Thermal bridges, shading and other thermal complications

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R2
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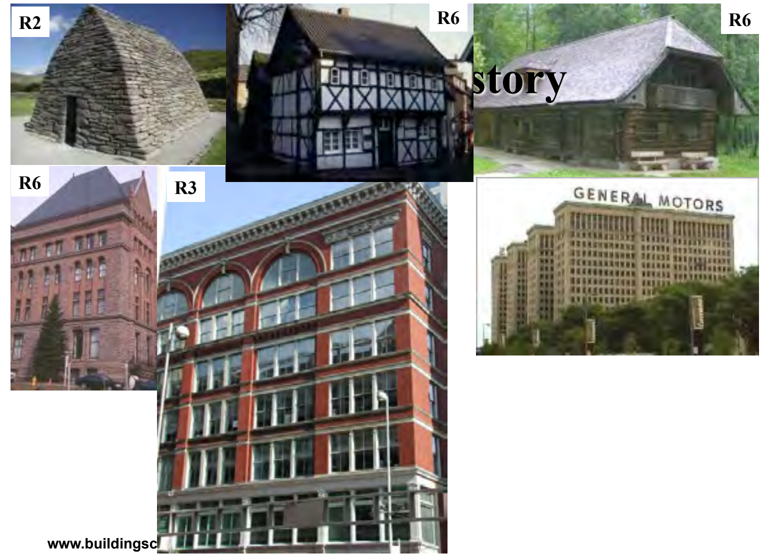
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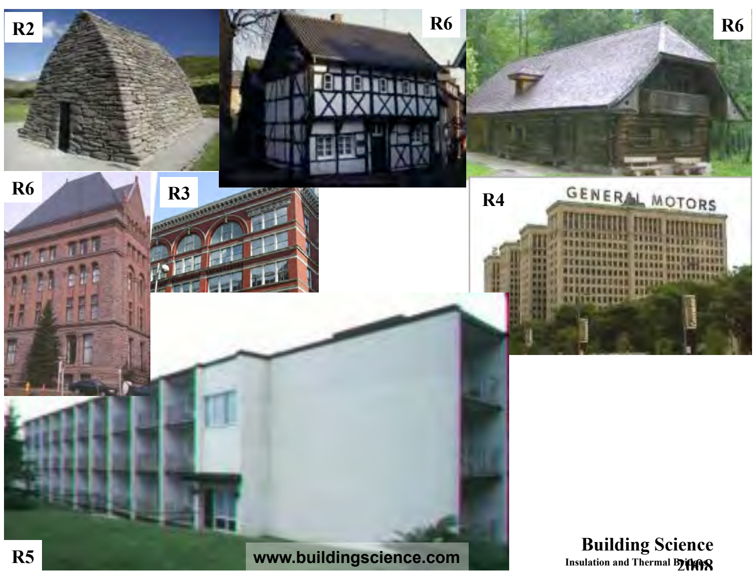
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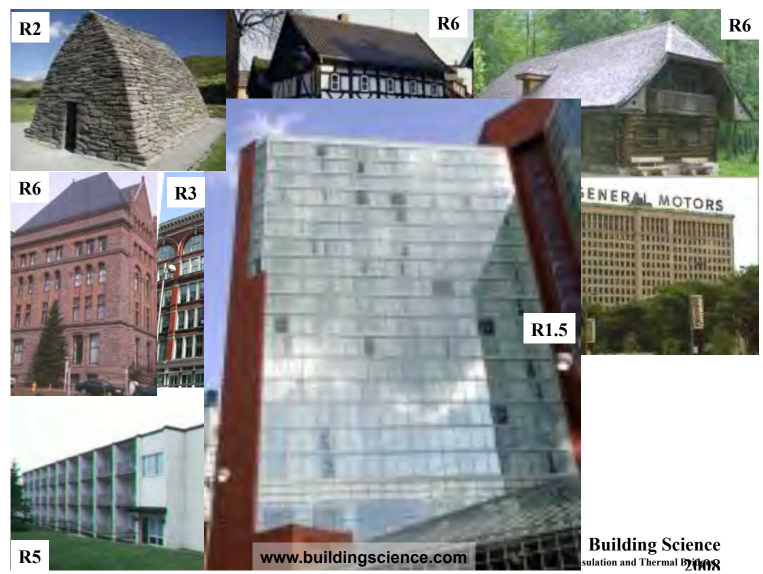
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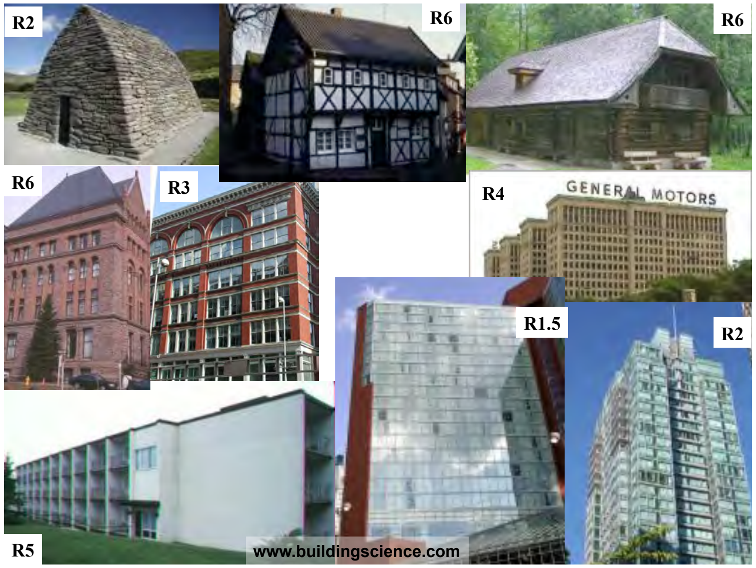


Presentation

- Heat Flow
  - Basics: One D
  - Two D
  - Three D
- Walls + Windows
- Practical Detailing Applications
- Window Solar Gain Control

Heat Flow Basics

Why control heat flow?

- Occupant Comfort
- Energy Savings
- Control surface and interstitial condensation
- Save duct and heating plant costs (Capital)
- Meet Codes and specs

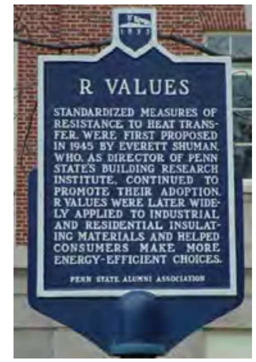
Heat & Temperature

- Heat
  - A form of energy (like Light & Sound)
- Temperature
  - A measure of the amount of thermal energy
- Heat Flow
  - From more to less energy

What about the old metric?

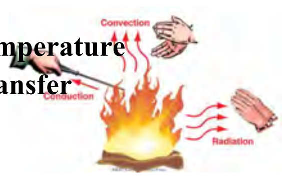
R-Value

- Property of a material
- Measurement of resistance to heat flow
- Proposed in 1945 by Everett Schuman, Penn State's Housing Research Institute



Benefits of R-Value

- Widely Accepted
  - FTC Regulation
- Simple to Measure
  - Commercially available test machines
- Easy to Communicate
  - ONE Number at standard temperature
  - Lumps all 3 modes of heat transfer into an *effective* conductivity
    - Conduction
    - Convection
    - Radiation



Heat Flow

- Always moves from more to less
- Rate of flow depends on
  - Temperature Difference
  - Material Properties
  - Type & Mode of Heat Flow

Categories of Heat Flow

- Mode of Heat Flow
  - Conduction
  - Convection
  - Radiation
- Type of Heat flow
  - steady-state or dynamic
  - one-, two- or three-dimensional
  - We usually use 1-D static!

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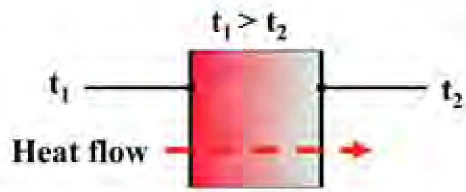
Conduction

- Heat Flow by direct contact
- Vibrating molecules
- Most important for solids



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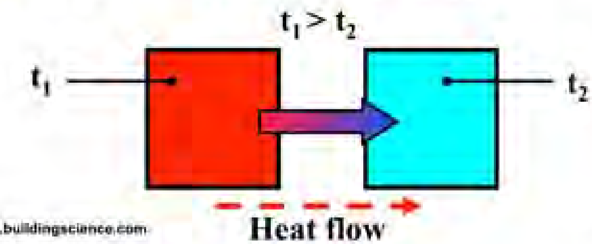
Convection

- Heat Flow by bulk movement of molecules
- Most important for liquids and gases
- E.g. air flow (forced air furnace)



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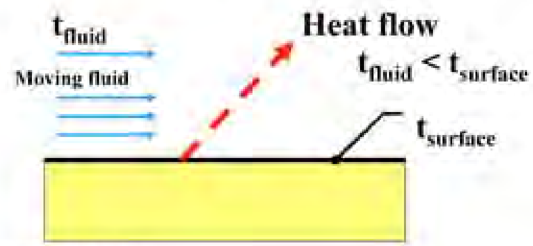
Convection

- Also heat flow from solid to liquid or gas
- Critical for surface heat transfer (e.g convectors, hot + cold surfaces)



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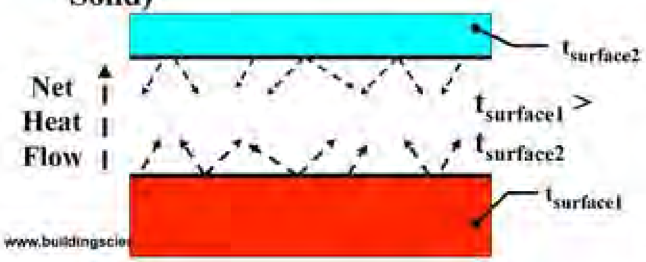
Radiation

- Heat flow by electromagnetic waves
- Heat radiates from *all* materials, e.g. campfire
- Passes through gases and vacuum (NOT Solid)



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Radiation

- Important for surfaces, air spaces, voids
- Foil faced insulation, radiant barriers only work when facing an air space
- Radiation within *pores* important for high void insulation (e.g., glass batt)
- e.g. Thermos bottle
- Critical for low-E windows

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Calculating Heat Flow

- Conduction
  - $q = k/l\ A(T_1-T_2) = C\ A\ \Delta T = A\ \Delta T\ /R$
  - k = conductivity f(T, MC, density, time?)
  - C = k/l conductance
  - R = resistance = 1/C
- Convection
  - E.g. $q = 1.42\ (\Delta T/L)^{0.25} A(\Delta T)$
  - Typical C_{equiv}=2 to 20 W m²K
- Radiation
  - E.g. $q = F_E A_1 \sigma(T_1^4 - T_2^4)$

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Calculating Heat Flow

$Q = CA(\Delta T)$

$C = k/l \quad R = 1 / C$

- Where
  - Q = heat flow rate (Btu/hr, W = J/s)
  - A = area heat is flowing through (ft², m²)
  - ΔT = temperature difference (°F, °C)
  - C = conductance of the layer (W/m²K)
  - U = conductance of an assembly (Btu/hr/ft²/°F)
  - k = thermal conductivity (Btu/ft/F, W/mk)
  - l = length of flow path (ft, m)

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Example

0.144 Btu·in / (hr·ft²·°F) = W / m·K
6.944 W/mk = Btu·in / (hr·ft²·°F)

- **Insulation**
  - **k= 0.20 Btu·in / (hr·ft²·°F) (= 0.029 W/mK)**
  - **R5 /inch (= 1 / 0.20)**
- **3 inch thick layer**
- **T_{in}= 70 °F**
- **T_{out}= 20 °F**
- **Q= k/L (T_{in}-T_{out}) = 0.20/3 (70 - 20)= 0.0667 * 50 = 3.33 Btu/hr/sf**

Q= ΔT/R = 50 / 15 = 3.33

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Measuring Thermal Conductivity

- **A material property**
- **Measure heat flow through a unit thickness and unit area of material under a unit temperature difference**
- **Heat flow Btu/h, J/s**
- **Area sq ft, sq m**
- **Thickness ft, m**

ASTM C518
ASTM C166

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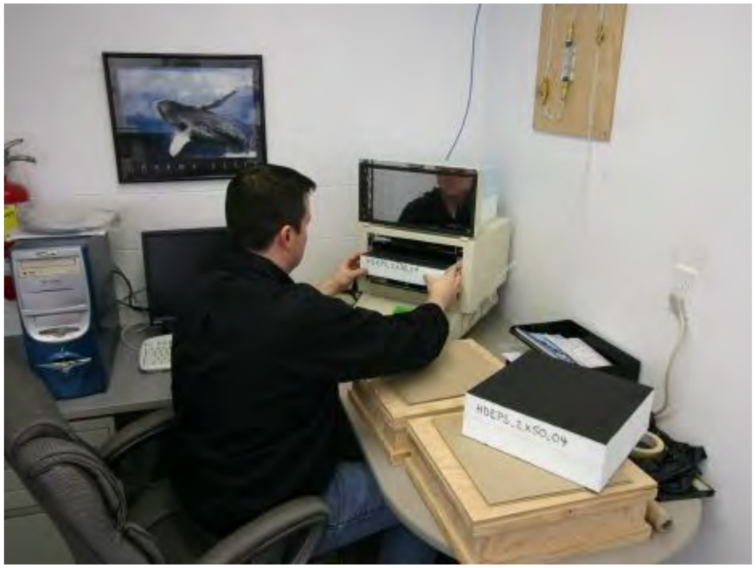

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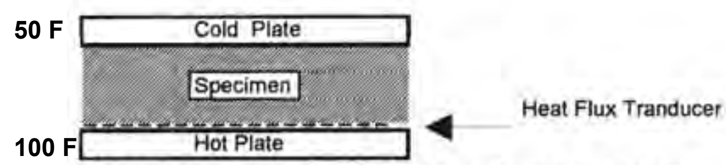

