Linear and Point Transmittance

Dealing with Thermal Bridges in Building Enclosures

Sept. 2011

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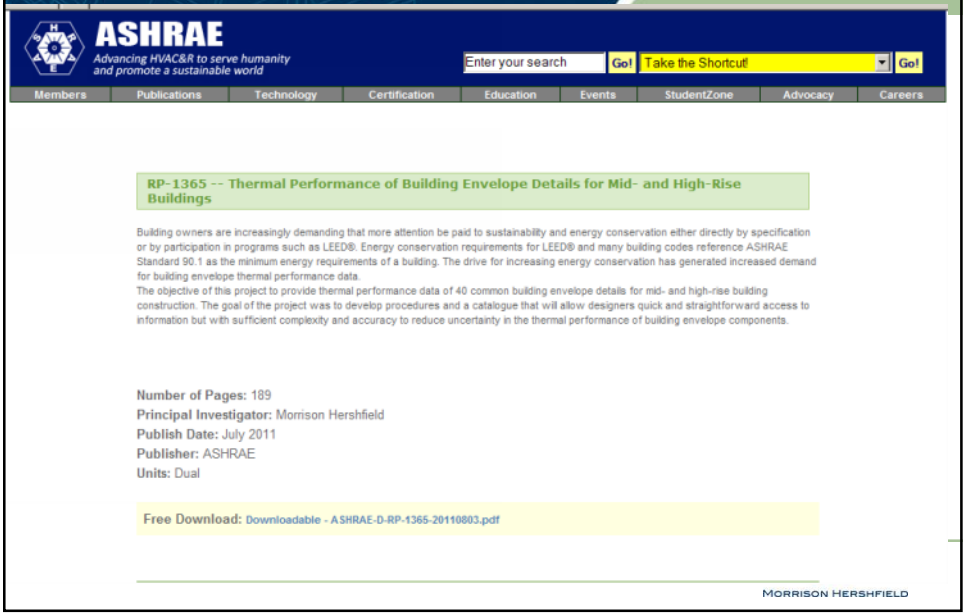
http://rp.ashrae.biz/researchproject.php?rp_id=601



ASHRAE 1365 RP

Project Scope

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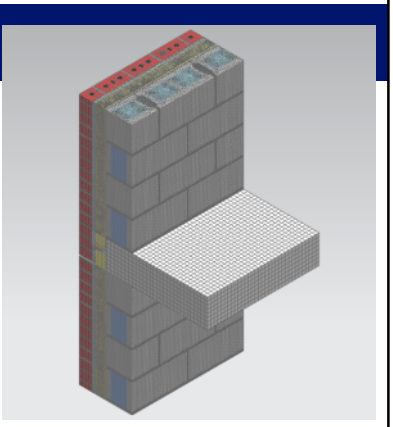
Advancing HVAC&R to serve humanity and promote a sustainable world

- To model a catalogue of details (40) to find the effects of thermal bridging
- Common details found throughout North America
- Modeled using a 3D finite element model (Seimens NX)



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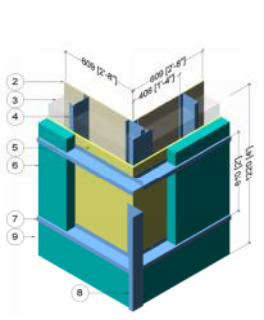
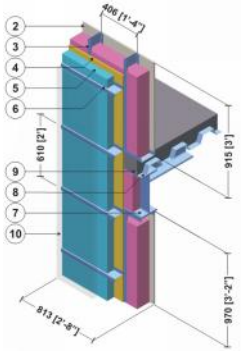
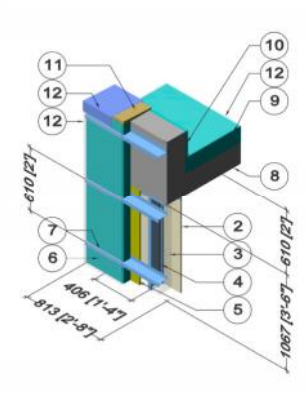
Exterior Insulated Steel Stud Walls







