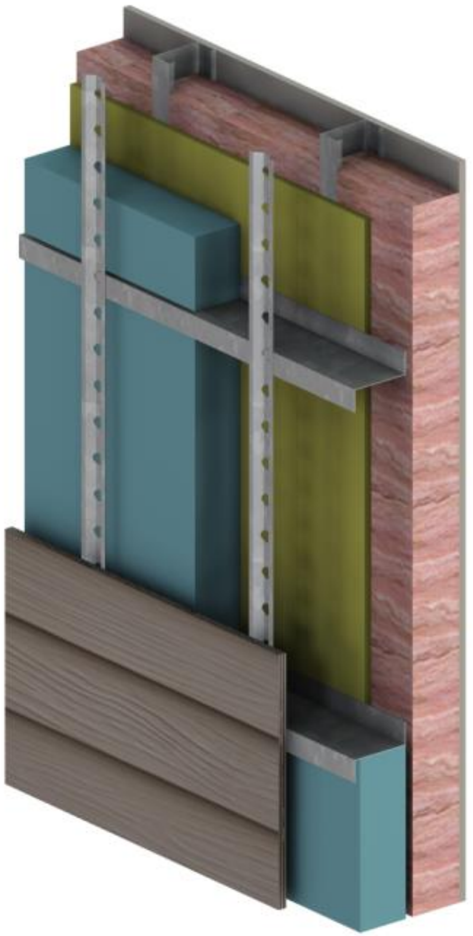
Building Envelope
Thermal Bridging Workshop

February 13, 2015

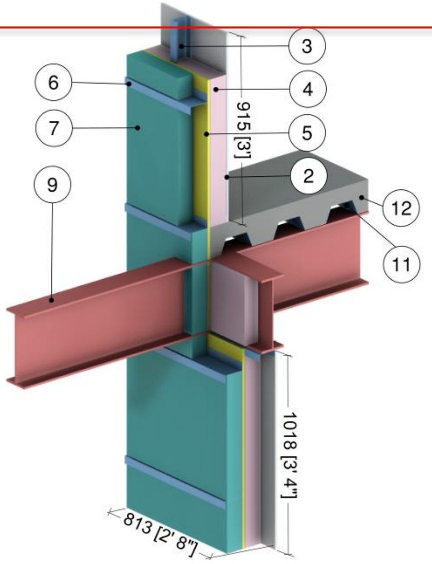
OUTLINE

- Enclosure Heat Flow Basics
  - Thermal Bridging and its Significance
  - Parallel Path vs 2D/3D Methods
- Resources
  - Clear Field Heat Flow
  - Heat Flow through Details
- BETB Guide Introduction and How To
- Model Inputs and Consultant Responsibility

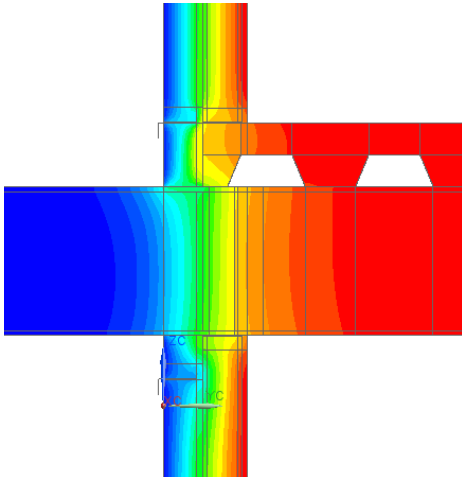


Why Do We care about Envelope Thermal Performance

- Heat flows determine:
  - Heating and cooling system capacity
  - Purchased energy requirements
  - Compliance with energy codes
  - Compliance with voluntary energy programs



- Arrangement of materials determine:
  - Surface temperatures
  - Condensation and moisture collection
  - Durability
  - Mold growth and health issues



Purpose Defines Requirements

Purpose	Need for Simplicity	Need For Accuracy	Need for Clarity of Assumptions
Evaluating design options	High	Moderate	Moderate
Evaluation heating/cooling load	Moderate	Moderate	Moderate
Compliance to energy codes	High	Low	High
Compliance with voluntary energy standards	"It Depends"	Moderate	Moderate
Compliance with incentive plans	Payer's choice	Payer's choice	Moderate
Predicting actual energy use	Low	High	Low
Evaluating surface temperatures (condensation, comfort)	Low	High	Moderate

Heat Flow Basics

Perspective

How does heat flow through an enclosure assembly?

Envelope Performance Parameters

Material Properties

- Thermal Conductivity (k) – of a material
  - Heat transmission/unit area/unit thickness/degree temperature
- Heat Capacity (Cp) – of a material
  - Amount of energy storage within a material
- Density (ρ) – of a material
  - Mass per unit volume

Actual Heat Flow

- Conductive heat flow (q) watts or BTU/hr

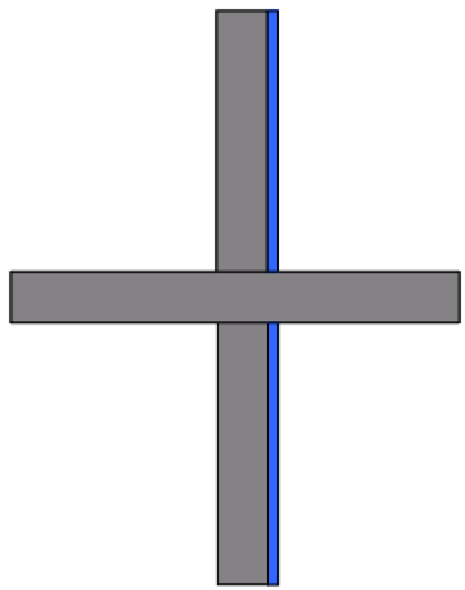
Thermal Performance (per area)

- Thermal transmission (U) of assembly
  - Heat transmission/unit area/degree temperature
- Thermal Resistance (R)
  - Inverse of U

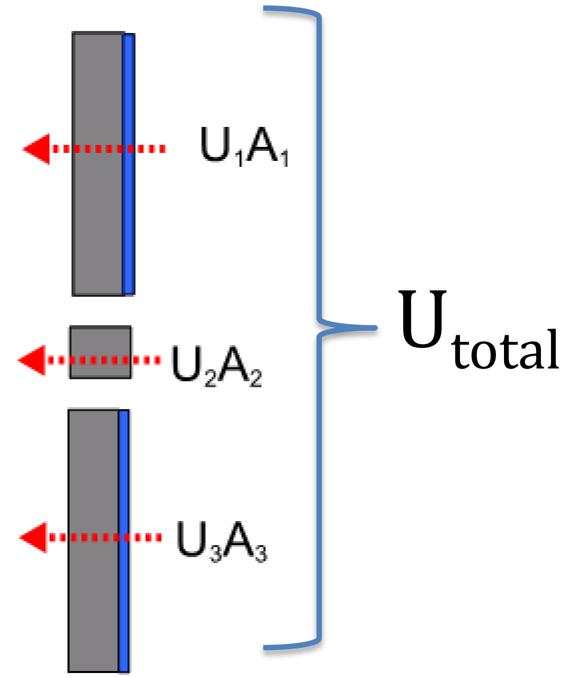
Parallel Path Heat flow

- Assumes heat flows are separate and do not influence each other
- Averages overall heat flow/resistance based on the areas of components

Insulated Concrete Wall with Projected Balcony

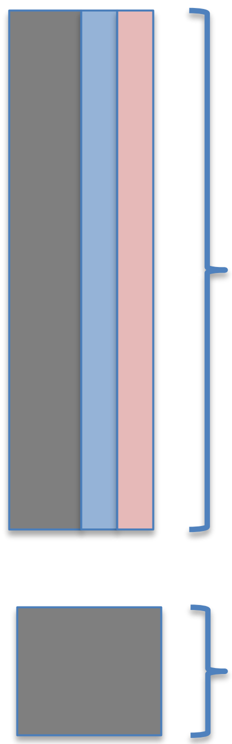


Simplified Assembly for Parallel Path



$$U_{total} = \frac{(U_1A_1 + U_2A_2 + U_3A_3 \ldots)}{(A_1 + A_2 + A_3 \ldots)} \cdot \Delta T$$

Parallel path method



R20 for 8’3” wall

R2 for 9” slab edge

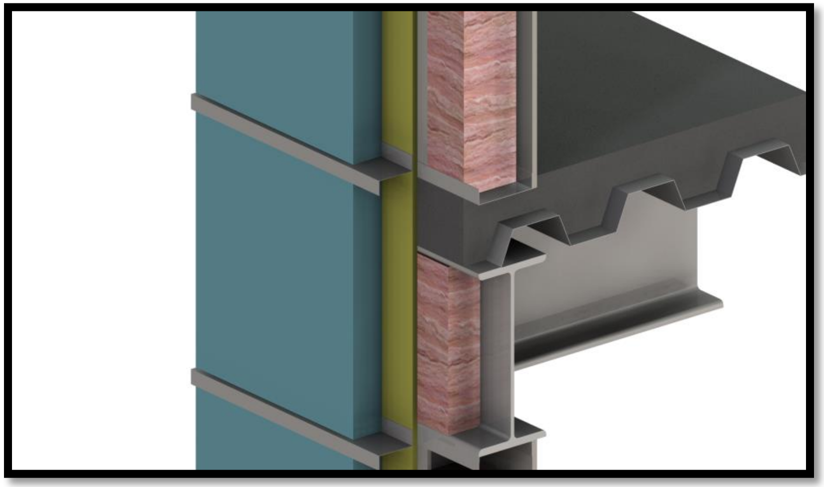
$$\frac{1}{R} = \frac{0.75 \times {}^{1}/_{2} + 8.25 \times {}^{1}/_{20}}{0.75 + 8.25}$$