FIG. 1 Apparatus with One Heat Flux Transducer and One Specimen

Thermal Performance Metrics

- Conduction Only:
  - Thermal Conductivity k
  - Conductance C = k / thickness
  - Resistance = thickness / conductivity
- "Effective" conductivity includes other modes
  - ASTM "R-value" includes all three modes
  - ASTM picks "standard" conditions

Effective Conductance

- A layer property
- Expresses how easily heat can flow through a layer of the material

C = k/*l* = 1/R

Conductance = Conductivity / Thickness = 1 / Resistance

- R-Value is an expression of how well a *layer* of the material resists heat flow
  - = 1 / C

Apparent Conductance

- **Measurements are actually a result of conductivity, radiation, convection**
- **Typical batt is**
  - **35-45% radiation**
  - **40-60% conduction**
  - **0-20% convection**
- **Depending on orientation, temperature, etc**

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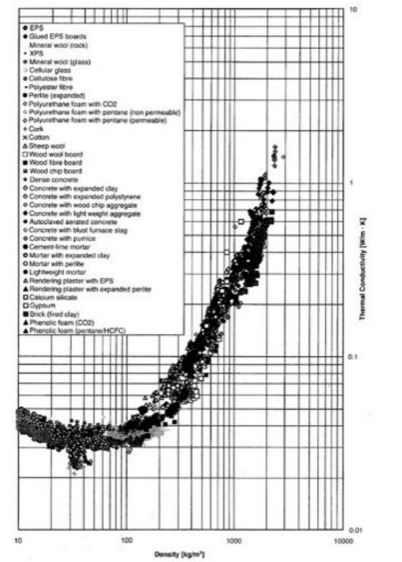
At a single mean temperature we can compare materials



Density matters

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Thermal Insulation

Insulation	R-value/inch	k (W/mK)
Empty airspace 0.75"-1.5" (20-40 mm)	R2.0 - 2.75	0.36 –0.50 W/m²K
Empty airspace 3.5"-5.5" (90-140 mm)	R2.75	0.50 W/m²K
Batt (mineral fiber)	3.5-3.8	0.034 - 0.042
Extruded polystyrene (XPS)	5.0	0.029
Polyisocyanurate (PIC)	6.0-6.5	0.022 - 0.024
Expanded polystyrene (EPS)	3.6-4.2	0.034 - 0.040
Semi-rigid mineral fiber (MFI)	3.6-4.2	0.034 - 0.040
Spray fiberglass	3.7-4.0	0.034 - 0.038
Closed-cell spray foam (2 pcf) ccSPF	5.8-6.6	0.022 - 0.025
Open-cell spray foam (0.5 pcf) ocSPF	3.6	0.040
Aerogel	8-12	0.012-0.018
Vacuum Insulated Panels (VIP)	20-35	0.004-0.008

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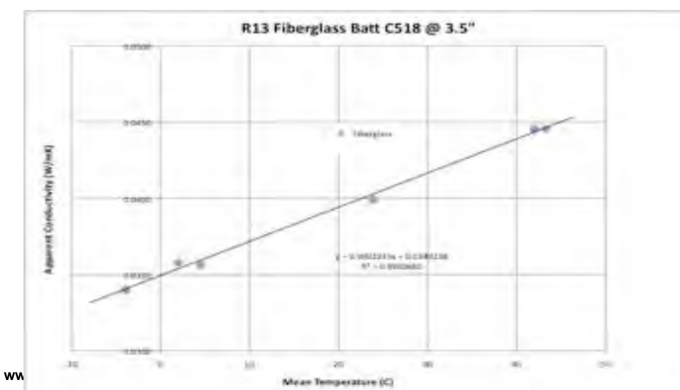
Design vs Actual

- **"Safe" k or "Actual" k**



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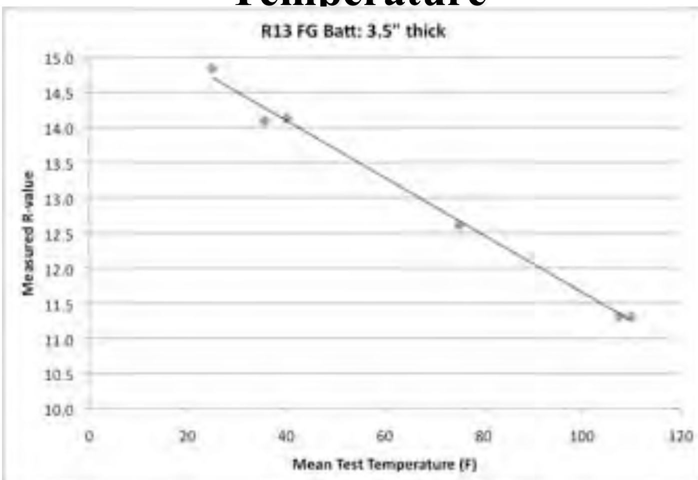
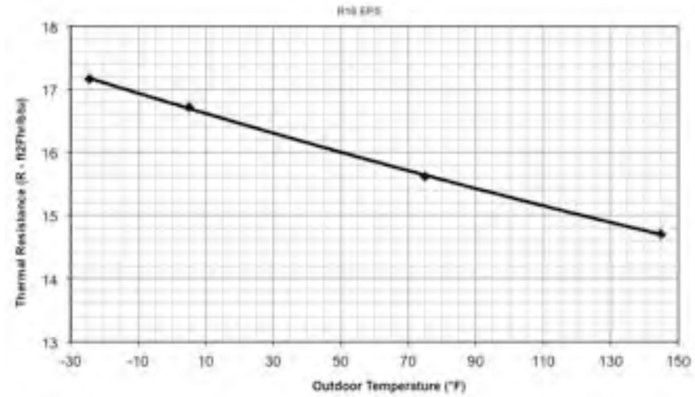
Temperature



R16 High Density EPS



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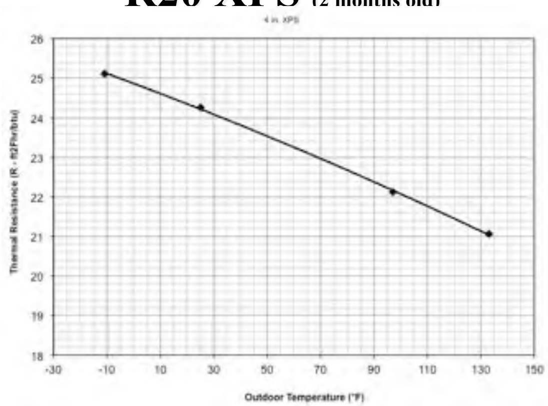
R20 XPS (2 months old)



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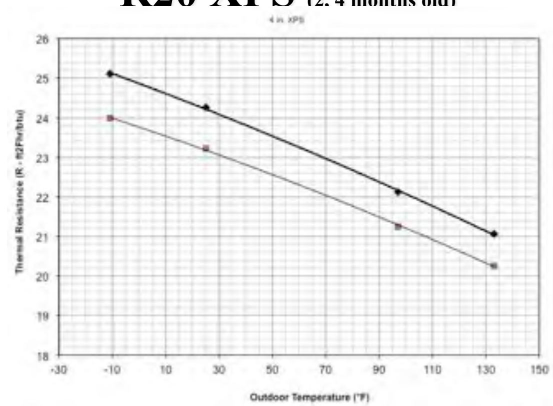
R20 XPS (2, 4 months old)



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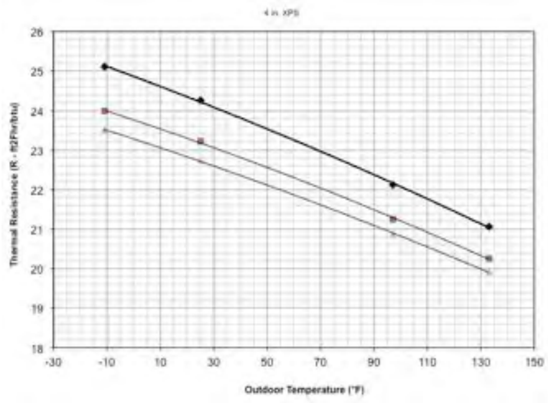
R20 XPS (2, 4, 6 months old)



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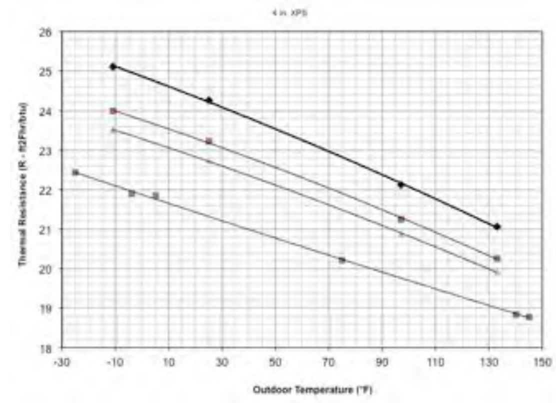
R20 XPS (2, 4, 6, 44 months old)



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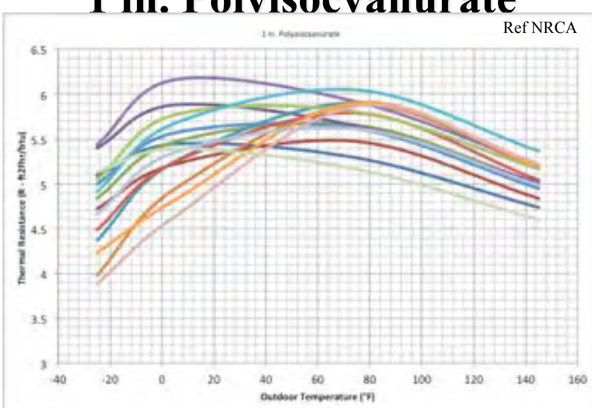
1 in. Polyisocyanurate



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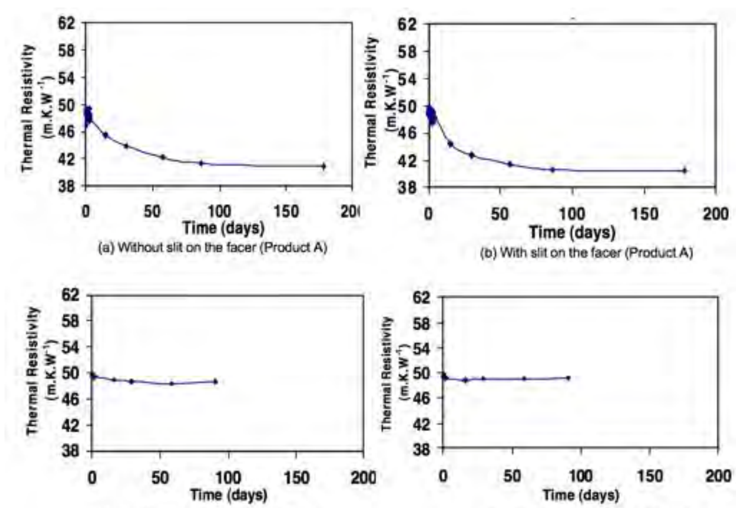

(a) Without slit on the facer (Product A)
(b) With slit on the facer (Product A)
(c) Without slit on the facer (Product B)
(d) With slit on the facer (Product B)

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Multi-layer Assemblies

- Building enclosures are typically assemblies of several layers of different materials
- R-value of each layer

$$R_1 = l_1/k_1 = 1/C_1$$

- The overall resistance must be calculated

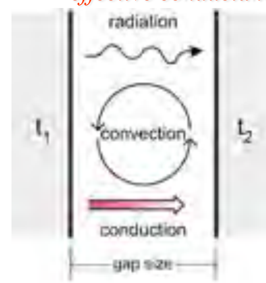
$$R_{tot} = R_1 + R_2 + R_3 \ldots$$

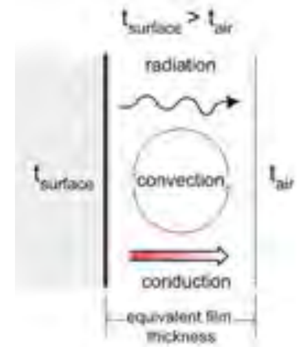
- The conductance of the assembly is then

$$U = 1/R_{tot}$$

Air Spaces & Surface Films

- All 3 modes of heat transfer play a large role
- The effects are lumped into a coefficient, h_o which can be used in the conduction equation as an *effective conductance*





Air Spaces

- Airspaces are important in windows and old buildings
- Heat flow depends on heat flow *direction* and surface *emissivity*

Situation (poorly vented or sealed)	R/ RSI Value	Conductance
Heat Flow Down (20-100 mm)	1.0 / 0.18	5.5
Heat Flow Across (20-100 mm)	0.96 / 0.17	5.9
Heat Flow Up (20-100 mm)	0.85 / 0.15	6.5
Reflective Airspace (Fe=0.05)	3.46 / 0.61	1.6

Surface Films

- "Surface film" is a fictitious layer with a thermal property that represents resistance to heat flow from the air to the surface
- Surface films are important to define surface temperature at poorly insulated components
  - E.g. thermal bridges, windows, old building walls
- Convection PLUS radiation
  - Both convection and radiation coefficient vary

Surface Films

Surface Position	Flow Direction	Resistance	Conductance
Still Air (e.g. indoors)		**R / RSI**	**[W/m²K]**
Horizontal (i.e. ceilings & floors)	**Upward**	**0.61 / 0.11**	**9.3**
	Downward	**0.93 / 0.16**	**6.1**
Vertical (i.e. walls)	**Horizontal**	**0.68 / 0.12**	**8.3**
Moving Air (e.g. outdoors)			
Stormy 6.7m/s (winter)	**Any**	**0.17 / 0.03**	**34**
Breeze 3.4m/s (summer)	**Any**	**0.25 / 0.04**	**23**
Average Conditions	**Any**	**0.33 / 0.06**	**17**

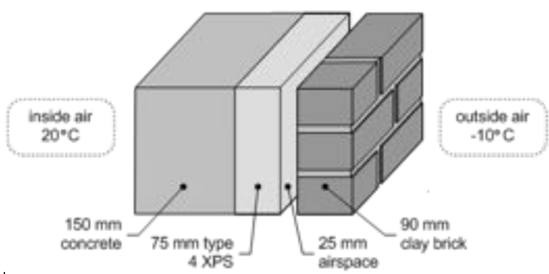
Look to *ASHRAE Handbook* or *Bldg Sci for Bldg Enclosures* for more detailed data.