4

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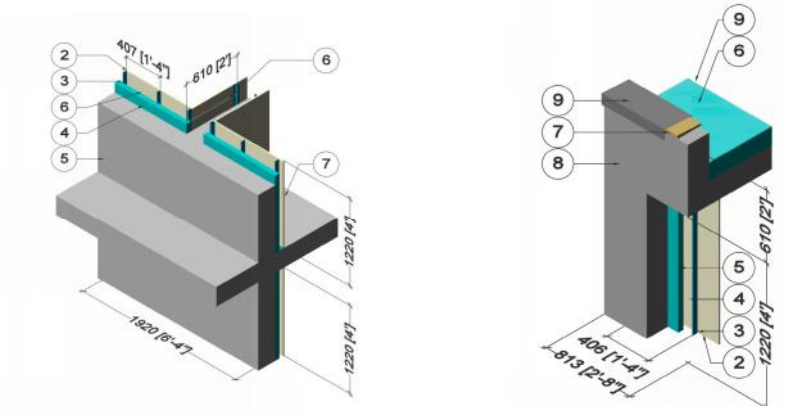
Concrete Mass Wall



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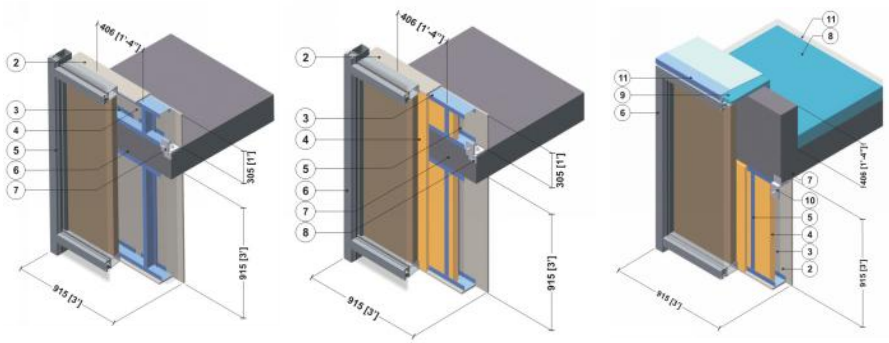
Curtain Wall



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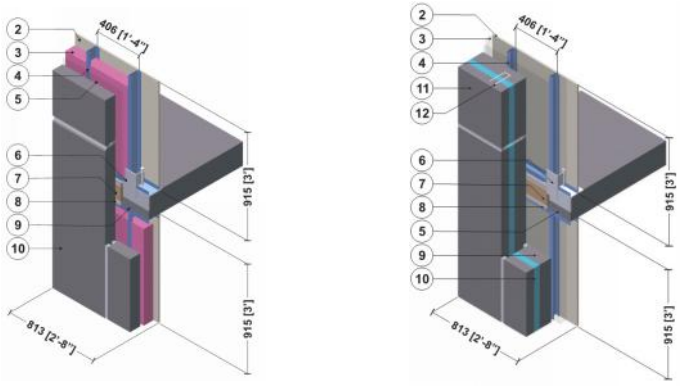
Precast and Sandwich Panel Walls



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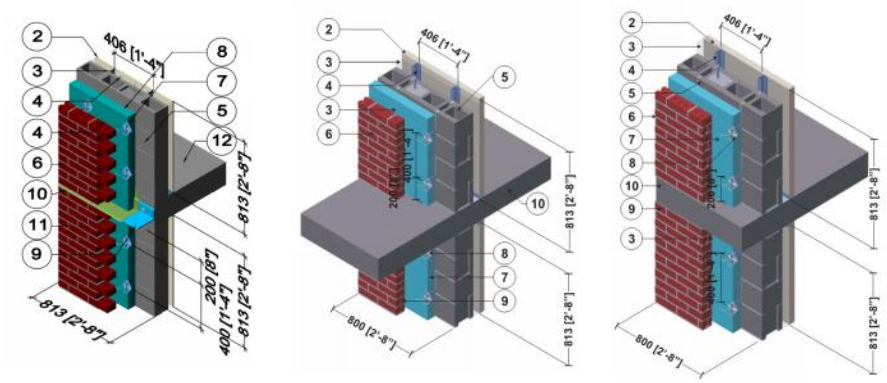
Brick Veneer