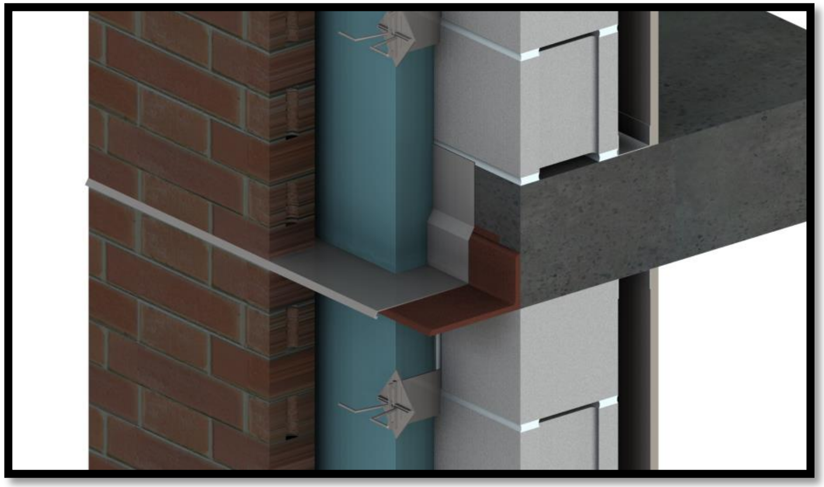
$$R \cong 11.5$$

Morrison Hershfield

Thermal Bridging

- Parallel path doesn't tell the whole story
- Many thermal bridges don't abide by "areas" ie: shelf angle
- Can greatly affect the thermal performance of assemblies





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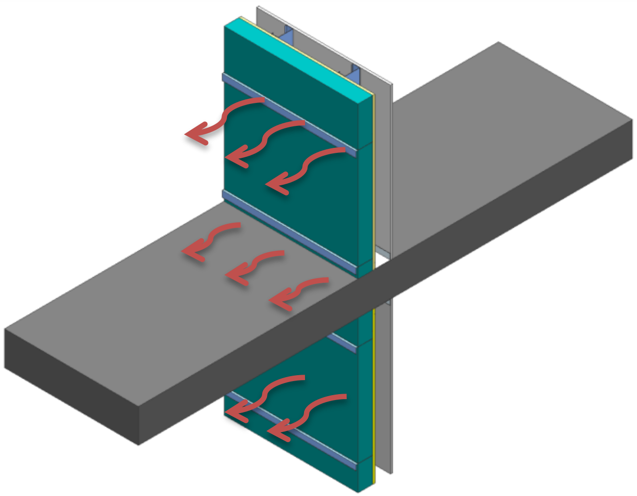
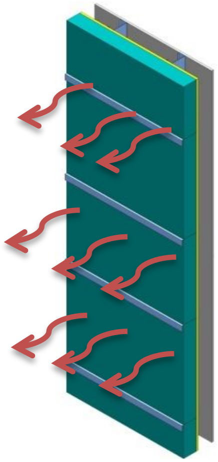
Overall Heat Loss

$$Q - Q_o = Q_{slab}$$

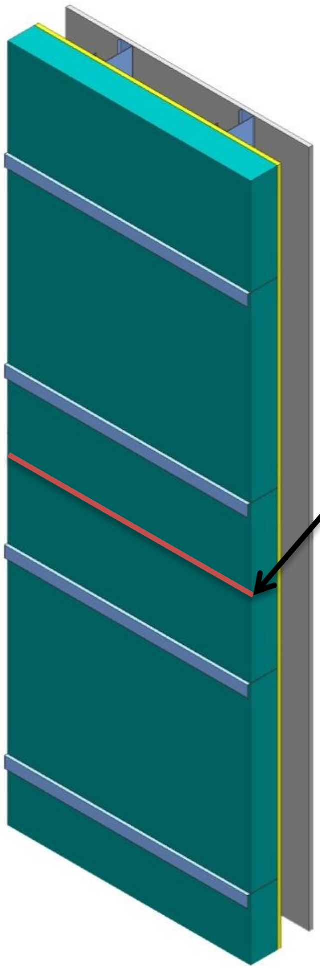




Additional heat loss due to the slab

Morrison Hershfield

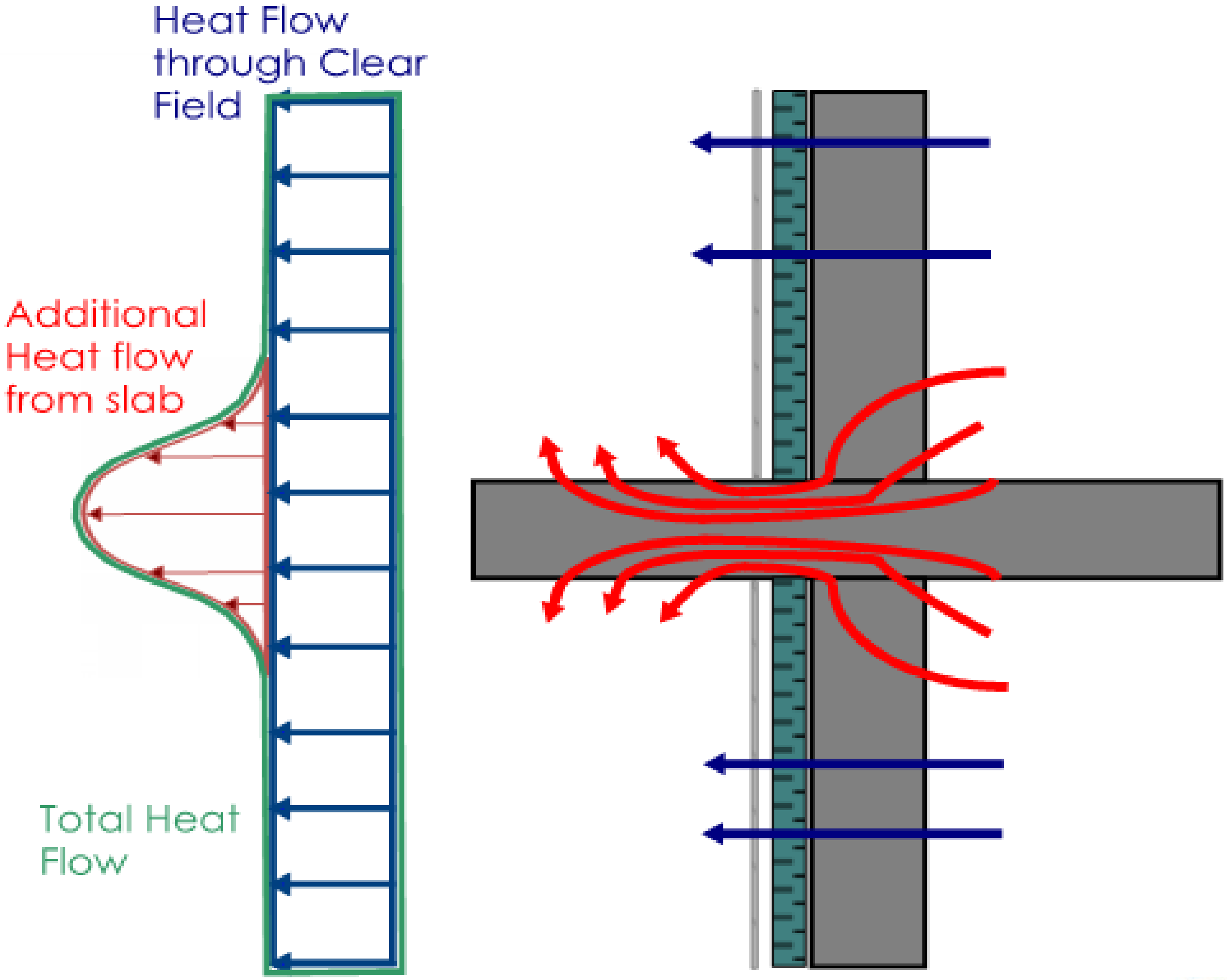
Overall Heat Loss



$$\Psi = Q_{slab} / L$$

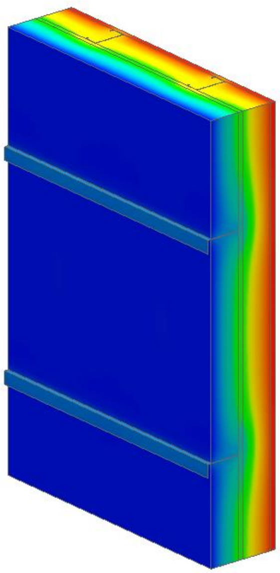
- The linear transmittance represents the additional heat flow because of the slab, but with area set to zero