But there are Complications

- **Add up the R-values of the layers to get the total R-value of the assembly**
- **BUT the actual thermal resistance of an assembly is affected by**
  - **Thermal Bridges**
  - **Thermal Mass**
  - **Air Leakage**

Calculating Heat Flow through an Assembly

- **To calculate assembly, add layers: materials, air gaps and surface films**



How much Insulation

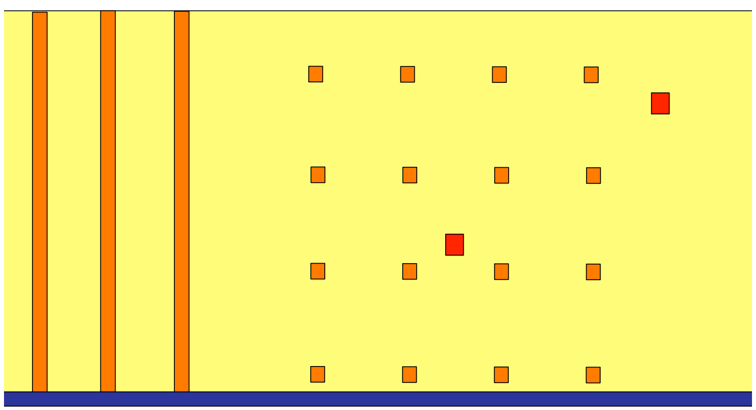
- **Heat Flow = $\frac{\text{Area} * (T_{inside} - T_{outside})}{\text{R-value}}$**
- **Double R-value, halve heat flow. Always.**
- **Optimum depends on**
  - **Cost of energy over life of building**
  - **Cost of adding more insulation**
  - **Savings in mechanical equipment, controls**

Thermal Bridges

What is a thermal bridge?

- A local area with significantly higher heat transmission (lower heat flow resistance) than
  - intended for the assembly, or
  - than the majority of the area

Types of Thermal Bridge



Types of Thermal Bridges

- Occurrence
  - A) Repeating
    - Non-interacting, but numerous
  - B) Unique/Special Case
    - non-interacting, but few
- Geometry
  - 1) Linear
  - 2) Point
  - 3) complex
- Can be A1 or B2 or B3, etc

Calculating Impact

- Simple area-weighted average for materials without very dissimilar properties
- Often computer calculations needed
  - 2D (linear)
  - 3D (point, complex)
- Results presented as either
  - Additional heat flow/unit
  - Total heat flow of specific area around TB

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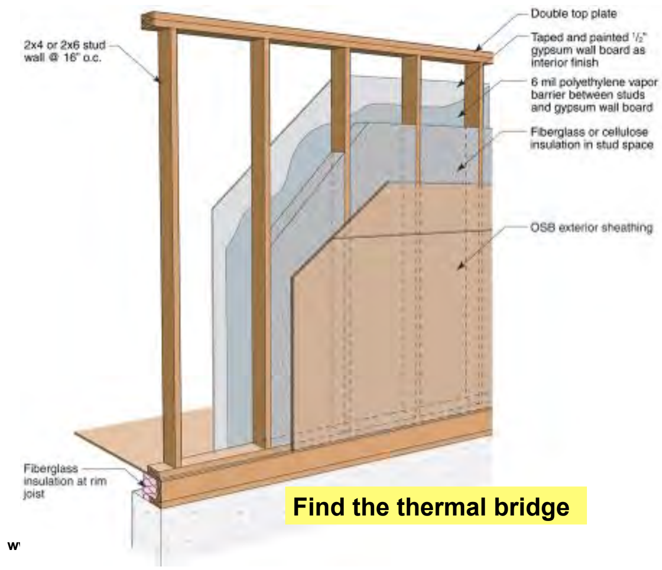

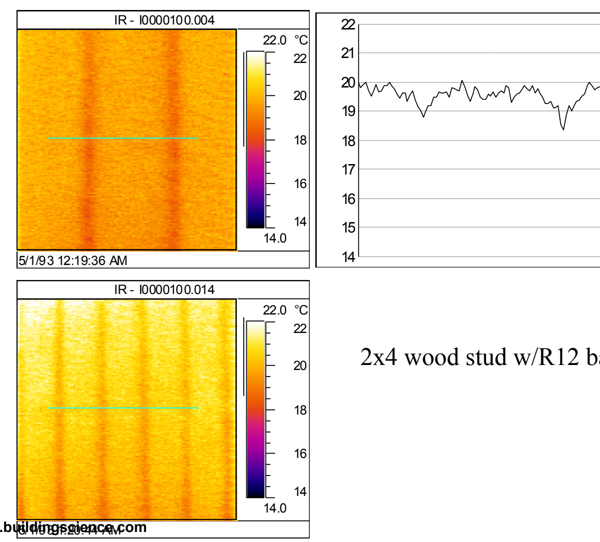

2x4 wood stud w/R12 batt

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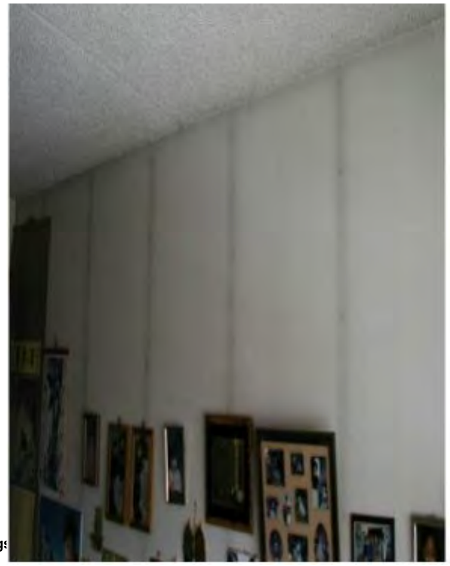

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Two-dimensional heat flow

- **Works for wood studs**

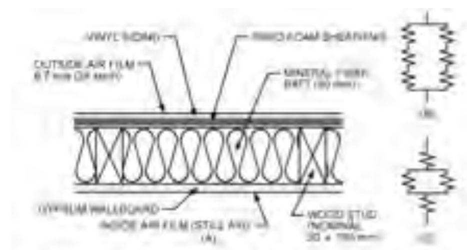

Fig. 3 (A) Wall Assembly for Example 3, with Equivalent Electrical Circuits: (B) Parallel Path and (C) Isothermal Planes

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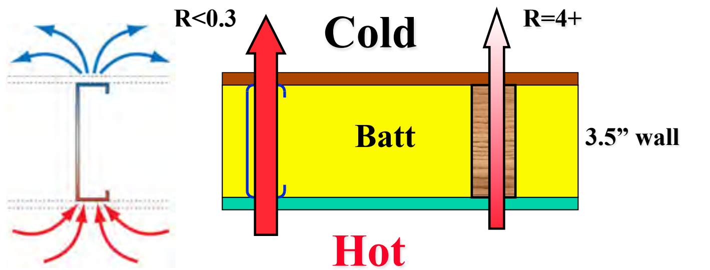
Thermal Bridging

- Steel is 400 times more conductive than wood
- Steel studs are about 40 times thinner



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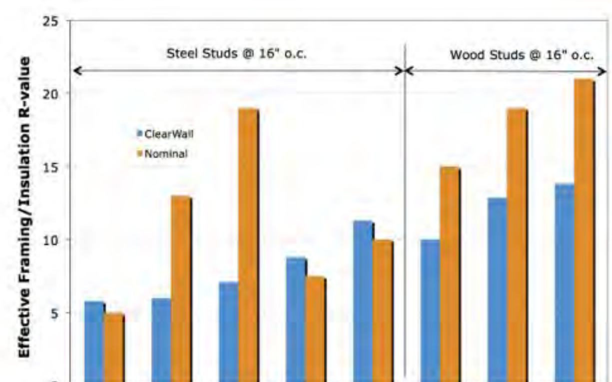
Assumes no floor slabs, no double studs etc.

Best-case R-values for stud walls

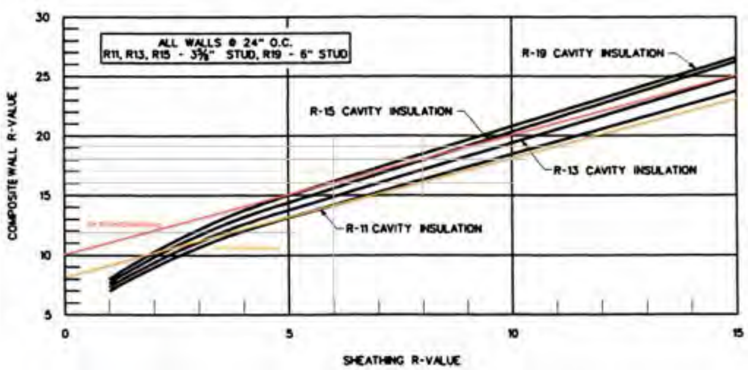


	R5ci 3.5in	R-13 3.5in	R-19 6in	R7.5ci 6in	R10ci 6in	R-15 3.5in	R-19 6in	R-21 6in
ClearWall	5.8	6.0	7.1	8.8	11.3	10.0	12.9	13.8
Nominal	5	13	19	7.5	10	15	19	21

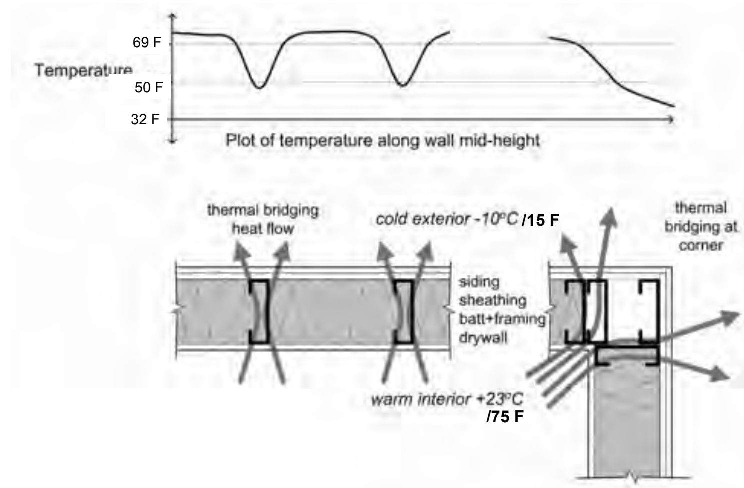
Source: ASHRAE 90.1-2007, Table A9.28. ci denotes a layer of continous insulation with no framing penetrations

AISI

- 24” o.c., include air films + drywall + sheathing + airspace behind cladding

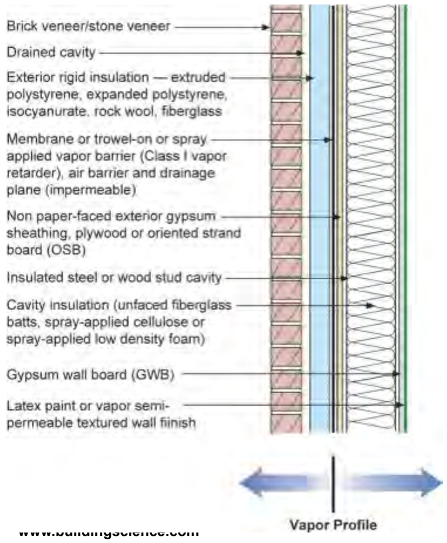


Cold surfaces where R<5



Solutions?

- A continuous layer of insulation not interupted by structure
- E.g. insulated sheathing on the exterior



Any R-value, e.g.
6" wood stud+
2" PIC= R30
3"XPS= R32
4"SPF= R40

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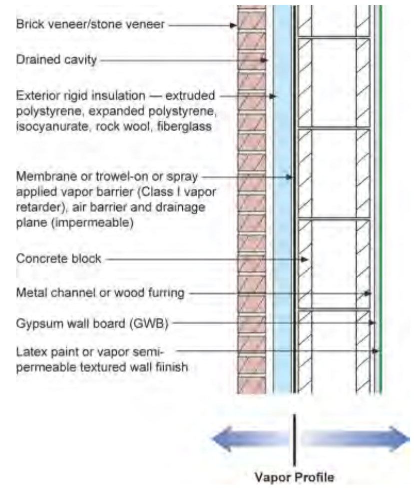
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



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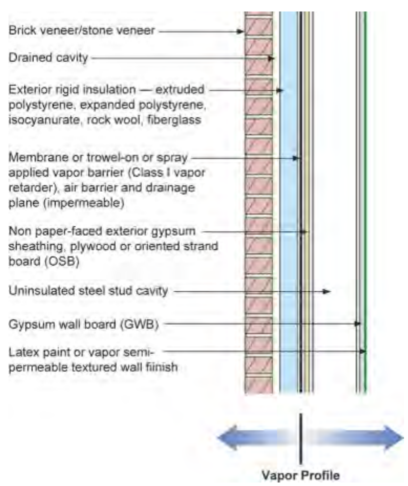

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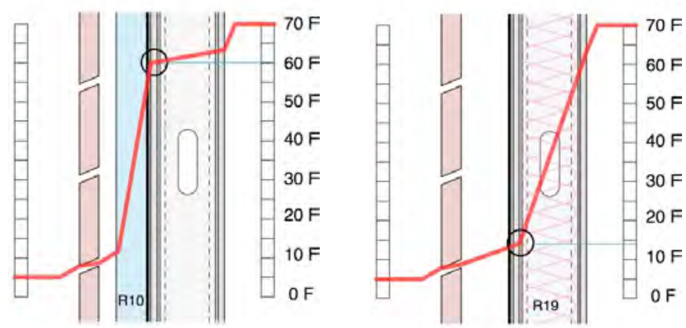
Condensation & Drying