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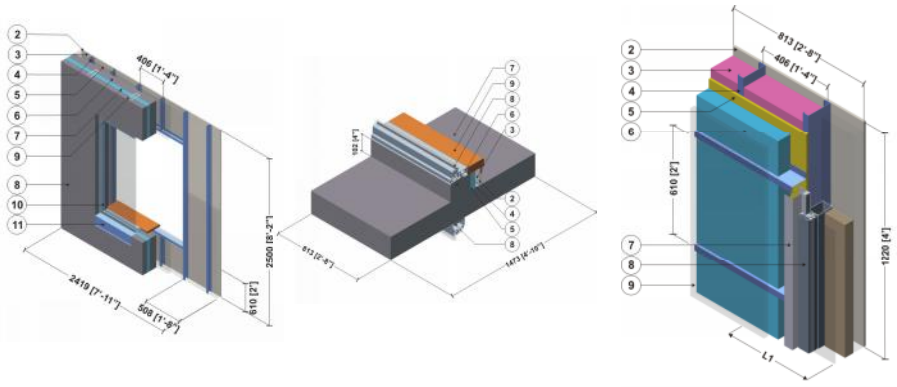
Misc. Details



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So What?

- How do we use this information in real life?
- Can we use the power of 3D modeling to help us in everyday projects?
- Can we “generalize” the information so we can use the same modeling results on multiple buildings
- Can we create a method of dealing with thermal bridges for inclusion in ASHRAE 90 .1?

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ASHRAE 90.1 Enclosure Requirements

TABLE 5.5-5 Building Envelope Requirements for Climate Zone 5 (A, B, C)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.119	R-7.6 c.i.
Metal Building	U-0.065	R-19.0	U-0.065	R-19.0	U-0.097	R-10.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.090	R-11.4 c.i.	U-0.080	R-13.3 c.i.	U-0.151[a]	R-5.7 c.i.[a]
Metal Building	U-0.113	R-13.0	U-0.057	R-13.0 + R-13.0	U-0.123	R-11.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.064	R-13.0 + R-3.8 c.i.	U-0.051	R-13.0 + R-7.5 c.i.	U-0.089	R-13.0

$$U_{value} = \frac{1}{R_{value}}$$

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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 — 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
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
	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
	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
	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
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
	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
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
	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
	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
	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
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
	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

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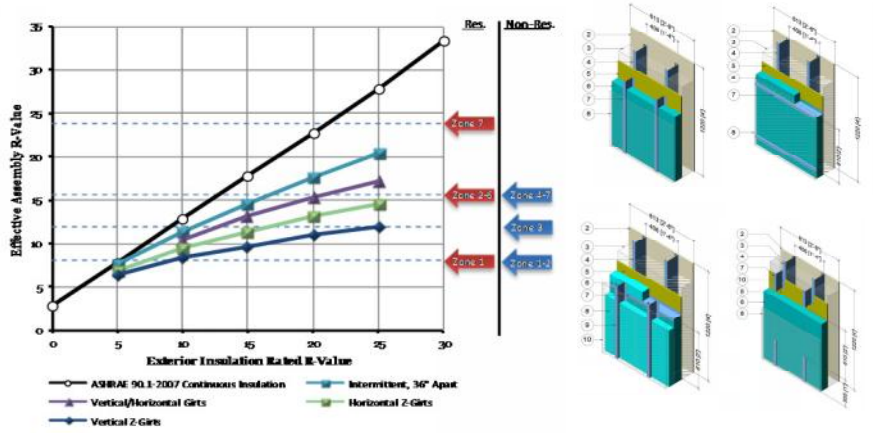
Applying Results

Comparing to ASHRAE 90.1-2007 Requirements



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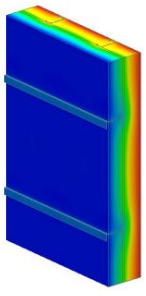
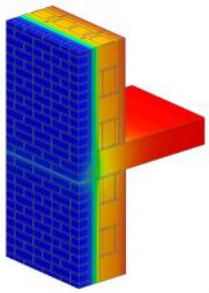
Applying Results