Addressing lateral Heat Flow



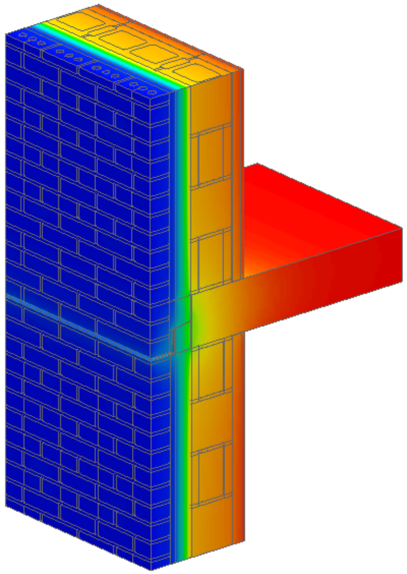
The Conceptual Leap

Types of Transmittances



Clear Field

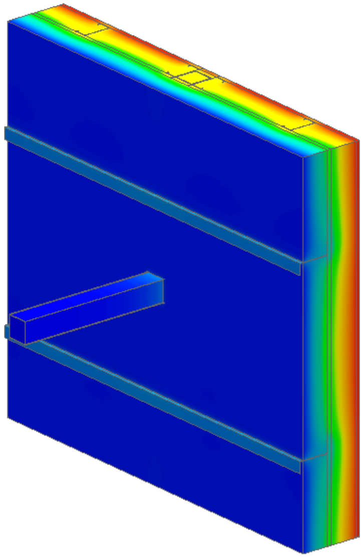
U_o



Linear

Ψ

psi



Point

χ

chi

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OVERALL HEAT LOSS

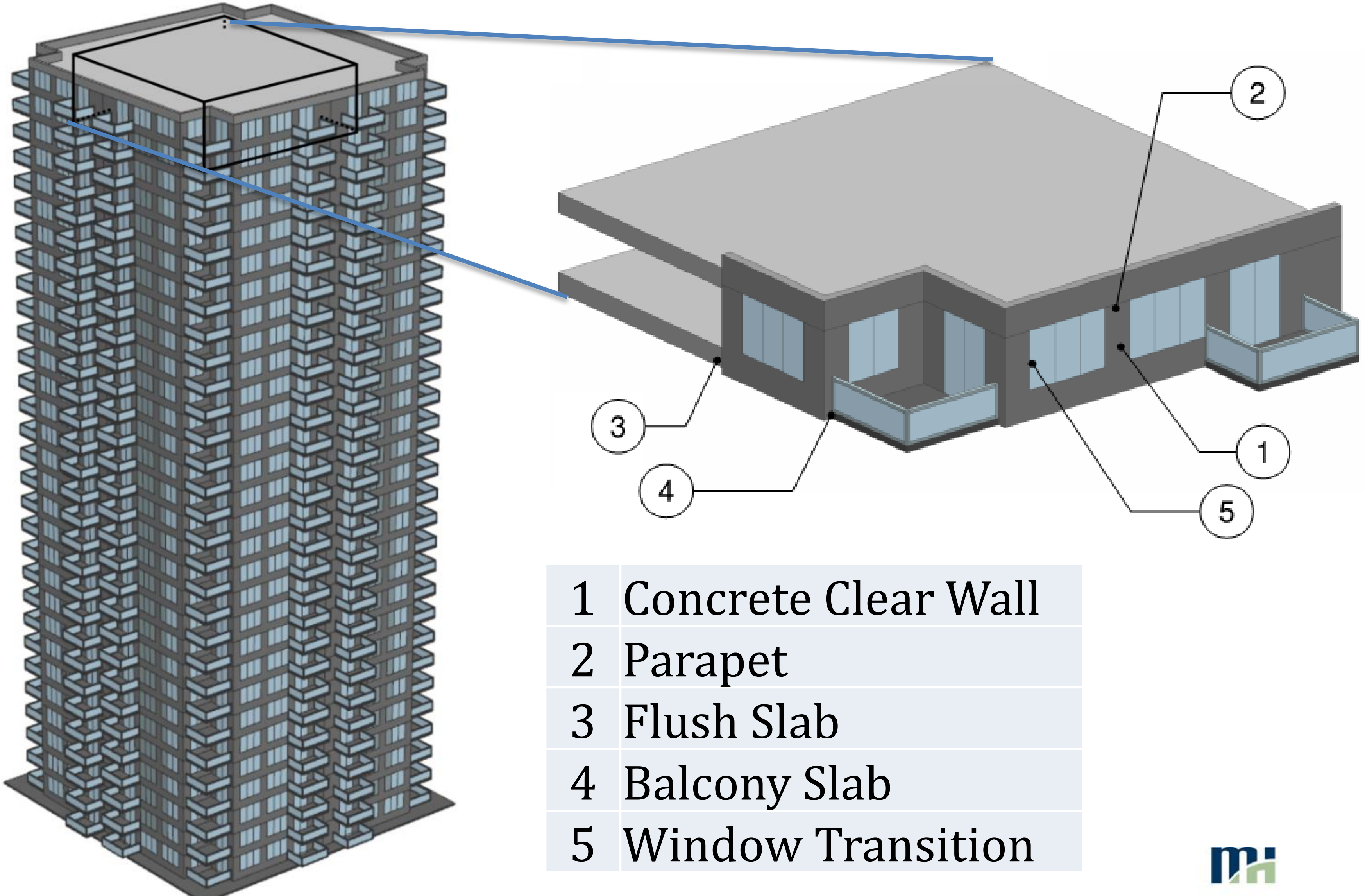
Total Heat loss = heat loss due to clear field + Heat loss due to interface details

OR

$$Q/\Delta T = (U_o \cdot A_{Total}) + \Sigma(\Psi \cdot L) + \Sigma(\chi)$$

OR

$$U_T = \frac{\Sigma(\Psi \cdot L) + \Sigma(\chi)}{A_{Total}} + U_o$$



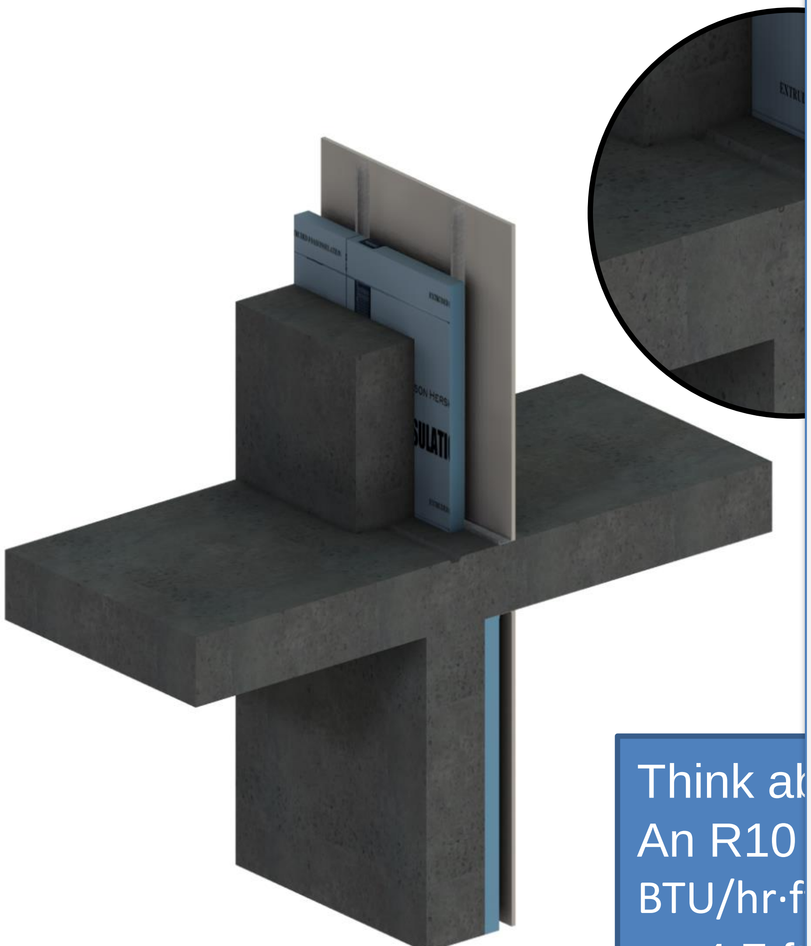
1	Concrete Clear Wall
2	Parapet
3	Flush Slab
4	Balcony Slab
5	Window Transition

Morrison Hershfield

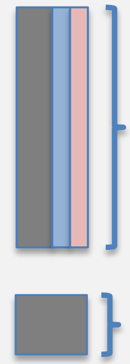
Proposed Building Entries								Totals	1975.7	100%
Add/Remove Detail	**Transmittance Type**	**Include**	**Transmittance Description**	**Area, Length or Amount Takeoff**	**Units**	**Transmittance Value**	**Units**	**Source Reference**	**Heat Flow (BTU/hr°F)**	**%Total Heat Flow**
Add Clear Field	Clear Field	☑	Exterior wall	22957.00	ft^2	0.040	BTU/ hr ft² °F	Enter Source Here	918.3	46%
Add Linear Interface Detail	Linear Interface Detail	☑	Parapet	1879.21	ft	0.231	BTU/ hr ft °F	Enter Source Here	434.1	22%
Remove Linear Interface Detail	Linear Interface Detail	☑	Floor Slab	2179.56	ft	0.286	BTU/ hr ft °F	Enter Source Here	623.4	32%
Remove Linear Interface Detail	Linear Interface Detail	☑	Glazing Transitions	2757.63	ft	Enter Psi-Value Here	BTU/ hr ft °F	Enter Source Here	-	-
Add Point Interface Detail	Point Interface Detail	☑	Enter Description Here	Enter Amount Here	#	Enter Chi-Value Here	BTU/ hr °F	Enter Source Here	-	-

Proposed Building	
Opaque U-Value (BTU/hr ft^2 °F)	**0.086**
Effective R-Value (hr ft^2 °F/BTU)	**11.6**