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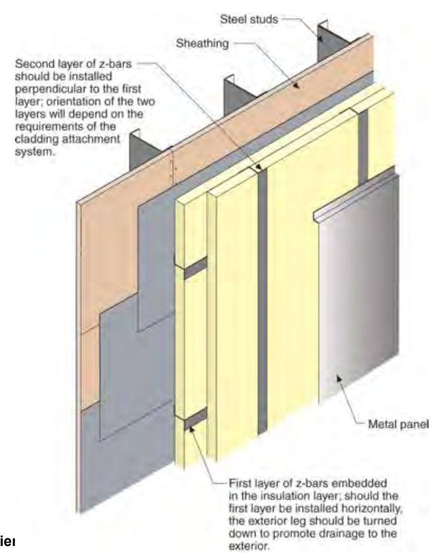

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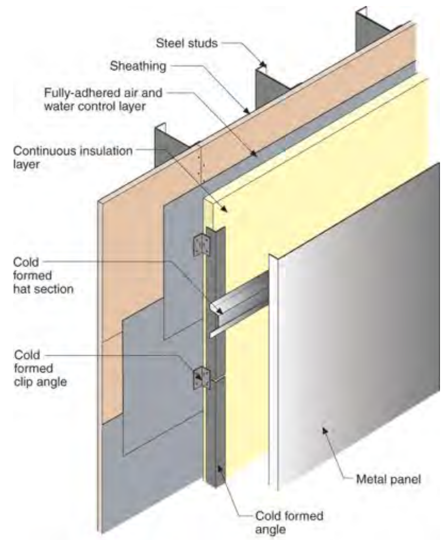

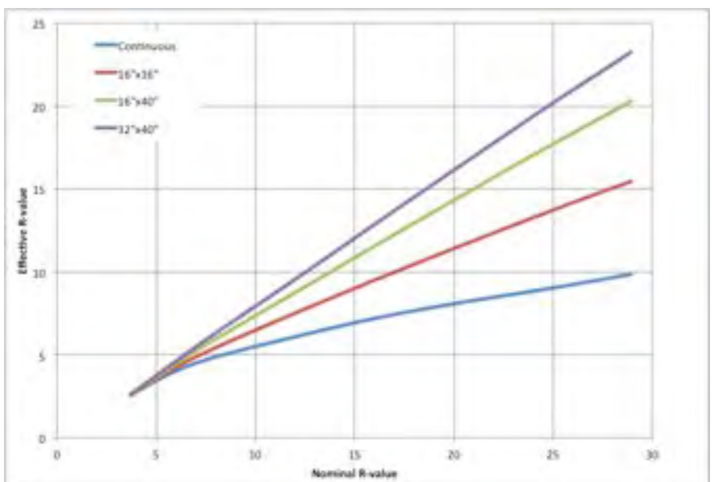

5.5” empty steel stud, 4” long 16 ga Z clips

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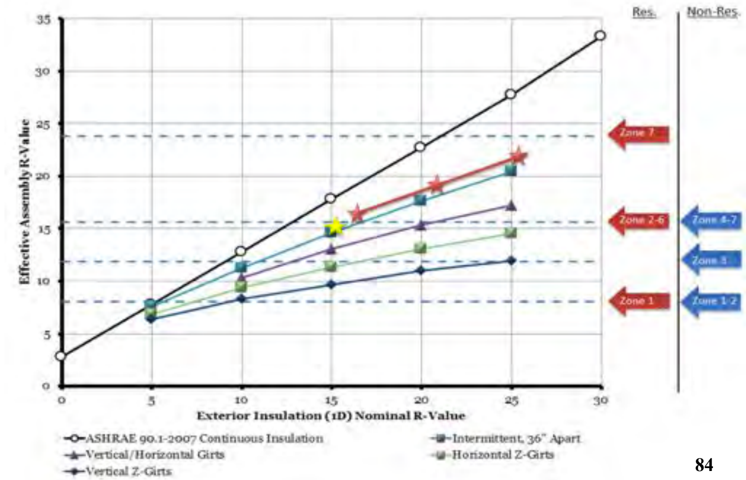
ASHRAE Research- Morrison Hershfield



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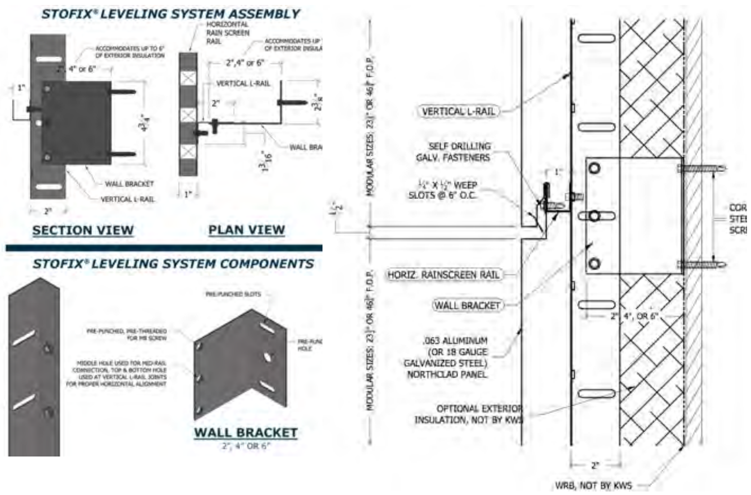

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Special Cases

- Relieving angles
- Balconies
- Canopies

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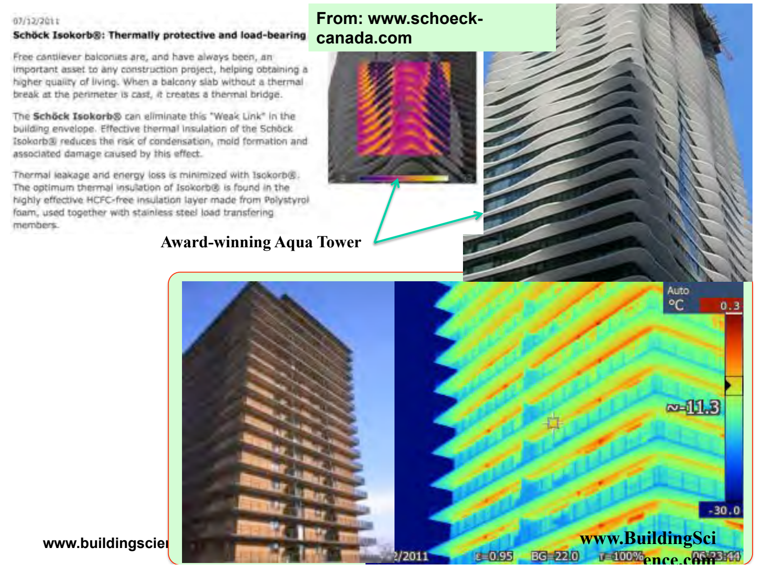
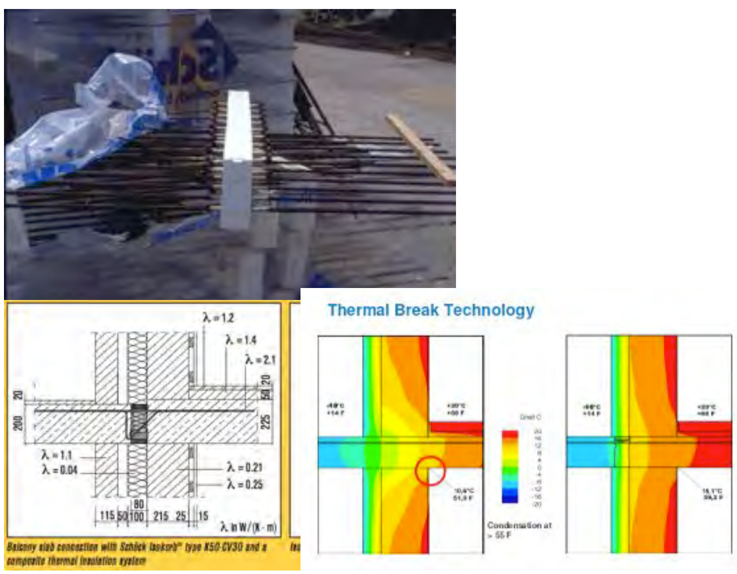
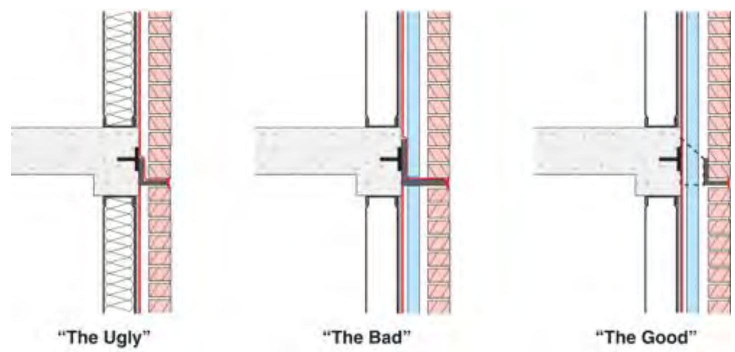




Relieving Angles



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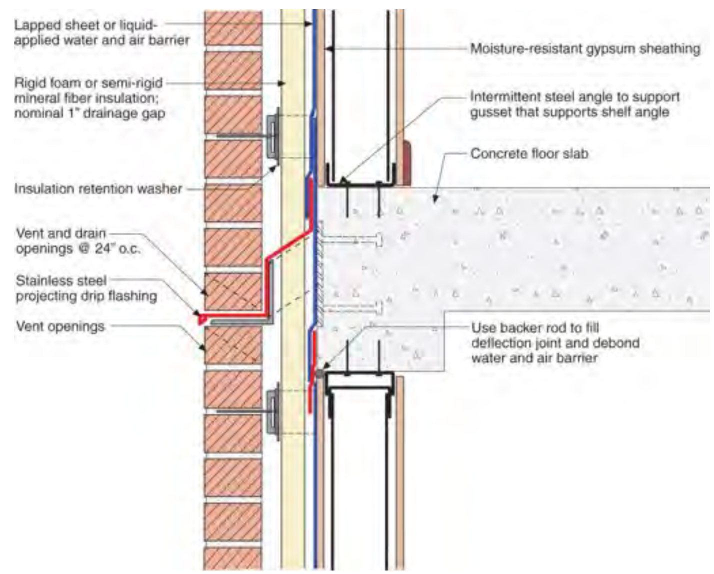
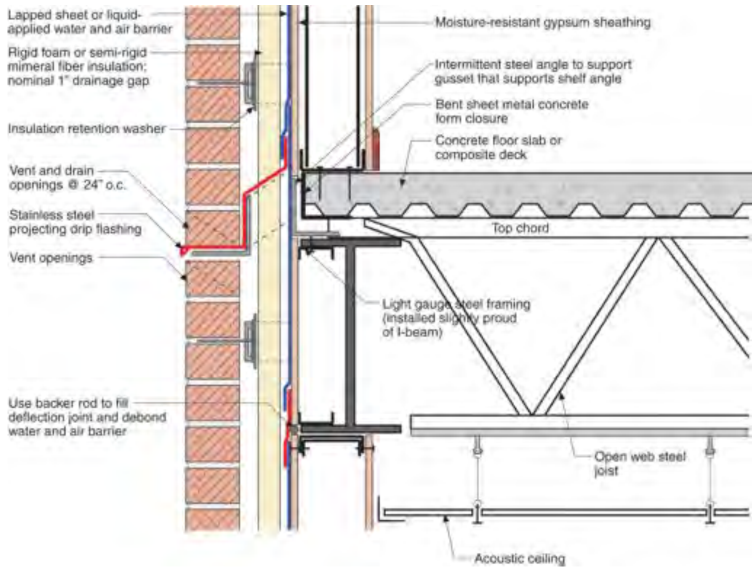
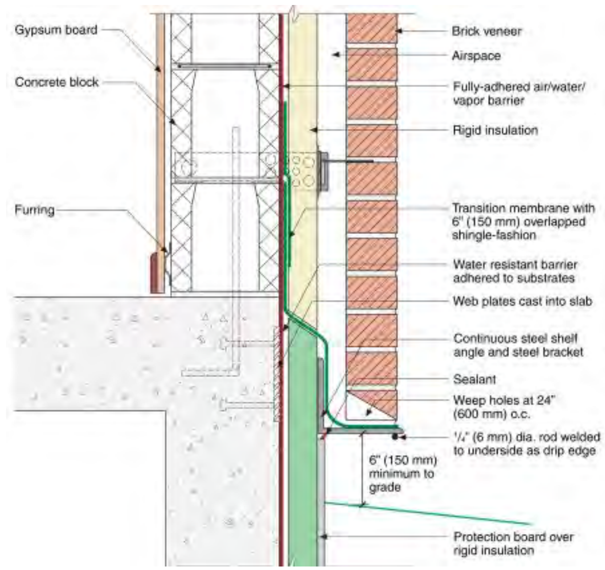
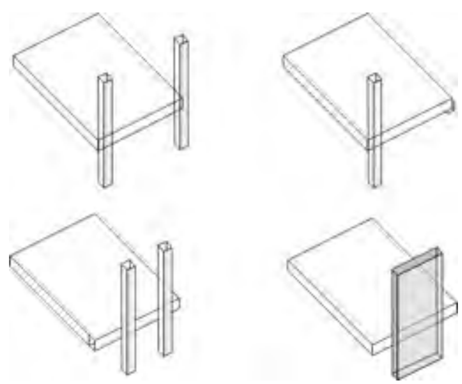
Small metal clips dramatically reduce thermal bridging


Lapped sheet or liquid-applied water and air barrier
Rigid foam or semi-rigid mineral fiber insulation; nominal 1" drainage gap
Insulation retention washer
Vent and drain openings @ 24" o.c.
Stainless steel projecting drip flashing
Vent openings
Moisture-resistant gypsum sheathing
Intermittent steel angle to support gusset that supports shelf angle
Concrete floor slab
Use backer rod to fill deflection joint and debond water and air barrier