Types of Thermal Transmittances

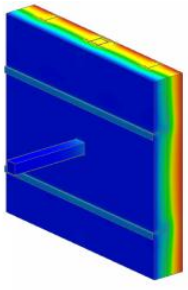


Clear Field

U_o



Linear



Point

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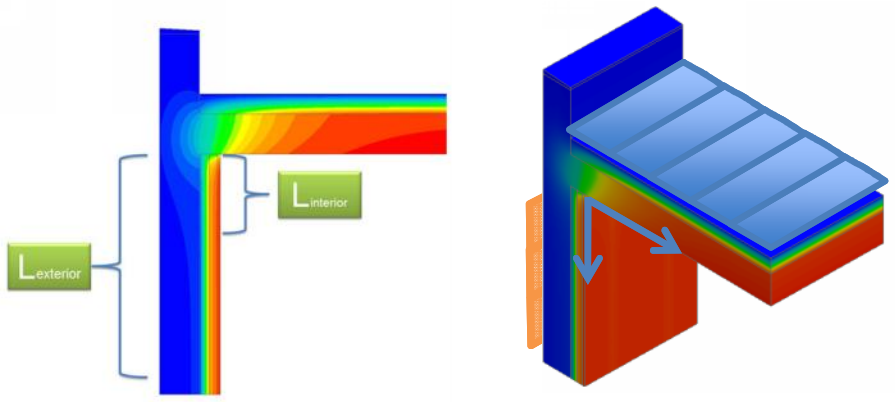
Applying Results

Dealing with other anomalies



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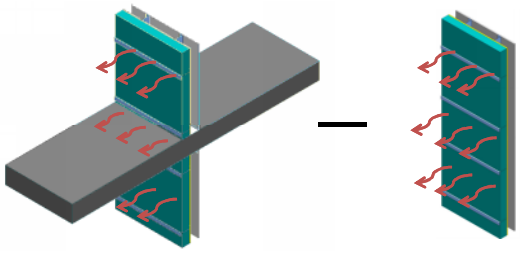
Applying Results

Linear Transmittance



Additional heat loss due to the slab

$$\Psi_{slab}$$

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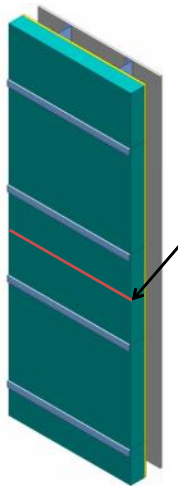
Applying Results



Ψ The linear transmittance represents the slab but with no need for the slab areas

$$U = U_o + \frac{\Psi \cdot L}{A_{Total}}$$

- To find the assembly U-value, take clear wall U-value and add the incremental heat loss from the slab

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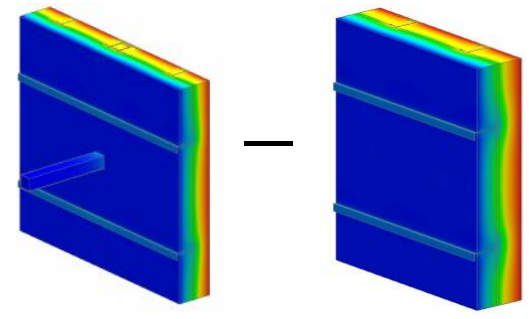

Additional heat loss due to HSS structural attachment

χ_{HSS}

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Applying Results

$$U = \frac{\Sigma\left(\Psi \cdot L\right) + \Sigma\left(\chi.n\right)}{A_{Total}} + U_o$$

- The assembly U Value is the clear field U-Value, plus all the linear and point transmittances

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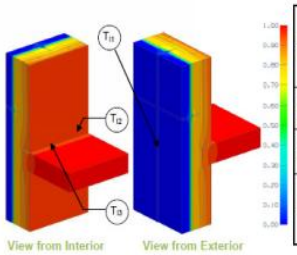
ASHRAE Data Sheets

Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings (1365-RP)

Detail 32 Precast Sandwich Panel Wall Assembly with 3 5/8" Steel Stud (16" o.c.) – Slab Intersection



Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	Nominal Thermal Resistance of Exterior Concrete, Panel Insulation, Interior Concrete, Air Gap, Gypsum
Transmittance / Resistance without Anomaly	R_o, U_o	"clear wall" R- and U-value of just concrete wall and steel stud assembly
Condensation Resistance	T_i	Temperature Index 0.00 = exterior temp 1.00 = interior temp
Linear Transmittance	Ψ_e, Ψ_s	Incremental increase in transmittance per linear length for e = panel edge s = slab

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Concrete Wall

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-13.09 (2.30)	R-12.64 (2.22)	0.079 (0.45)

Panel Edge Transmittance

R_e ft² hr °F / Btu (m² K / W)	U_e Btu/ft² hr °F (W/m² K)	Ψ_e Btu/ft hr °F (W/m K)
R-11.67(2.05)	0.086 (0.49)	0.013 (0.023)

Slab Transmittance

R_o ft² hr °F / Btu (m² K / W)	U_o Btu/ft² hr °F (W/m² K)	Ψ_s Btu/ft hr °F (W/m K)
R-8.75 (1.54)	0.114 (0.65)	0.118 (0.205)

Temperature Indices

T_{i1}	0.734	Min T on interior concrete wall, at slab and panel joint
T_{i2}	0.820	Max T on concrete wall, at slot anchor
T_{i3}	0.915	Min T in interior surface, at floor/gypsum intersection and anchor

How to Access Results

Tables of Clear Field, Linear and Point Transmittances

Detail: Wall Type, Transmittance Description	Linear Transmittance Btu/ft hr °F (W/m K)		
	R5	R15	R25
Slabs			
Detail 7: Ext Insulated Steel Stud Wall, Insulated flush slab intersection	0.061 (0.106)	0.025 (0.044)	0.019 (0.034)
Detail 16,17: Ext/Int Insulated Steel Stud Wall, Insulated flush slab and I-Beam intersection	0.177 (0.306)	0.093 (0.162)	0.067 (0.117)
Parapets			
Detail 10: Ext/Int Insulated Steel Stud Wall, Ext/Int Insulated Steel Stud parapet w/ I-Beam	0.289 (0.500)	0.201 (0.348)	0.176 (0.304)
Glazing Transitions			
Detail 7: Ext Insulated Steel Stud Wall, Window Transition	0.119 (0.206)	0.202 (0.349)	0.230 (0.399)
Misc Transmittances			
Detail 12: Ext/Int Insulated Steel Stud Wall, Steel post in stud cavity	0.034 (0.060)	0.027 (0.047)	0.023 (0.040)
Detail 13: Ext/Int Insulated Steel Stud Wall, Interior acoustic wall	0.023 (0.039)	0.010 (0.017)	0.007 (0.013)

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Detail: Wall Type, Transmittance Description	Average Linear Transmittance Btu/ft hr °F (W/m K)	
Slabs		
Detail 6: Ext Insulated Steel Stud Wall, Un-insulated extended slab intersection	0.432 (0.748)	
Detail 14: Ext/Int Insulated Brick Veneer and Steel Stud Wall, Shelf angle attached directly to slab.	0.293 (0.507)	
Detail 15: Ext/Int Insulated Brick Veneer and Steel Stud Wall, Shelf angle attached to slab /w knife edges /w insulation between angle and slab	0.188 (0.326)	
Detail 35: Ext Insulated Brick Veneer and Concrete Block wall, Shelf angle attached directly to slab	0.260 (0.450)	
Detail 36: Ext Insulated Brick Veneer and Concrete Block wall, Shelf angle attached to slab /w knife edges /w insulation between angle and slab	0.177 (0.306)	
Detail 38: Ext Insulated Brick Veneer and Concrete Block wall, Un-insulated extended slab intersection	0.340 (0.588)	
Detail 39: Ext Insulated Brick Veneer and Concrete Block wall, Balcony slab attached to floor slab /w knife edges /w insulation between angle and slab		
Detail 40: Ext Insulated Brick Veneer and Concrete Block wall, Un-insulated flush slab intersection	0.360 (0.623)	