R-25 ---> R11.6



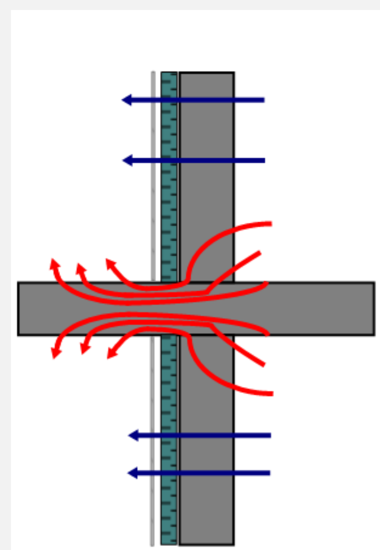
Think ab
An R10
BTU/hr·f
as 4.7 ft



Parallel Path

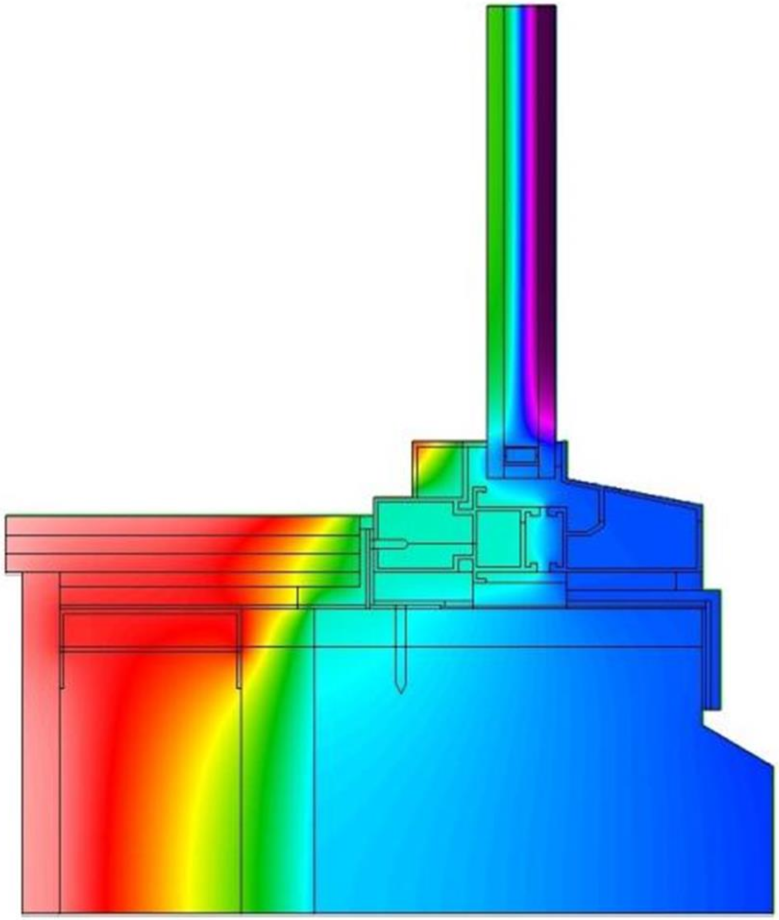
$R \cong 11.5$

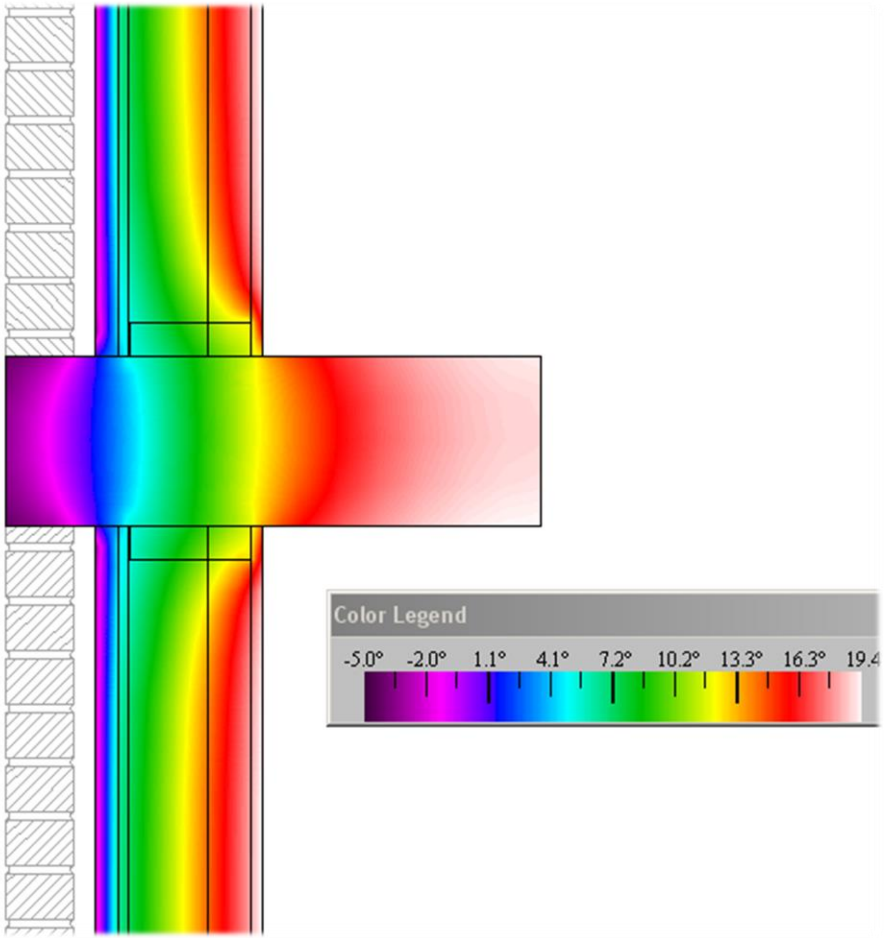
Linear Transmittance

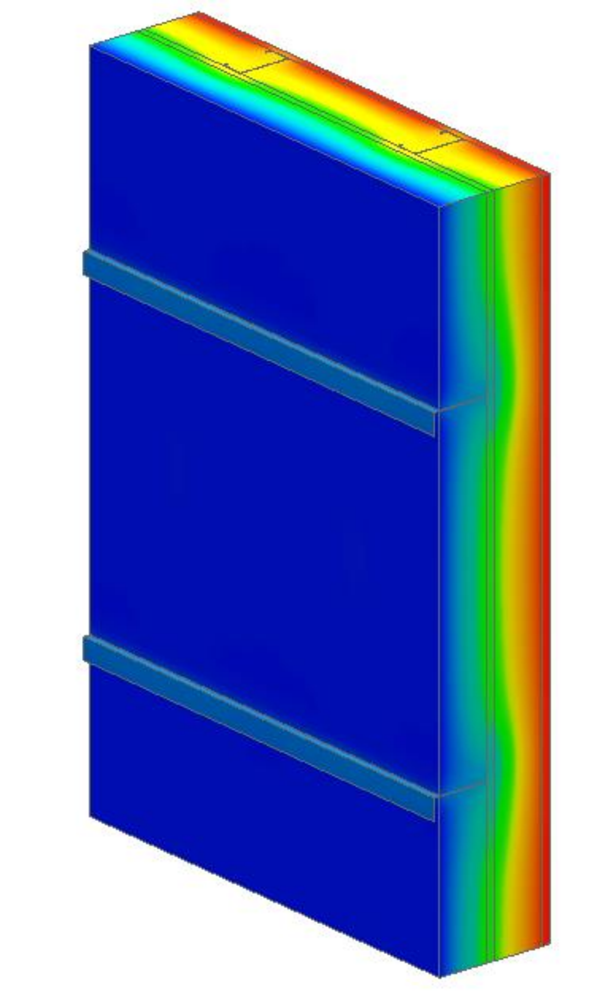


$R \cong 9.8$

Therm Modeling







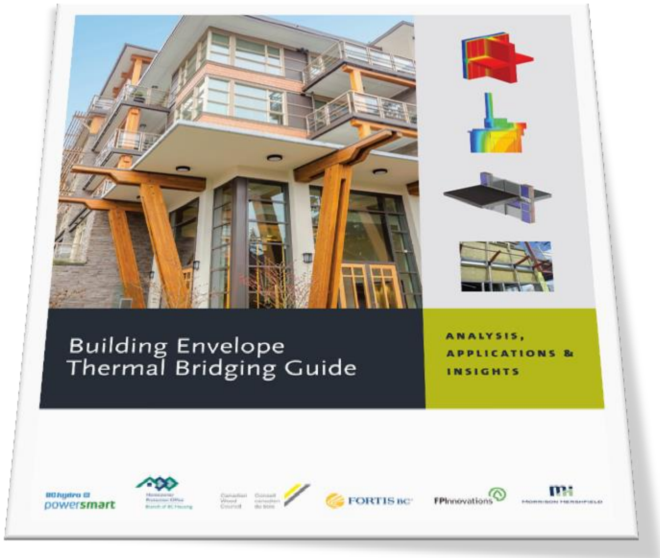
Clear Walls

$$U_o$$

WHERE TO FIND DATA

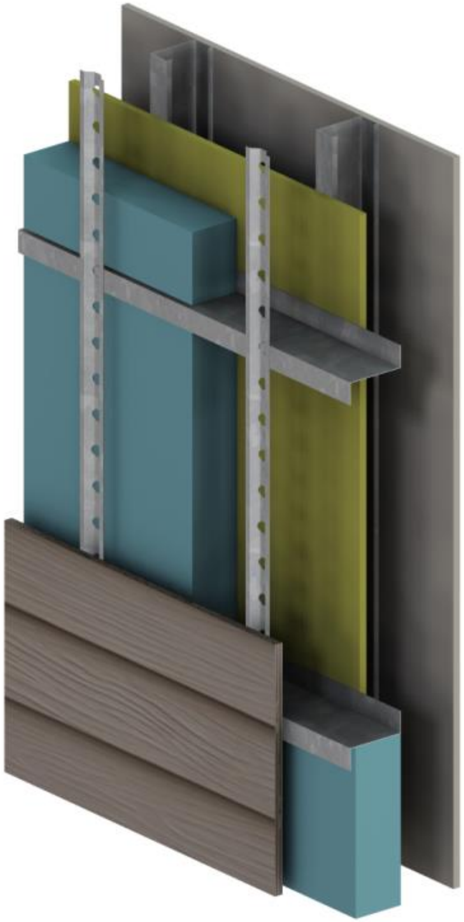
- ASHRAE 90.1 Appendix A
- Manufacturers Reports

- Building Envelope Thermal Bridging Guide
  - Extensive catalogue of assemblies (300+)
  - Includes clear field transmittances for a variety of constructions and configurations



MORRISON HERSHFIELD

USING ASHRAE 90.1 APPENDIX A



What is R_{eff} value ($1/ U_0$)

- Wall with no insulation in stud cavity or exterior insulation (see table A3.3)
- What might R13 in cavity add
- What might R15 exterior insulation add (see table A3.1D and/or A4.2)