Balconies



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Insulation and

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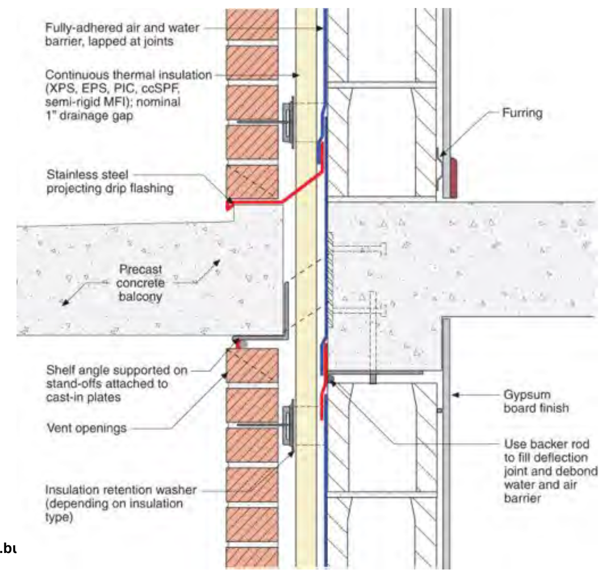
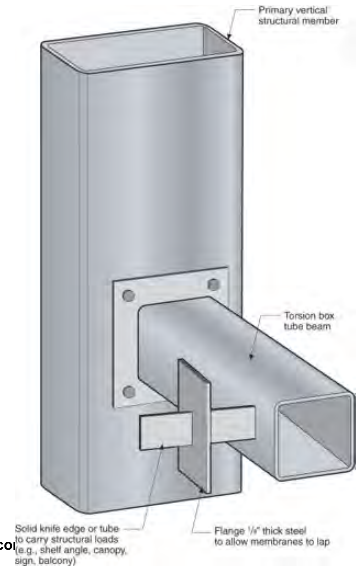
Insulation and Thermal


Precast balcony supported on knife edge supports to limit thermal losses





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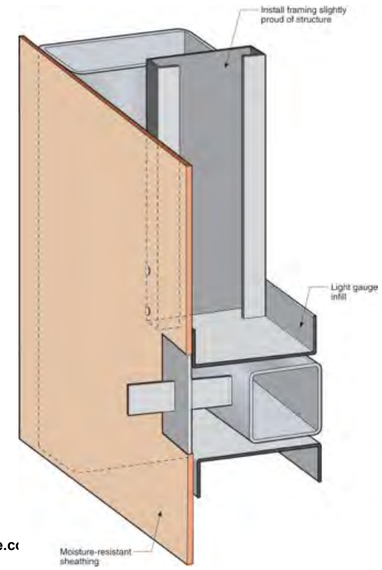

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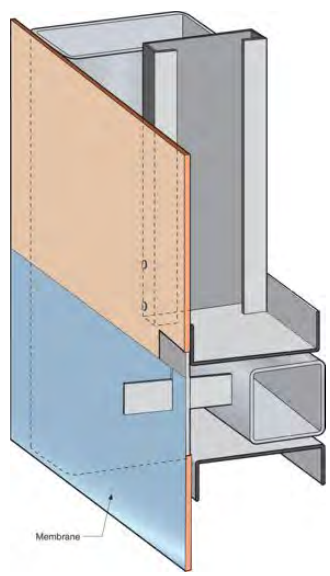

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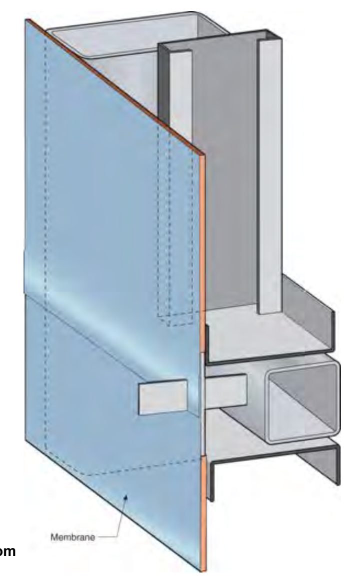

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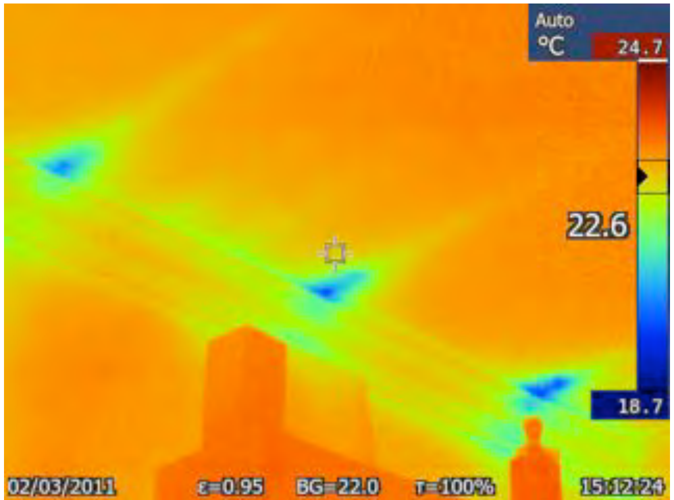

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Windows

… such a pane.

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Windows

- Our most expensive thermal bridges
- Aluminum is 4-5 times as conductive as steel
- Or 1600 times more than wood
- Difficult to buy commercial aluminum windows / curtainwall over R3.
- Allow solar heat in
  - Useful in cold weather
  - Requires cooling in summer

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Frames

- A large amount of heat can also be conducted through the frame
  - Conductivity of the material (lower = better)
  - Geometry of the frame

Frame Material	Conductivity W/mk	Conductivity R/inch
Wood	0.10 to 0.18	0.8 to 1.4
PVC	0.17	0.8
Fiberglass	0.30	0.5
Bronze	93	0.002
Aluminum	221	0.001

www.buildingscience.com Building Science Windows and Curtainwalls

Gas Fills

- Gas fills reduce the amount of heat transferred by conduction and convection through the space in the glazing unit
- Gas fills leak about +/-1% per year

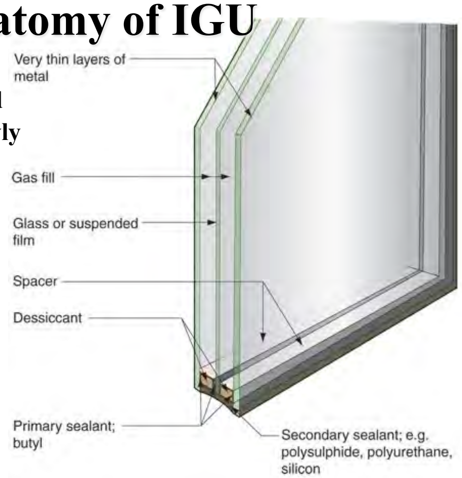
Fill	Conductivity W/mK	Conductivity R/inch	Reduction in Conduction
Air	0.0241	6.0	-
Argon	0.0162	8.9	33%
Krypton	0.0086	16.8	64%
Xenon	0.0051	28.3	79%

Window U-values

- Window U-value = 1 /R-value
- Window values usually include airfilms
  - Inside and outside R-1.0
- Hence, single-glazed, R1
- A still air space adds R1
- Change to argon, another R1
- Add low-e, another R1

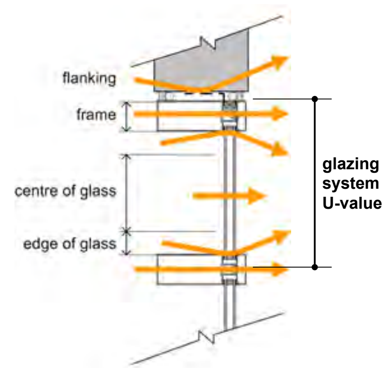
Anatomy of IGU

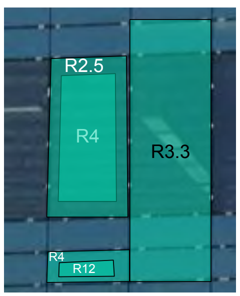
- Hermetically sealed
- Gas leaks very slowly



Total Heat Flow

Curtain Wall Plan View





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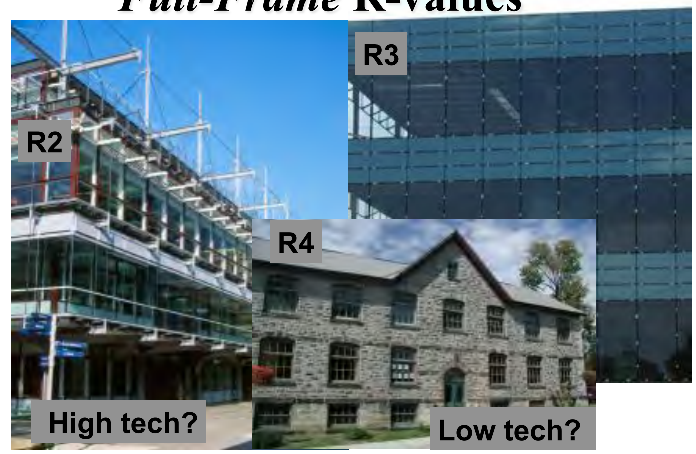
Full-Frame R-values



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Windows and Curtainwalls

Thermal Break

- Critical for alu windows
- ½" should be min thermal break

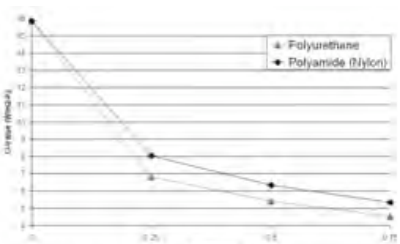
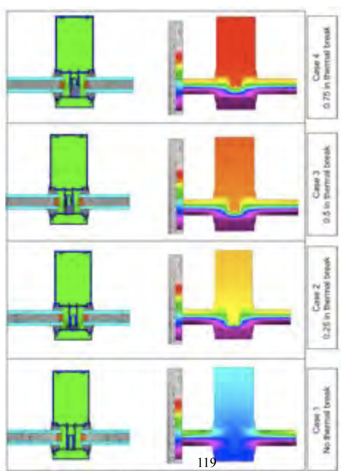


Figure 4: Frame U-Value vs. thermal break thickness.



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High Performance

Getting better . .

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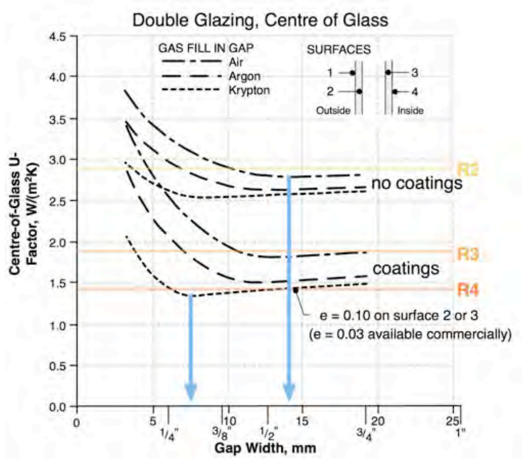

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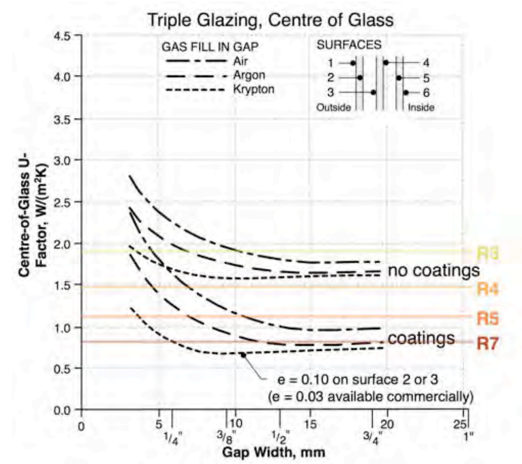

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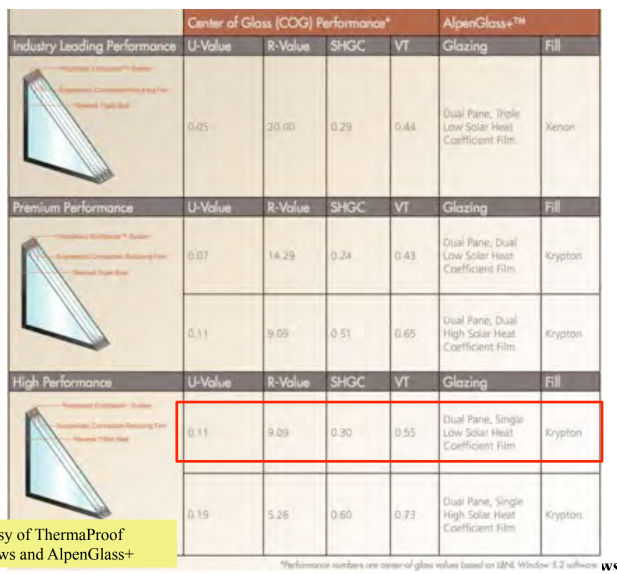

	Center of Glass (COG) Performance*				AlpenGlass+™	
Industry Leading Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.05	20.00	0.29	0.44	Dual Pane, Triple Low Solar Heat Coefficient Film	Xenon
Premium Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.07	14.29	0.24	0.43	Dual Pane, Dual Low Solar Heat Coefficient Film	Krypton
	0.11	9.09	0.51	0.65	Dual Pane, Dual High Solar Heat Coefficient Film	Krypton
High Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.11	9.09	0.30	0.55	Dual Pane, Single Low Solar Heat Coefficient Film	Krypton
	0.19	5.26	0.60	0.73	Dual Pane, Single High Solar Heat Coefficient Film	Krypton

*Performance numbers are center-of-glass values based on LBNL Window 5.2 software

