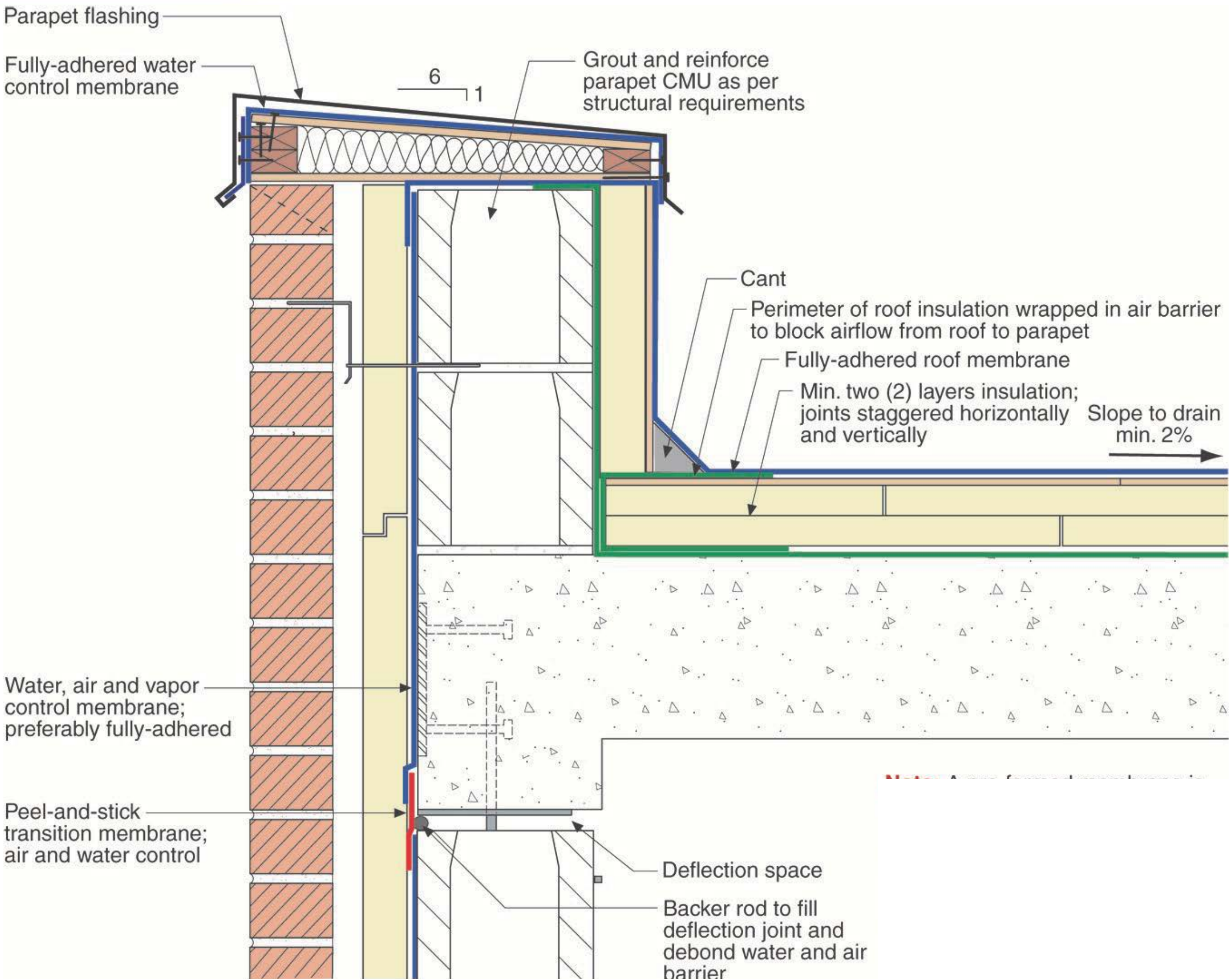
90%

Parapets



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

Parapet with Wrap-Around Insulation



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

Questions?

AND THANKS FOR LISTENING

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