ASHRAE 90.1 Steel Stud Walls

TABLE A3.3 Assembly U-Factors for Steel-Frame Walls

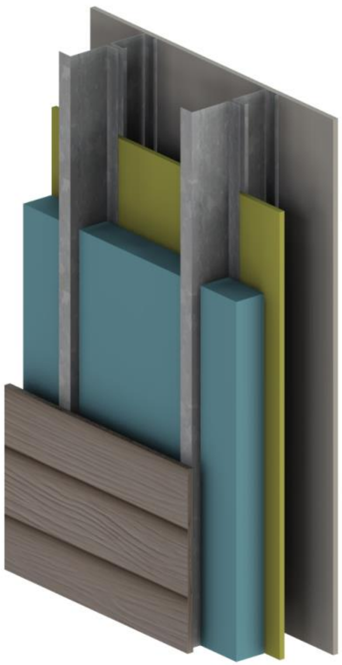
Framing Type and Spacing Width (Actual Depth)	Cavity Insulation R-Value: Rated (Effective Installed [see Table A9.2B])	Overall U-Factor for Entire Base Wall Assembly	Overall U-Factor for Assembly of Base Wall Plus Continuous Insulation (Uninterrupted by Framing), Rated R-Value of Continuous Insulation																			
			R-1.00	R-2.00	R-3.00	R-4.00	R-5.00	R-6.00	R-7.00	R-8.00	R-9.00	R-10.00	R-11.00	R-12.00	R-13.00	R-14.00	R-15.00	R-20.00	R-25.00	R-30.00	R-35.00	R-40.00
Steel Framing at 16 in. on center																						
3.5 in. depth	None (0.0)	**0.352**	0.260	0.207	0.171	0.146	0.128	0.113	0.102	0.092	0.084	0.078	0.072	0.067	0.063	0.059	0.056	0.044	0.036	0.030	0.026	0.023
	R-11 (5.5)	**0.132**	0.117	0.105	0.095	0.087	0.080	0.074	0.069	0.064	0.060	0.057	0.054	0.051	0.049	0.046	0.044	0.036	0.031	0.027	0.024	0.021
	R-13 (6.0)	**0.124**	0.111	0.100	0.091	0.083	0.077	0.071	0.066	0.062	0.059	0.055	0.052	0.050	0.048	0.045	0.043	0.036	0.030	0.026	0.023	0.021
	R-15 (6.4)	**0.118**	0.106	0.096	0.087	0.080	0.074	0.069	0.065	0.061	0.057	0.054	0.051	0.049	0.047	0.045	0.043	0.035	0.030	0.026	0.023	0.021
6.0 in. depth	R-19 (7.1)	**0.109**	0.099	0.090	0.082	0.076	0.071	0.066	0.062	0.058	0.055	0.052	0.050	0.047	0.045	0.043	0.041	0.034	0.029	0.026	0.023	0.020
	R-21 (7.4)	**0.106**	0.096	0.087	0.080	0.074	0.069	0.065	0.061	0.057	0.054	0.051	0.049	0.047	0.045	0.043	0.041	0.034	0.029	0.025	0.022	0.020
Steel Framing at 24 in. on center																						
3.5 in. depth	None (0.0)	**0.338**	0.253	0.202	0.168	0.144	0.126	0.112	0.100	0.091	0.084	0.077	0.072	0.067	0.063	0.059	0.056	0.044	0.036	0.030	0.026	0.023
	R-11 (6.6)	**0.116**	0.104	0.094	0.086	0.079	0.073	0.068	0.064	0.060	0.057	0.054	0.051	0.048	0.046	0.044	0.042	0.035	0.030	0.026	0.023	0.021
	R-13 (7.2)	**0.108**	0.098	0.089	0.082	0.075	0.070	0.066	0.062	0.058	0.055	0.052	0.049	0.047	0.045	0.043	0.041	0.034	0.029	0.025	0.023	0.020
	R-15 (7.8)	**0.102**	0.092	0.084	0.078	0.072	0.067	0.063	0.059	0.056	0.053	0.050	0.048	0.046	0.044	0.042	0.040	0.034	0.029	0.025	0.022	0.020
6.0 in. depth	R-19 (8.6)	**0.094**	0.086	0.079	0.073	0.068	0.064	0.060	0.057	0.054	0.051	0.048	0.046	0.044	0.042	0.041	0.039	0.033	0.028	0.025	0.022	0.020
	R-21 (9.0)	**0.090**	0.083	0.077	0.071	0.066	0.062	0.059	0.055	0.052	0.050	0.048	0.045	0.043	0.042	0.040	0.038	0.032	0.028	0.024	0.022	0.020

How does ASHRAE 90.1 deal with bridging?

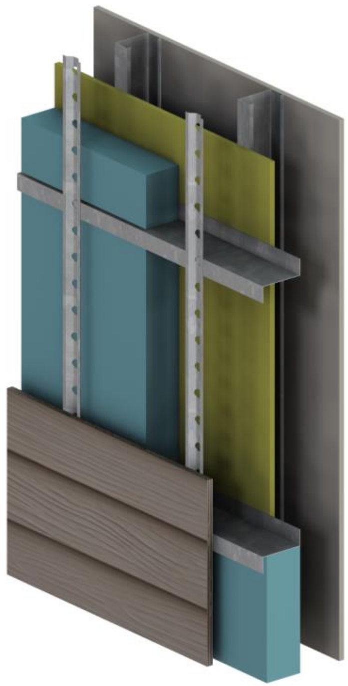
TABLE A3.3 Assembly U-Factors for Steel-Frame Walls

Framing Type and Spacing Width (Actual Depth)	Cavity Insulation R-Value: Rated (Effective Installed [see Table A9.2B])	Overall U-Factor for Entire Base Wall Assembly	Overall U-Factor for Assembl… For Continuous Insulation							
			R-1.00	R-2.00	R-3.00	R-4.00	R-5.00	R-6.00	R-7.00	R-8.00
Steel Framing at 16 in. on center										
3.5 in. depth	None (0.0)	**0.352**	= 2.8	.207	0.171	0.146	0.128	0.113	0.102	0.092
	R-11 (5.5)	**0.132**	0.117	0.105	0.095	0.087	0.080	0.074	0.069	0.064
	R-13 (6.0)	**0.124**	= R-8	.100	0.091	0.083	0.077	= R-13		0.062
	R-15 (6.4)	**0.118**	0.106	0.096	0.087	0.080	0.074	0.069	0.065	0.061