Courtesy of ThermaProof Windows and AlpenGlass+

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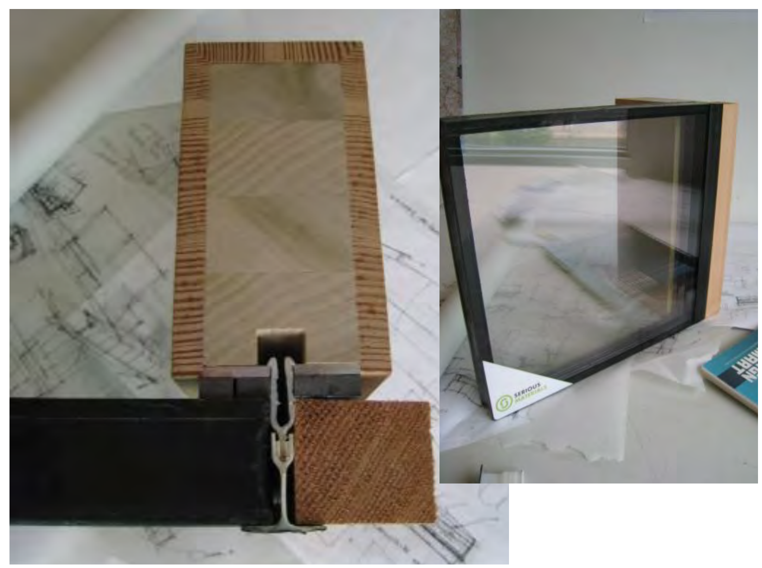
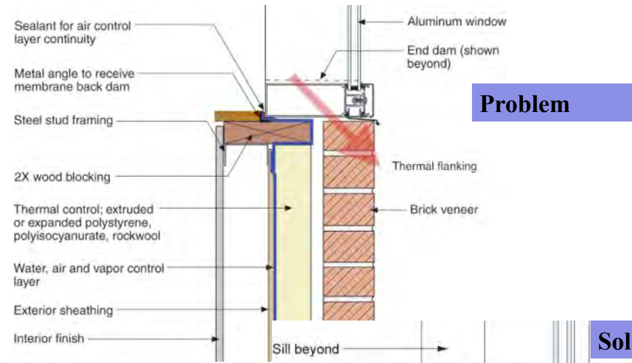
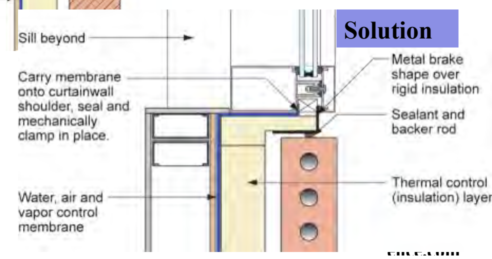
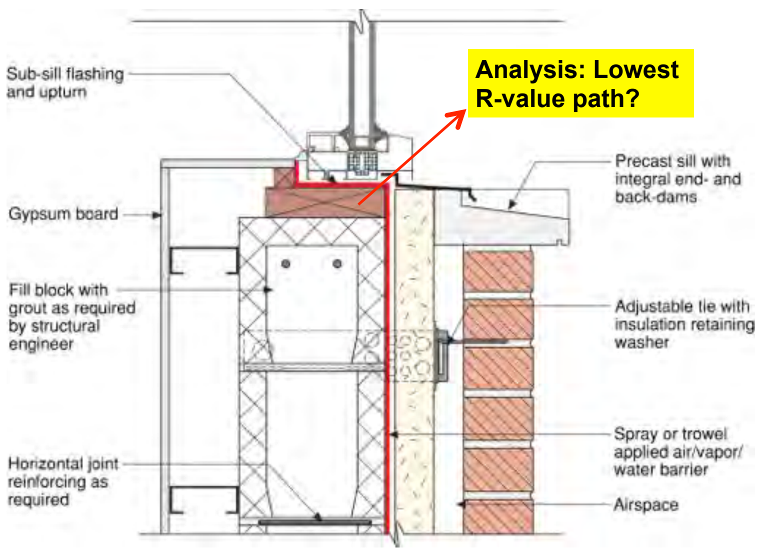


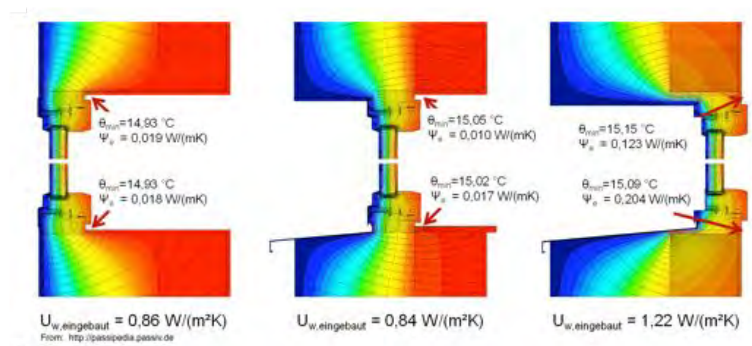
Flanking

- Defined as heat flow around a window
- Includes the rough opening and any special flashing, fasteners, etc.
- Wood bucks often have R-value of 1/inch
- Plywood bucks usually 0.75/inch
- Air gaps >1/4" have low R-value
- Gaps filled with spray foam, R4-6/inch

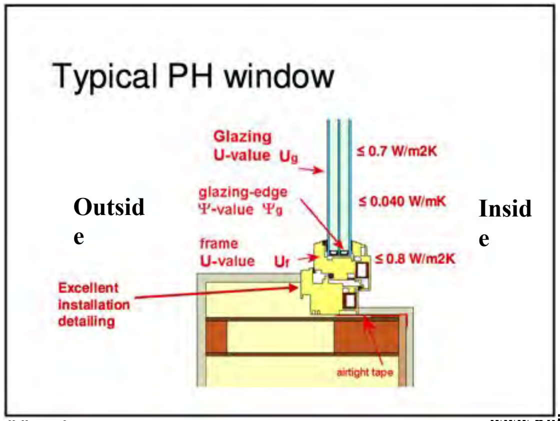








Don’t do this: it traps leak water



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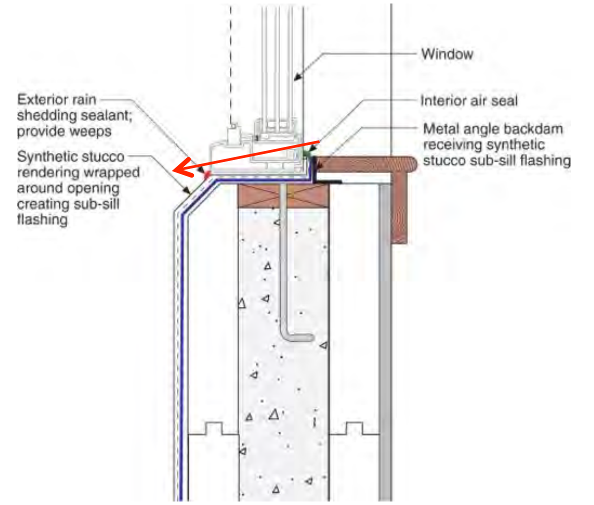

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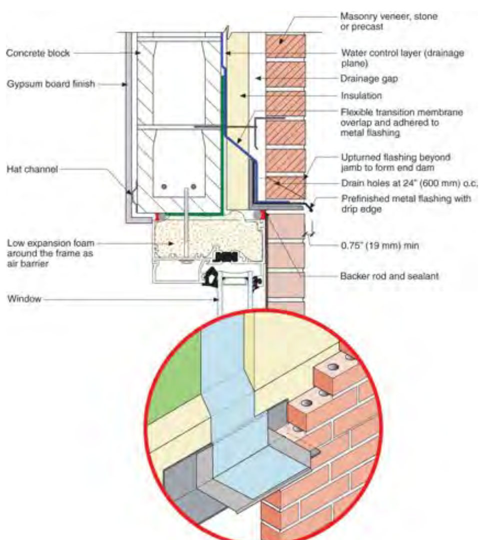

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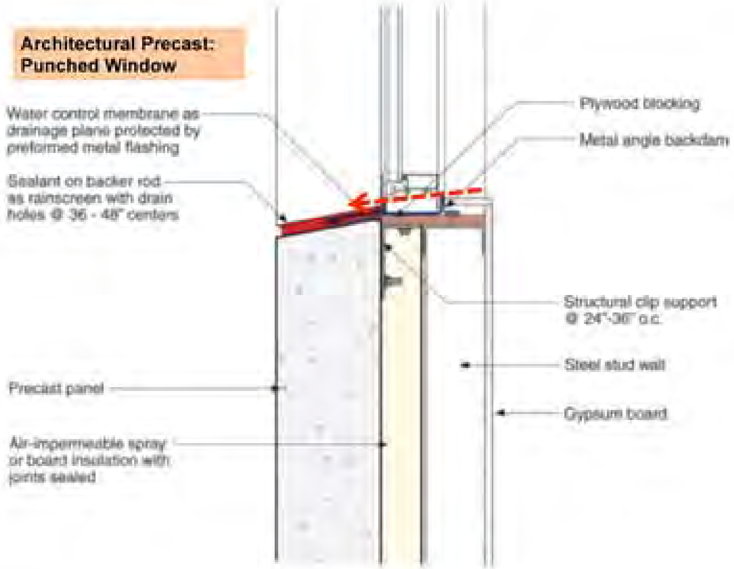
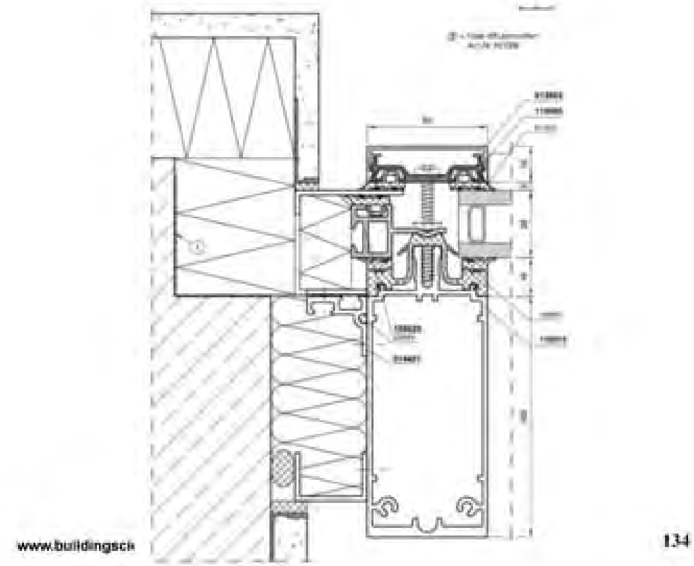

Architectural Precast:
Punched Window
Water control membrane as drainage plane protected by preformed metal flashing
Sealant on backer rod as rainscreen with drain holes @ 36 - 48" centers
Precast panel
Air-impermeable spray or board insulation with joints sealed
Plywood blocking
Metal angle backdam
Structural clip support @ 24"-36" o.c.
Steel stud wall
Gypsum board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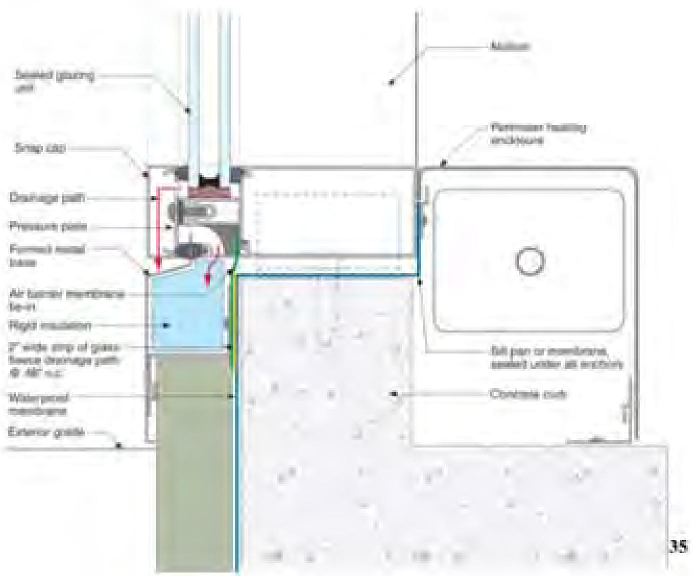
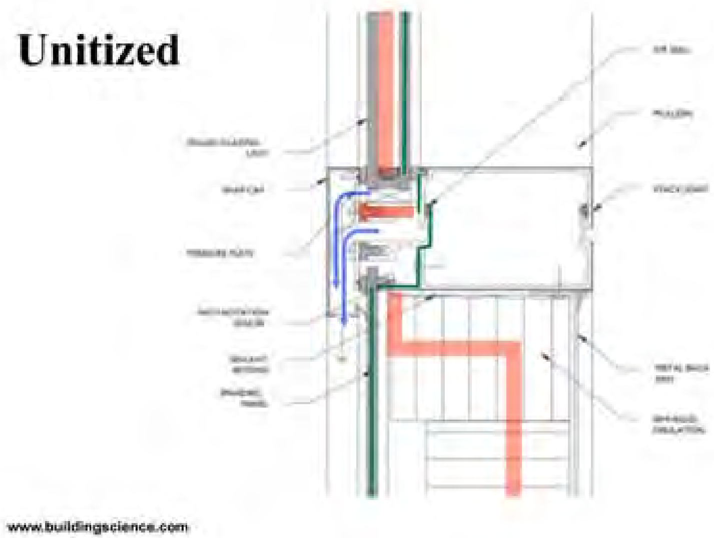
134


Sealed glazing unit
Snap cap
Drainage path
Pressure plate
Formed metal base
Air barrier membrane tie-in
Rigid insulation
Waterproof membrane
Exterior grade
Mullion
Perimeter heating enclosure
Concrete curb
35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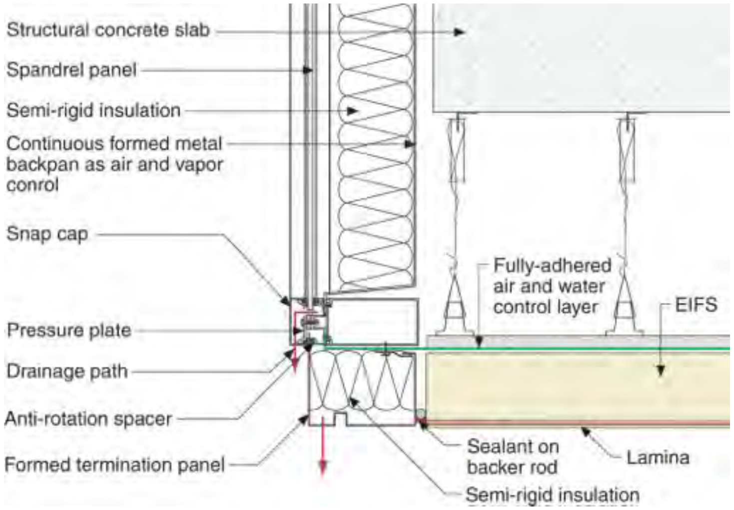