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Detail: Wall Type, Transmittance Description	Average Linear Transmittance Btu/ft hr °F (W/m K)	
Parapets		
Detail 9: Ext Steel Stud Wall, Insulated Concrete Parapet	0.279 (0.483)	
Detail 25: Spandrel Panel, Insulated Concrete Parapet	0.389 (0.673)	
Detail 37: Ext Insulated Brick Veneer and Concrete Block wall, un-insulated parapet wall at roof	0.225 (0.390)	
Glazing Transitions		
Detail 24: Ext/Int Insulated Steel Stud Wall, Curtain Wall Transition	0.088 (0.152)	
Misc Transmittances		
Detail 8: Ext Insulated Steel Stud Wall, Stud Corner v1	0.091 (0.158)	
Detail 8a: Ext Insulated Steel Stud Wall, Stud Corner v2	0.087 (0.150)	

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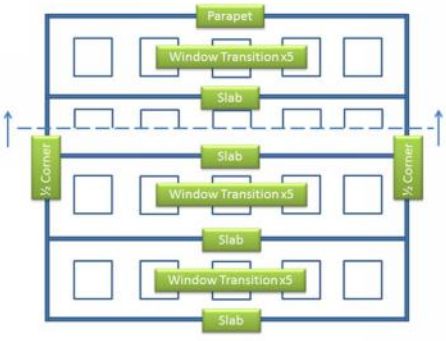
Applying Results

Example

Wall	Height	60 ft (18.3 m)
	Width	120 ft (36.6 m)
Total wall area		7200 sqft (669 m²)
# of floor s		12
# of windows		5 per floor, 60 in total
Window	Height	5 ft (1.5m)
	Width	4 ft (1.2m)
Total opaque wall area		6000
Total window area		1200 sqft (111.5 m²)
Window to wall ratio		20% glazing



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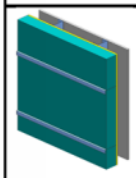
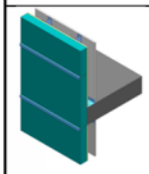
Exterior Insulated Steel Stud Assembly		Poured In Place Concrete Assembly	
	U_o 0.106 Btu/hr·ft²·°F (0.60 W/m²K) The clear field assembly is an exterior insulated steel stud (16" o.c.) assembly with horizontal z-girt cladding attachments (24" o.c.) and R-10 nominal insulation.		U_o 0.080 Btu/hr·ft²·°F (0.46 W/m²K) The clear field assembly is a poured in place concrete wall with an R-10 nominal insulation outboard of a stud cavity (16" o.c.)
	Ψ_{slab} 0.043 Btu/hr·ft·°F (0.075 W/m K) The floor slab is flush with the interior stud wall, with exterior insulation outboard of the slab face		Ψ_{slab} 0.465 Btu/hr·ft·°F (0.805 W/m K) The slab is an extended balcony slab with a concrete to concrete intersection

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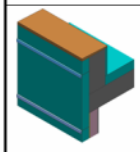
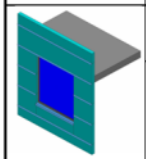
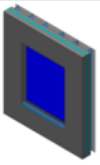
	Ψ_{corner} 0.091 Btu/hr·ft·°F (0.158 W/m K) The corner joint is a typical parallel stud arrangement with butted insulation	-	Ψ_{corner} - The corners have continuous insulation and can be considered negligible
	$\Psi_{parapet}$ 0.284 Btu/hr·ft·°F (0.491 W/m K) The parapet is a simple concrete curb with an R-5 insulation		$\Psi_{parapet}$ 0.449 Btu/hr·ft·°F (0.777 W/m K) The parapet is an un-insulated curb
	$\Psi_{window\ transition}$ 0.053 Btu/hr·ft·°F (0.093 W/m K) The window transition is a typical steel framing and full flashing at the jambs, head and sill, broken at the window thermal break		$\Psi_{window\ transition}$ 0.028 Btu/hr·ft·°F (0.048 W/m K) The window transition is a typical steel framing with flashing only at the sill, broken at the window thermal break