CLEAR WALLS

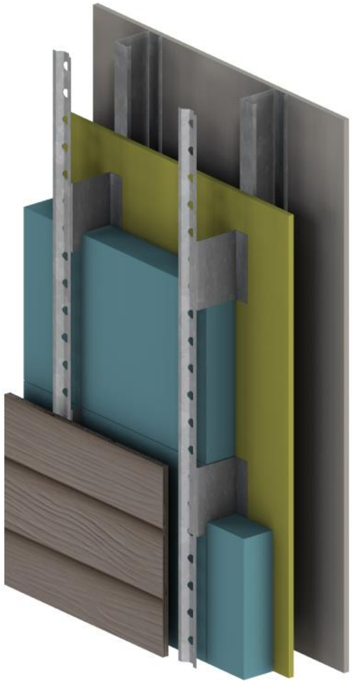


Vertical Z-Girts



Horizontal Z-Girts

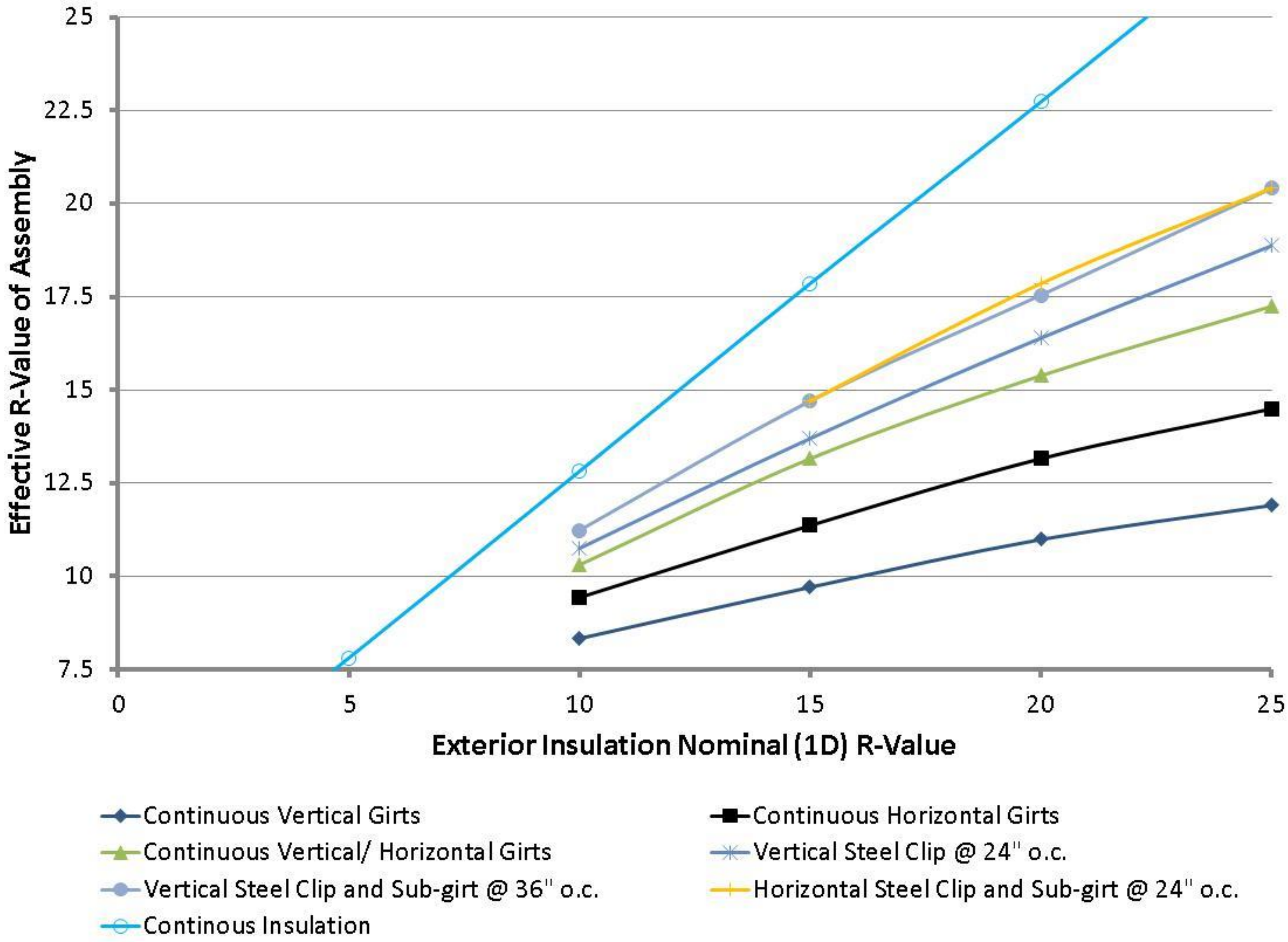
Mixed Z-Girts



Intermittent Z-Girts

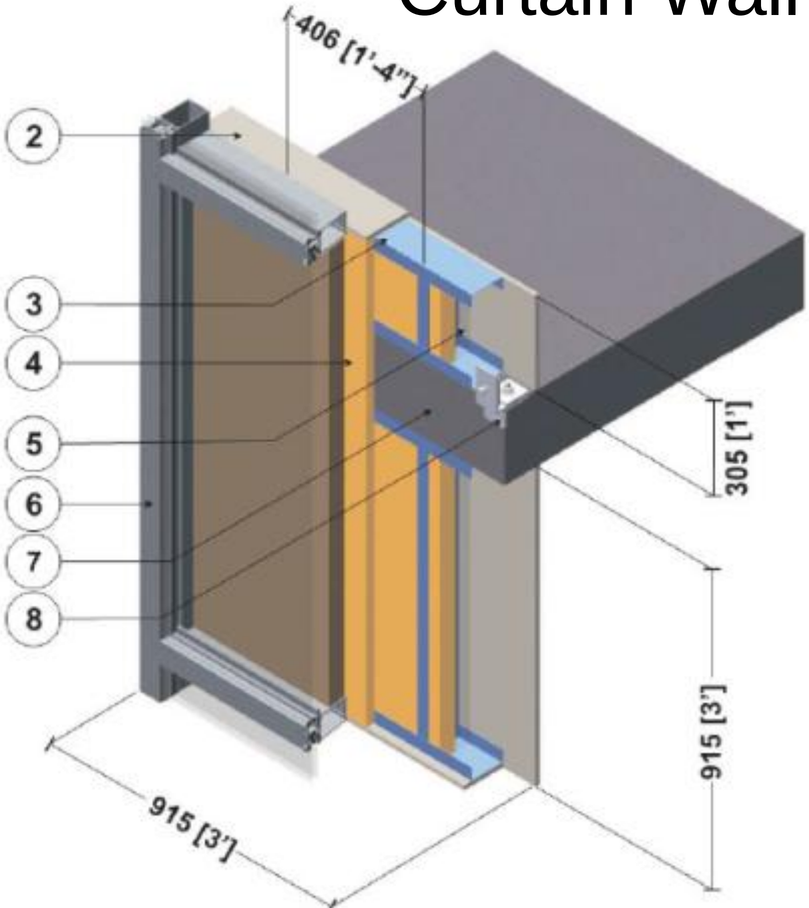
EFFECT OF THERMAL BRIDGING IN 3D

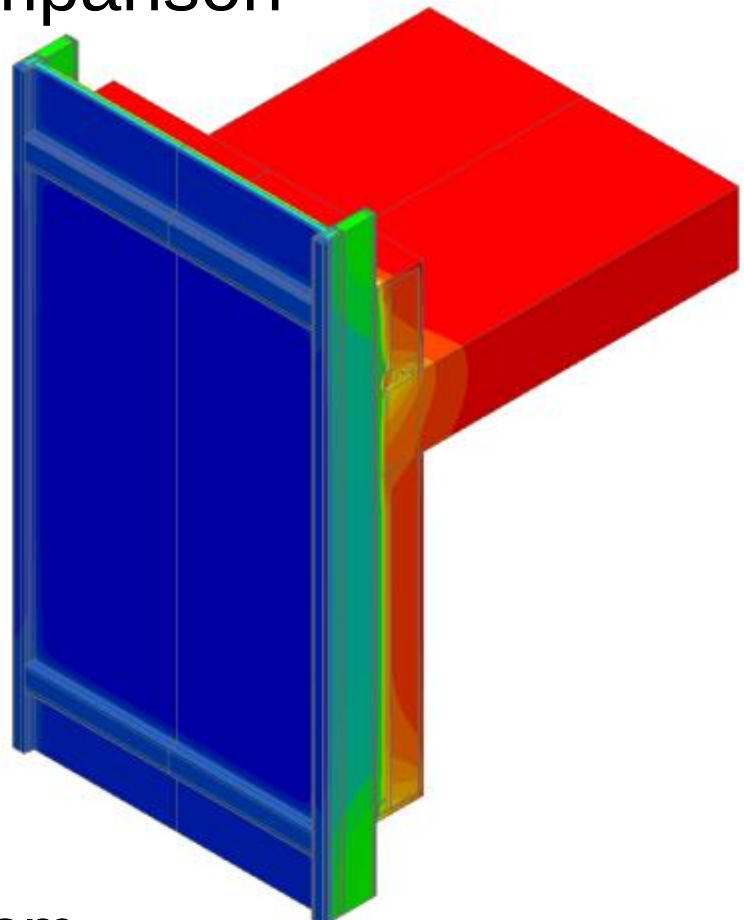
From 3D Modelling



MORRISON HERSHFIELD

Curtain Wall Comparison





Spray Foam

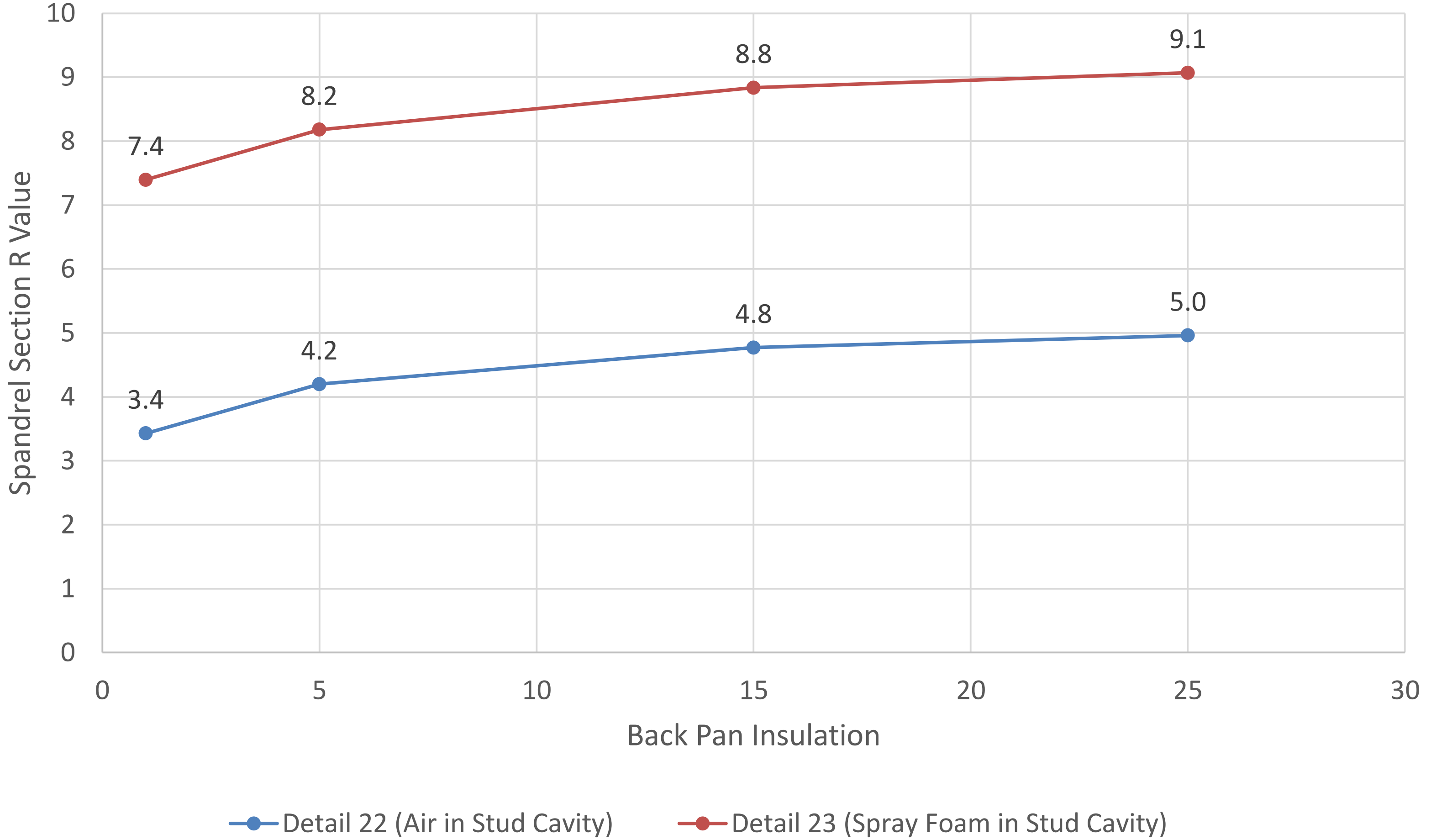
Effect of Thermal bridging in 3D

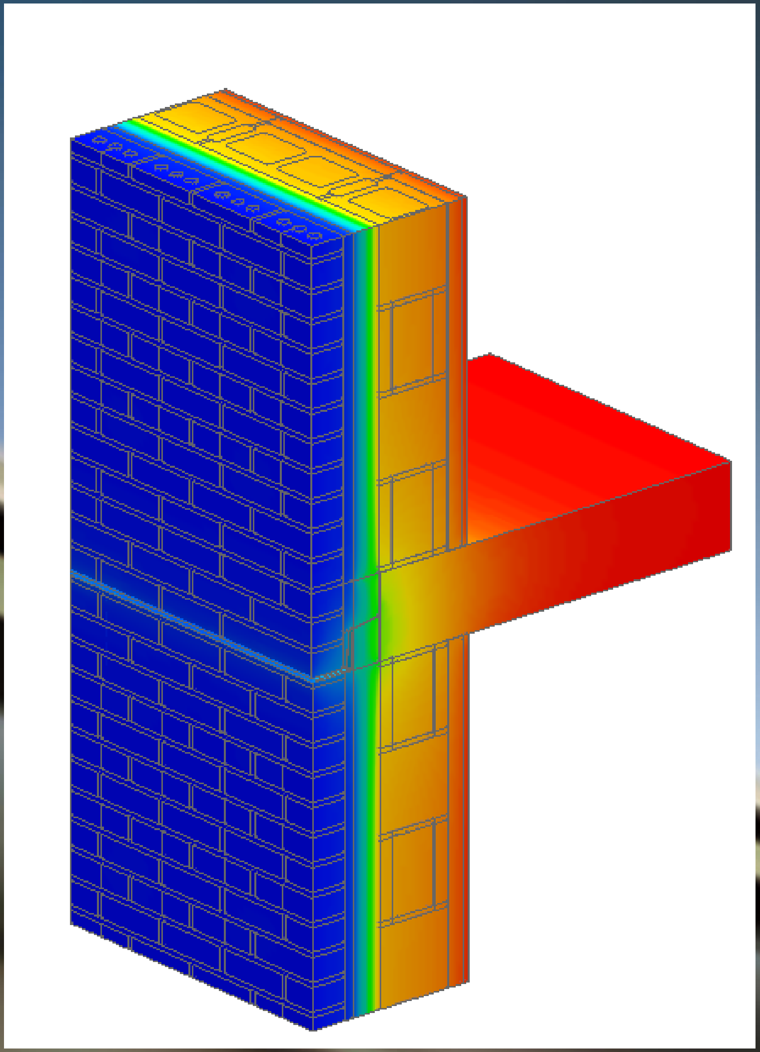
RESULTS	Glazing System Only	Total Spandrel CSA Rated Size	Total Spandrel Specified Size
U-value (W/m^2/Â°C):	2.79	1.21	1.21
in (BTU/hr-ft^2-Â°F):	0.49	0.21	0.21
RSI:		0.83	0.83
R-value:		4.70	4.70

Without Sprayfoam

RESULTS	Glazing System Only	Total Spandrel CSA Rated Size	Total Spandrel Specified Size
U-value (W/m^2/Â°C):	2.79	0.56	0.56
in (BTU/hr-ft^2-Â°F):	0.49	0.10	0.10
RSI:		1.80	1.80
R-value:		10.20	10.20

With Sprayfoam


10
9
8
7
6
5
4
3
2
1
0
Spandrel Section R Value
0
5
10
15
20
25
30
Back Pan Insulation
7.4
8.2
8.8
9.1
3.4
4.2
4.8
5.0
Detail 22 (Air in Stud Cavity)
Detail 23 (Spray Foam in Stud Cavity)



Linear Transmittances

Ψ

Where to Find Data

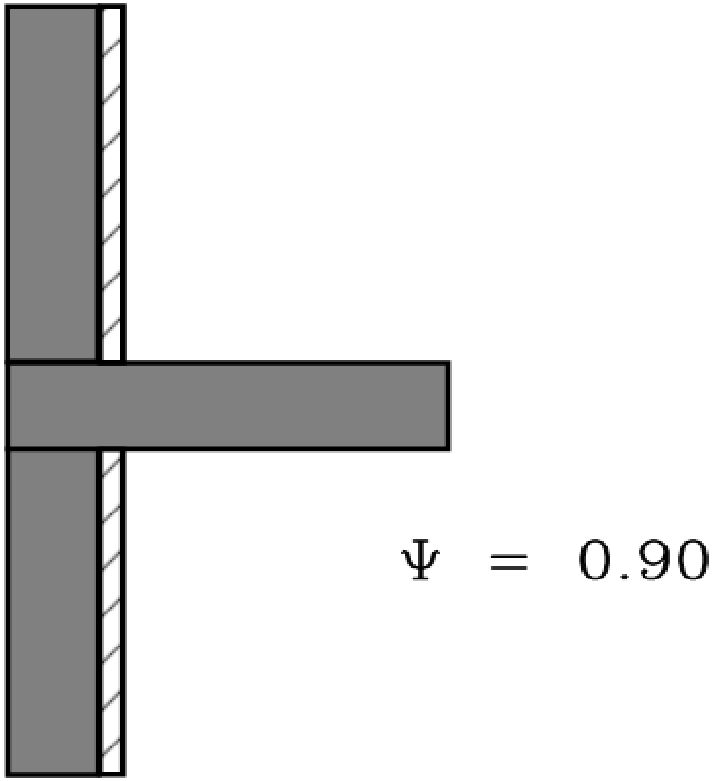
- ISO 14683
  - If nothing else available
- Manufacturers Reports

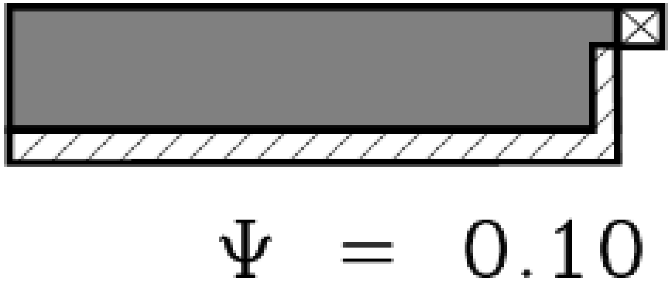