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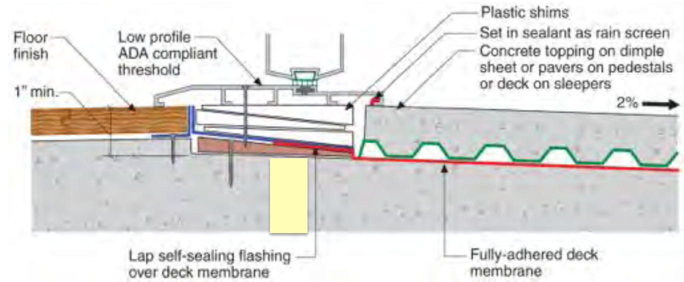

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Total Window

- Remember for total window installed, need to consider
  - IGU
  - Spacer
  - Window frame
  - Rough opening

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Window Overall U-value

$$U_w = (U_c A_c + U_e A_e + U_f A_f)/A_w$$

where

U_w = U-value of complete window product
U_c = calculated centre of glass U-value
U_e = calculated edge of glass U-value
U_f = calculated frame U-value
A_c = centre of glass area
A_e = edge of glass area
A_f = frame area
A_w = total window area

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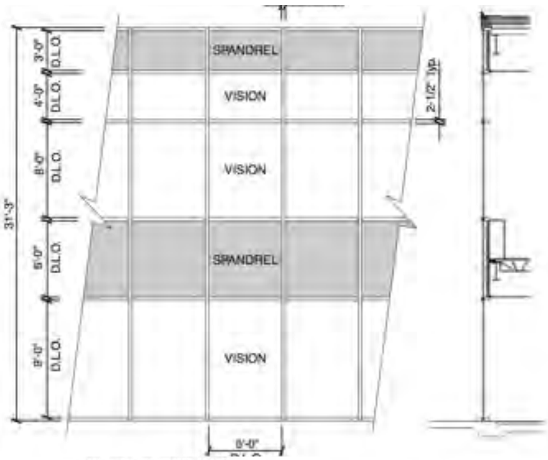
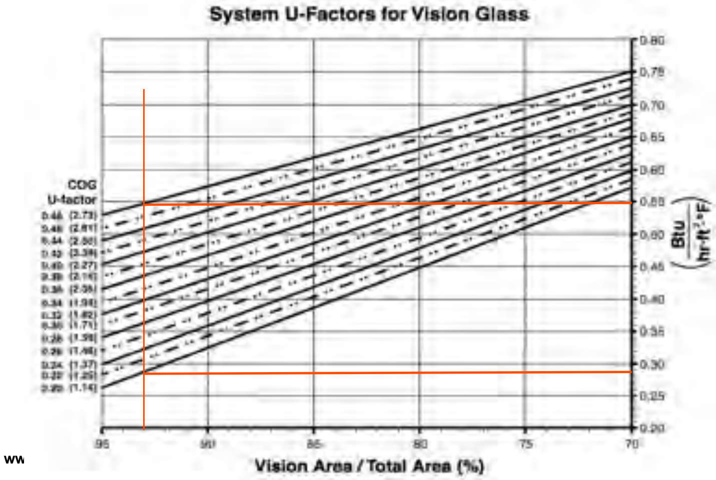


Vision Area	$= 5(9 + 8 + 4) = 105.0$ ft^2
Total Area (Vision)	$=$ 5' 2-1/2"(9' 3-3/4"+ 8' 2-1/2" + 4' 2-1/2") = 113.2 ft^2
Percent of Vision Glass	= (Vision Area ÷ Total Area)100 = (105.0 ÷ 113.2)100 = 93%

Courtesy Kawneer

141

Example Kawneer 1600



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Glazing size matter

Example: curtainwall
- 4’ x4’ lite size (4’ x 4’) = 16
- Total Area: (4’2.5” x 4’2.5”) =17.71
- Percent Vision: 90%

Example: punched window
- 2’6” x6’ clear glass size = 15
- Total Area: (2’6”+5”) =18.71
- Percent Vision: 80%

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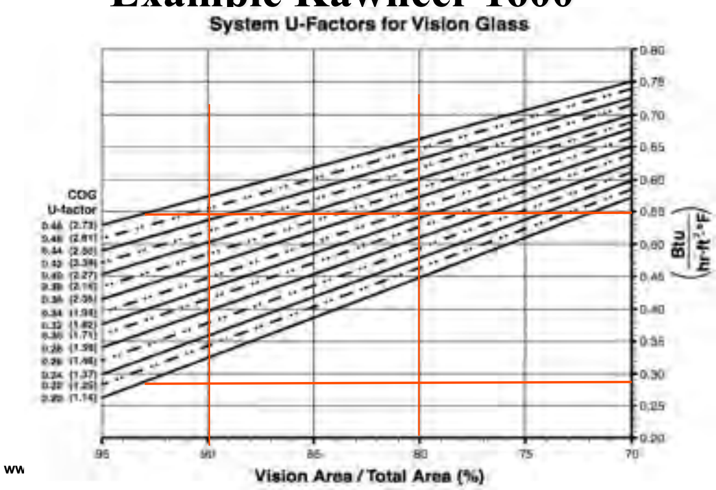
143

Example Kawneer 1600



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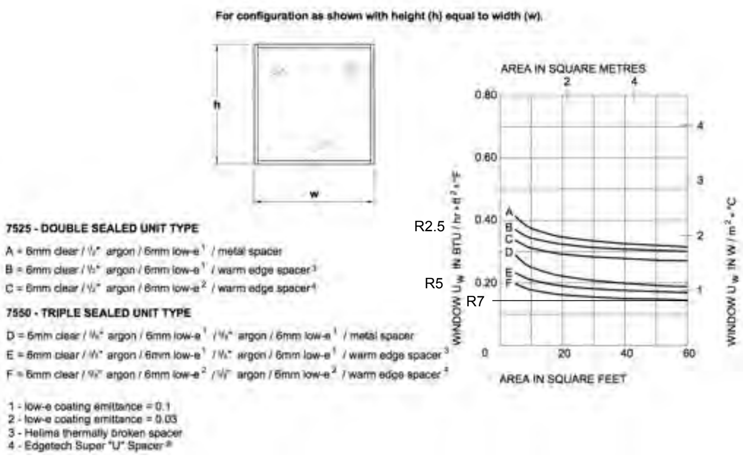
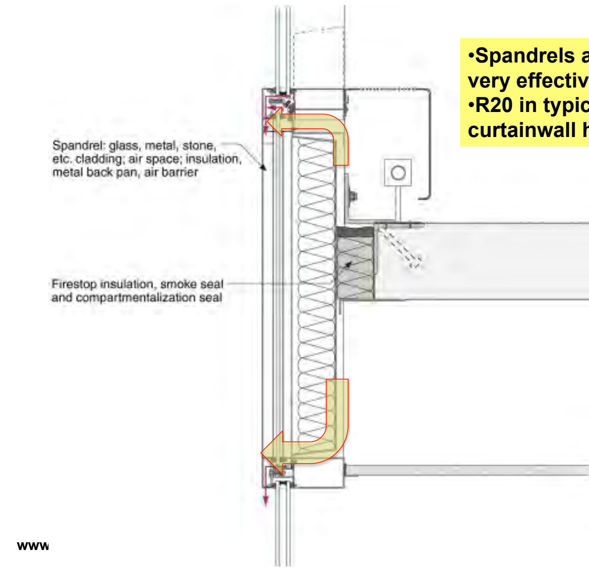
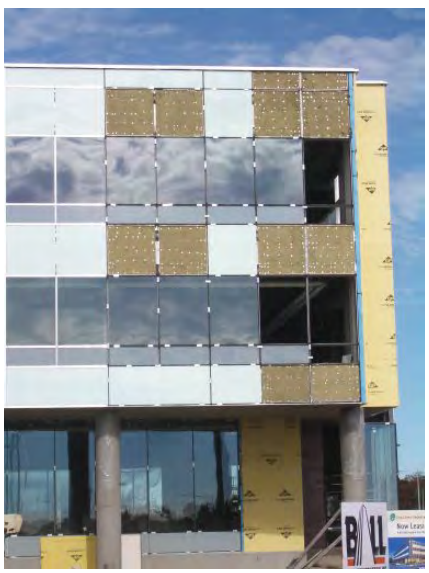
Example Kawneer 7550





- Spandrels are not very effective
- R20 in typical curtainwall has R5



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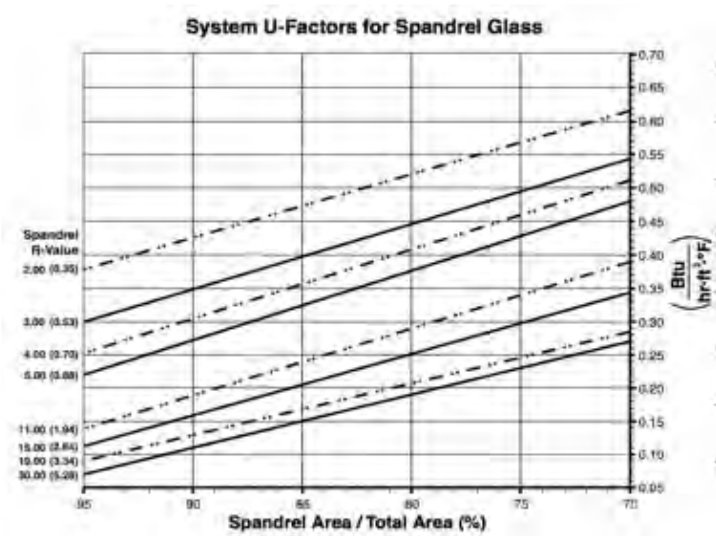

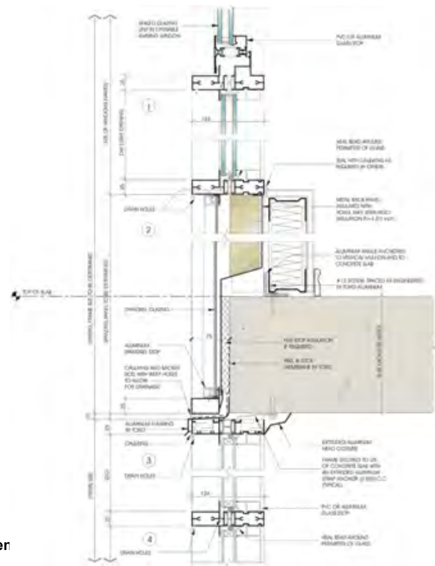

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149

Total System Impacts

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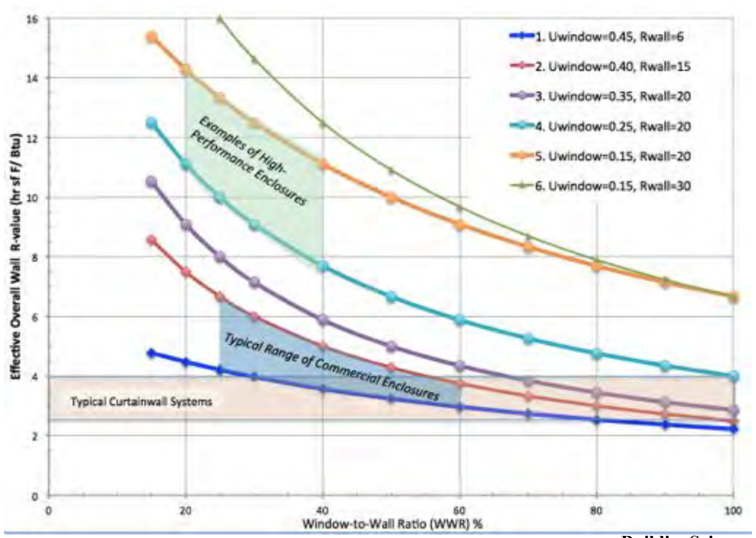
150



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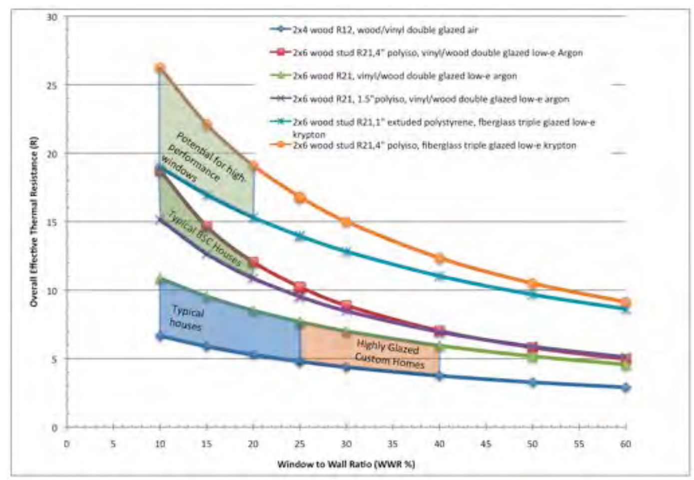

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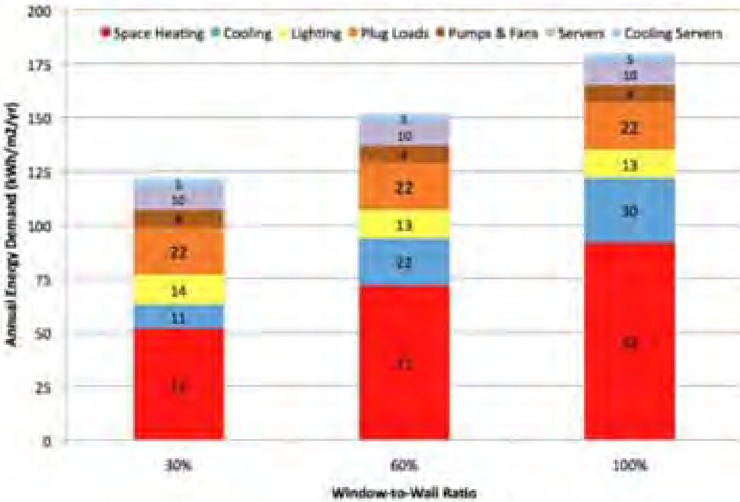
Windows and