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Applying Results

	Exterior Insulated Steel Stud Assembly		Poured In Place Concrete Assembly	
Transmittance Type	**Q** Btu/hr°F (W/K)	**%**	**Q** Btu/hr°F (W/K)	**%**
Clear Field	638.6 (337.1)	**84.6**	484.2 (255.6)	**55.3**
Floor Slab	31.2 (16.5)	**4.1**	334.9 (176.8)	**38.3**
Corner Joint	11.0 (5.8)	**1.5**	-	**-**
Parapet	17.0 (9.0)	**2.3**	26.9 (14.2)	**3.1**
Window Transition	56.8 (30.0)	**7.5**	29.5 (15.6)	**3.4**
Total	**754.5 (398.3)**	**100**	**875.5 (462.2)**	**100**

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Assembly Type	Exterior Insulated Steel Stud	Poured In Place Concrete
Overall U Btu/hr·ft²·°F (W/m²K)	0.125 (0.71)	0.145 (0.82)
Overall R hr·ft²·°F/Btu (m²K/W)	R-8.0 (1.41)	R-6.9 (1.22)

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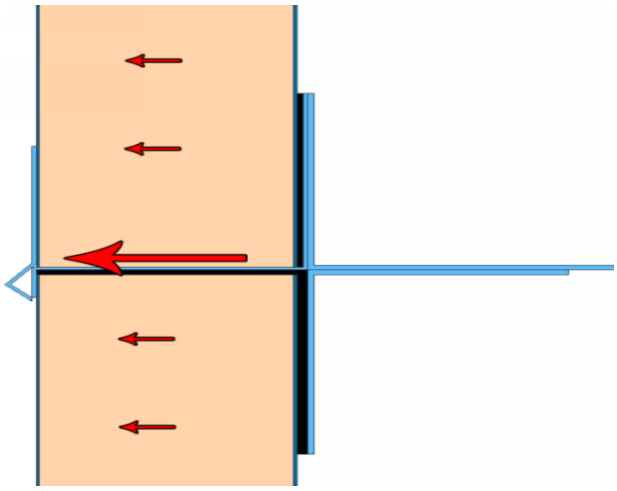
Insulated Metal Panel Building



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Insulated Metal Panel Building

	Vertical Panels		Horizontal Panels		R-20 Exterior Insulated Steel Stud assembly		Poured in place concrete with R-10 insulation assembly	
Transmittance Type	**Q Btu/hr°F (W/K)**	**%**	**Q Btu/hr°F (W/K)**	**%**	**Q Btu/hr°F (W/K)**	**%**	**Q Btu/hr°F (W/K)**	**%**
Clear Field	284.7 (150.3)	**37.4**	308.9 (163.1)	**48.2**	457.6 (241.6)	**80.0**	443.5 (234.1)	**53.1**
Gasket Joint	-	**-**	18.9 (10.0)	**3.0**	-	**-**	-	**-**
Floor Slab	134.2 (70.8)	**17.6**	11.3 (6.0)	**1.8**	16.2 (8.6)	**2.8**	334.7 (176.7)	**40.1**
Corner Joint	10.8 (5.7)	**1.4**	4.4 (2.3)	**0.7**	11.1 (5.84)	**1.9**	-	**-**
Parapet	16.9 (9.0)	**2.2**	14.2 (7.5)	**2.2**	16.0 (8.4)	**2.8**	26.9 (14.2)	**3.2**
Window Transition	314.9 (166.2)	**41.4**	283.3 (149.6)	**44.2**	71.1 (37.5)	**12.4**	29.9 (15.8)	**3.6**
Total	**761.6 (402.0)**	**100**	**641.1 (338.4)**	**100**	**571.6 (301.7)**	**100**	**835.1 (440.79)**	**100**

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Balcony slab w Isokorb Ψ = **0.20** W/m-K Standard balcony slab Ψ = **0.51** W/m-K

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Applying Results

Performance Approach: limit overall U-value for all thermal bridging. Provide information in the form of clear field transmittance (U_o), linear transmittance (Ψ) and point transmittance (χ) and guidance to users to thoroughly consider the effects of thermal bridging.

Prescriptive Approach: limit the clear field assembly U-value (U_0) and transmittances for details (χ- and Ψ-factors) for different types of construction. For example as proposed by Janssens et al (2007).

Solution Approach: provide acceptable solutions, including details and assemblies, which considers all thermal bridging for typical construction

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