- Building Envelope Thermal Bridging Guide
  - Extensive catalogue of assemblies (300+)
  - Includes linear transmittances for a variety of constructions and configurations

MORRISON HERSHFIELD

INTERNATIONAL STANDARD

ISO 14683

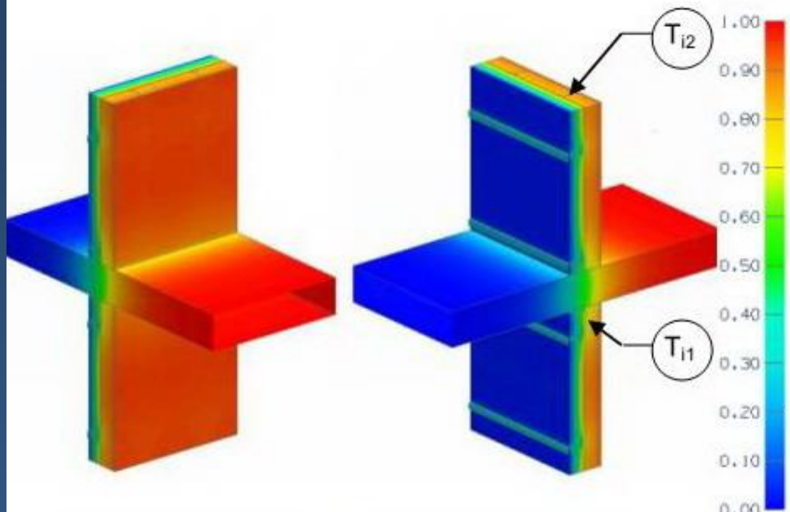




Morrison Hershfield

Detail 06

Exterior Insulated 3 5/8" x 1 5/8" Steel Stud (16" O.C.) Wall Assembly with Horizontal Z-Girts (24" O.C.) Supporting Metal Cladding – Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value without slab (Detail 11)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

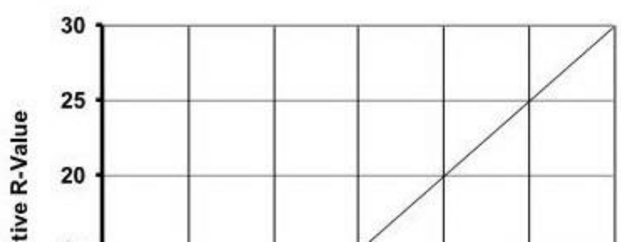
[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft²·hr·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft²·hr·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-8.2 (1.44)	R-6.9 (1.21)	0.146 (0.83)	R-4.74 (0.83)	0.211 (1.20)	0.433 (0.749)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)	R-6.45 (1.14)	0.155 (0.88)	0.445 (0.770)
R-25 (4.40)	R-28.2 (4.96)	R-14.6 (2.56)	0.069 (0.39)	R-7.61 (1.34)	0.131 (0.75)	0.418 (0.724)

Temperature Indices

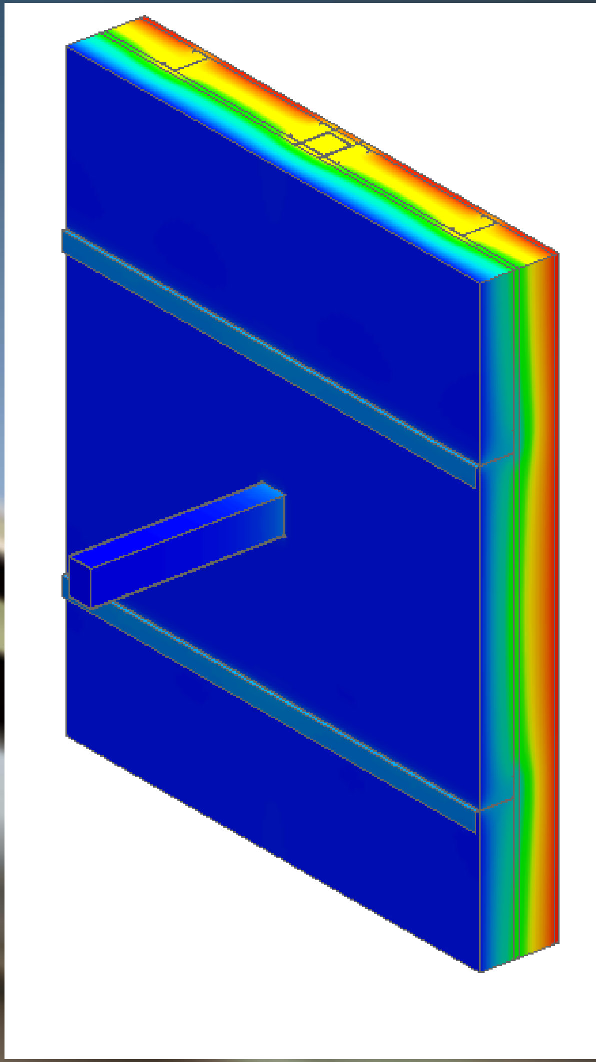
	R5	R15	R25	
T_{i1}	0.50	0.58	0.63	Min T on sheathing, at slab, between studs
T_{i2}	0.73	0.84	0.88	Max T on sheathing, at studs, between girts



LINEAR TRANSMITTANCE RANGES

Table 1.3: Performance Categories and Default Transmittances for Floor and Balcony Slabs

	Performance Category		Description and Examples	Linear Transmittance	
				Btu / hr ft F	W / m K
FLOOR AND BALCONY SLABS		Efficient	**Fully insulated with only small conductive bypasses** Examples: exterior insulated wall and floor slab.	0.12	0.2
		Improved	**Thermally broken and intermittent structural connections** Examples: structural thermal breaks, stand-off shelf angles.	0.20	0.35
		Regular	**Under-insulated and continuous structural connections** Examples: partial insulated floor (i.e. firestop), shelf angles attached directly to the floor slab.	0.29	0.5
		Poor	**Un-insulated and major conductive bypasses** Examples: un-insulated balconies and exposed floor slabs.	0.58	1.0



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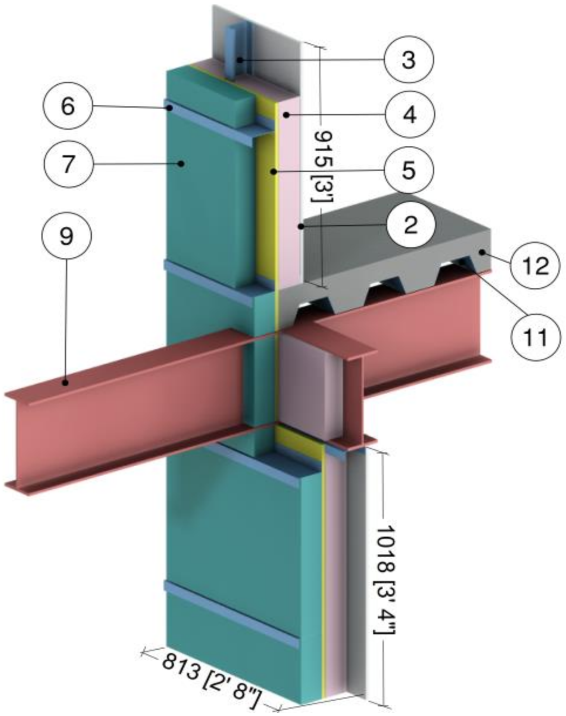

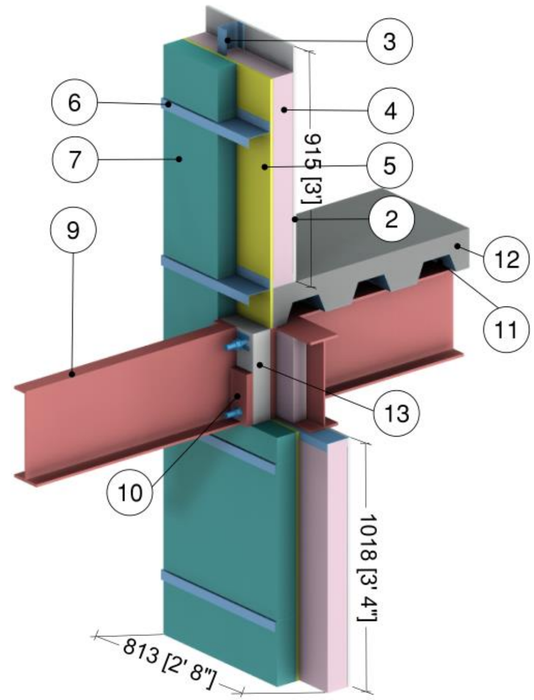

Condition	Clear Wall R-Value (W/m²K)	χ Btu/hr °F (W/°K)
Continuous Beam	R-17 (3.04)	1.73 (0.92)
With Schoeck Isokorb Type S	R-17 (3.04)	0.91 (0.48)

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Modeling Input

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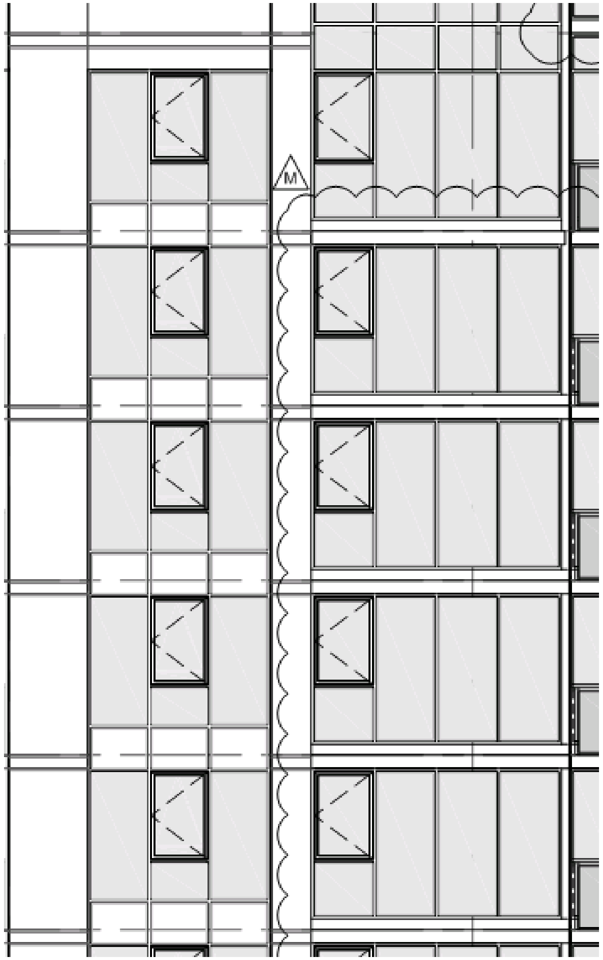
MODELING INPUTS

- Create layers of materials as appropriate to build up construction
- De-rate the insulation layers to account for thermal bridging
- Mass of assembly is maintained
- Some programs already de-rate insulation layers for steel studs, etc.
- Typically not a complete picture – don't rely on software automation – it doesn't know as much as you do! (relying on wizard not an excuse)
- Note whether your software includes outside air film in it's calculations

R-Value Resolution



- Resolution of R-Value ie: Whole building R-value, elevation R-value, wall type R-value, zone R-value
- Method can be scaled
- Depends on the purpose and accuracy of model required (professional judgment required)
- For example, heat load calcs may require more granularity if deemed appropriate (zone level)

Roles and Responsibilities

- Calculations well within expertise of energy modellers and mechanical engineers
- Selection of details will require discussion and coordination with architect and/or building envelope consultant
- Recommendations will be at the discretion of the modeler depending on his/her expertise (like any other building system)
- **Don’t be afraid to collaborate with design teams!**

Preliminary Modelling

- What do you do in early design when there is little information yet
- What are appropriate generic levels details?
- How can we input these into our models?

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Exercise 1 – Determine Heat Loss Elements (15min)

Exercise 1 – Determine Heat Loss Elements

As an energy modeler, we are brought on early in the design of this office building. The details haven't been drawn up yet and the majority of the design is preliminary. The architect has the basic look of the building through elevation and plan drawings.

The architect gives you the following:

- The building will be concrete floors with steel stud walls
- There will be a mix of steel stud assemblies and curtain wall with insulated spandrel panels as the envelope
- The cladding will be a mix of brick, stone and metal panel

Looking at A-1, A-2 and A-3 determine what the heat loss elements are. What are the clear walls? What are the linear details that can probably be expected on this building?

Exercise 2 – Preliminary Estimation (45min)

Exercise 2 – Estimation

With the basic elements determined, the architect then asks for a preliminary energy model of the building. For the envelope, the architect gives you more information:

- For the stone and metal cladding, they are going to go with a clip system for both, but don't know which yet. As a result the detailing will be the same for these walls. The brick will be held on by brick ties. These systems will be split insulated with the same level of exterior insulation and R-12 batt in the stud cavity.

- They are looking at conventional curtain wall system with 5ft high spandrels (2.5ft above and below the slab) and some amount of insulation in the backpan

Based on this new information, using A-1, A-2 and A-3, combine like assemblies and details where appropriate, then determine preliminary take-offs for the building (areas of the clear fields and lengths of linear details) for one elevation, since all elevations are the same.

- Using the Visual Summary, provide some preliminary values for the clear field assemblies.

- From there, using your judgment, select preliminary values for your linear details using the ranges in Part 1 of the Guide. What types of details should be selected in preliminary design if there are no details yet? Poor? Improved?

- Insert the values for the takeoffs and linear transmittances and assume a level of insulation for the exterior walls and insert that value. Using the heat flow %, are there recommendations you can make?

Break (15min)

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Exercise 3 – Detailed Model (45 min)

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Exercise 3 – Detailed Model

The design has progressed and now the architect has developed many of the details and has provided them in a drawings package, shown in the detail list A-4, A-5 and A-6.

- It has also been determined that the clip system will likely be the Knight Wall MFI with 3” of rigid insulation (R-15). The brick system will have the same amount of insulation.
- The backpan of the spandrels will have 3” of mineral wool (R-12.6)

Using the Building Envelope Thermal Bridging Guide Appendices, match the appropriate details to what is shown in the drawings package and determine the overall building U-Value.

Exercise 4 – Improving the Model (20min)

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Exercise 4 – Improving the Model

The architect now indicates they will be going for the BC Hydro New Construction program and as a result they want to see how their current design stacks up.

Determine the Base Building U-value and insert it into the spreadsheet

How does it compare? What recommendations can you make to improve the design? What would be the first place to suggest an improvement?

The architect indicates that, due to other design constraints, they want to be over 20% better on the envelope than the Base Building. What else can be done?

Questions?

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