More Windows means more energy consumption in a cold climate



Solar Heat Gain Control

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Solar Control and Shading

- Solar Control Glass
- Fixed exterior
- Operable Exterior
- Operable interior

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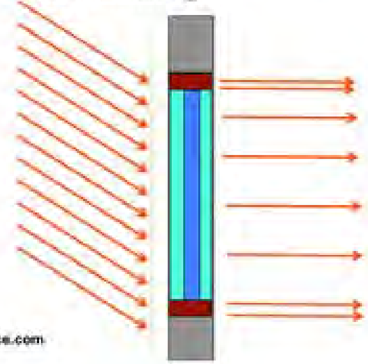
Solar Heat Gain

- SHGC = Ratio of Solar Incident to Heat Gain within Building



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Solar Gain

- Solar gain useful during cold sunny weather
- But … least heating is needed during daytime for commercial buildings
- Overheating discomfort is a real risk
- Must size glass Area x SHGC carefully
  - High values = air conditioning and discomfort

Impact of Angle

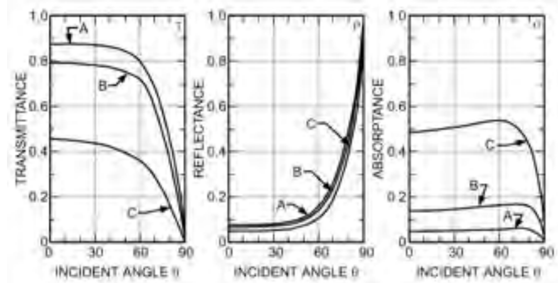


Fig. 8 Variations with Incident Angle of Solar-Optical Properties for (A) Double-Strength Sheet Glass, (B) Clear Plate Glass, and (C) Heat-Absorbing Plate Glass

Solar Properties

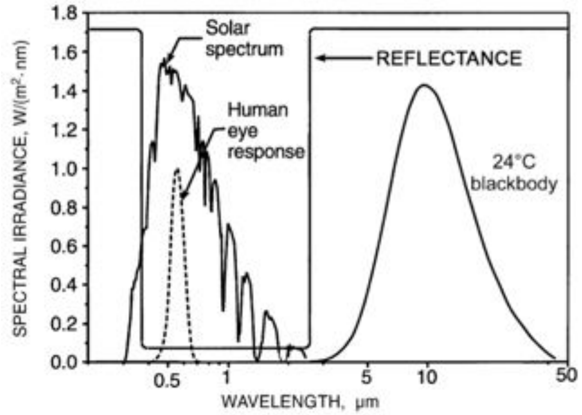
Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptance ($\mathcal{A}_n^f$) for Glazing and Window Systems (*Continued*)

Glazing System					Center-of-Glazing Properties							Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence			
					Incidence Angles							Aluminum		Other Frames		Aluminum		Other Frames	
ID	Glass Thick., mm		Center Glazing T_v		Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Low-e Double Glazing, e = 0.2 on surface 2																			
17a	3	LE CLR	0.76	SHGC	0.65	0.64	0.61	0.56	0.43	0.23	0.57	0.59	0.60	0.53	0.58	0.68	0.68	0.61	0.67
				T	0.59	0.56	0.54	0.48	0.36	0.18	0.50								
				R^f	0.15	0.16	0.18	0.24	0.37	0.61	0.22								
				R^b	0.17	0.18	0.20	0.26	0.38	0.61	0.24								
				$\mathcal{A}_1^f$	0.20	0.21	0.21	0.21	0.20	0.18	0.20								
				$\mathcal{A}_2^f$	0.07	0.07	0.08	0.08	0.07	0.05	0.07								

Spectrally Selective

- Allows low SHGC and high VT
- Coolness Factor (LSG)
  - VT / SHGC
  - Look of 1.7-2.0
  - E.g. VT=0.60, SHGC=0.30, LSG=2

Solar Control Glazing



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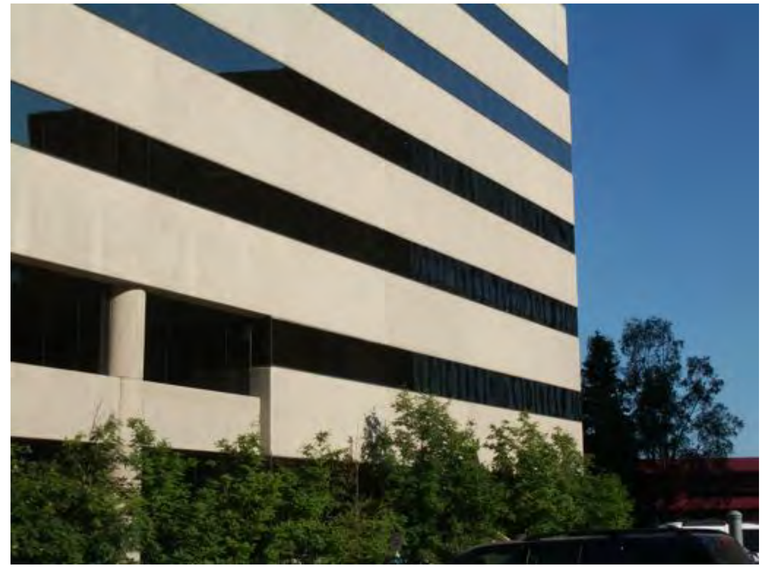

Fixed Shade

- **Only work some of the time**
- **Allow all diffuse light in**
  - **This is good for daylight and view!**
- **Limits solar reduction to about 50-60%**
- **Often can get shoulder season over heating**

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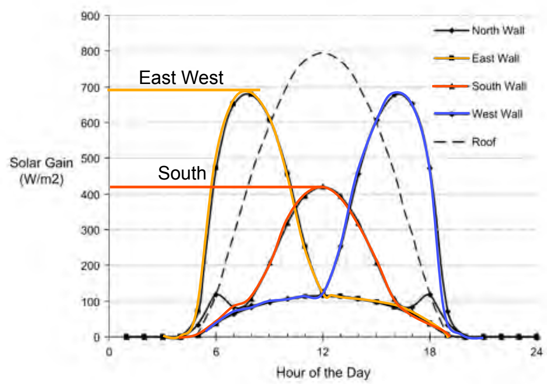
Solar Gains - July 21 @45 N



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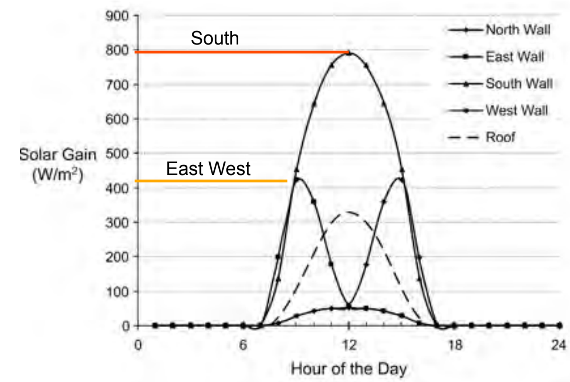
Windows and Curtainwalls

Mother Nature is try to tell you something



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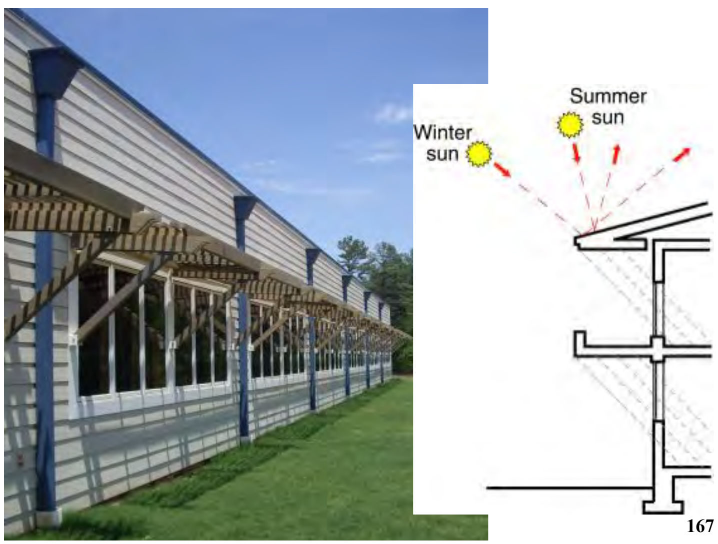
Windows and Curtainwalls



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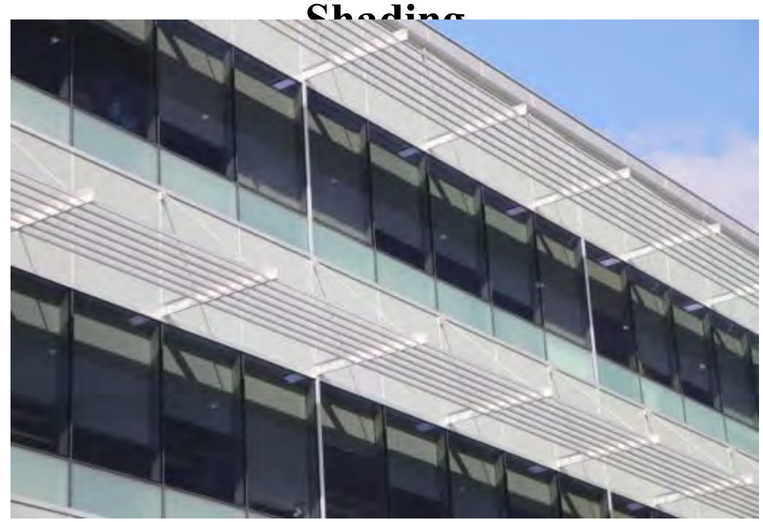
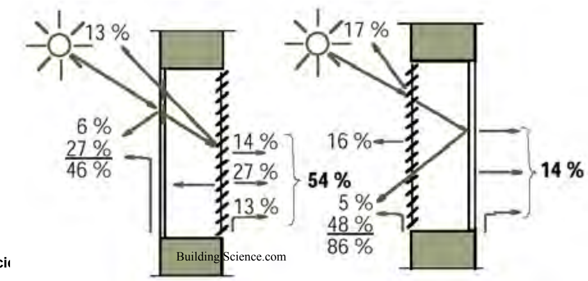
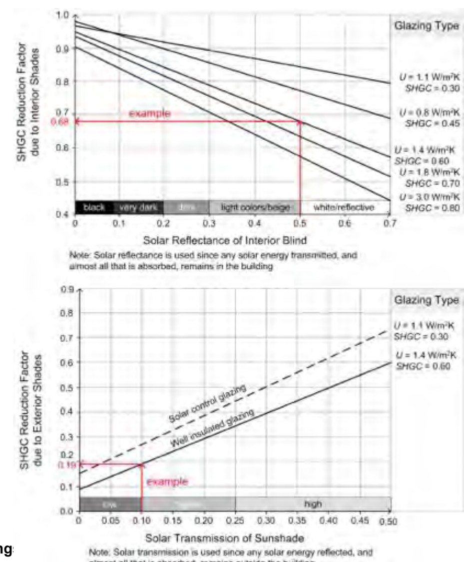
Shading



Interior or Exterior Shade

- Operable Solar Control of windows may be necessary for ultra-low energy buildings
- Exterior Shades always beat low SHGC glazing
  - But increased cost capital and maintenance
- Interior shades don't work well with good windows





Using Vision 5.0 (U of Waterloo)

Solar Control + shades

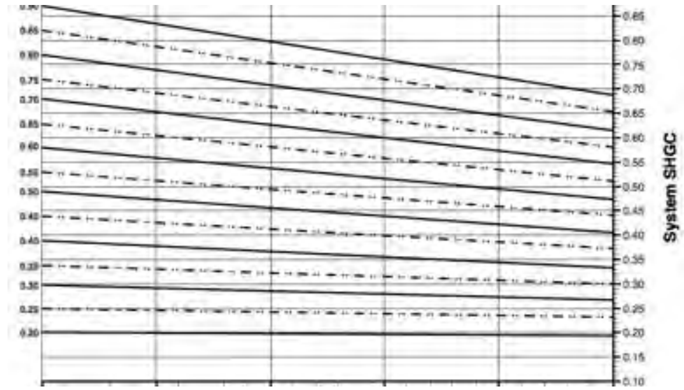
Double Glazing Results **Gas fill is 90% Ar**
SB70XL Strph-6 (5439) & Clear_6.PPG (5012), Low-e 2

	Case	Measure	0	rb	vb30	vb60	vb85
Summer	Interior	U-Value	4.3	4.9	4.9	4.9	4.9
	Shade	SHGC	0.27	0.2	0.24	0.2	0.16
	Exterior	U-Value	4.3	5.0	4.9	5.1	5.3
	Shade	SHGC	0.27	0.13	0.2	0.07	0.02
	Shade	U-Value	4.3	6.0	6.9	7.6	8.2
	Between	SHGC	0.27	0.16	0.23	0.16	0.11
Winter	Interior	U-Value	4.2	5.1	5.0	5.2	5.4
	Shade	SHGC	0.27	0.19	0.23	0.19	0.16
	Exterior	U-Value	4.2	5.5	5.5	5.6	5.6
	Shade	SHGC	0.27	0.13	0.2	0.07	0.02
	Shade	U-Value	4.2	4.3	4.4	4.3	4.3
	Between	SHGC	0.27	0.15	0.22	0.15	0.09

Triple Glazing Results **Gas fill is 90% Ar**
SB70XL Strph-6 (5439), LoE272-6.CIG (2014), Clear_6.PPG (5012), Low-e 2 & 4

	Case	Measure	0	rb	vb30	vb60	vb85
Summer	Interior	U-Value	7.2	7.7	7.7	7.7	7.7
	Shade	SHGC	0.18	0.15	0.16	0.15	0.13
	Exterior	U-Value	7.2	8.0	7.8	8.2	8.5
	Shade	SHGC	0.18	0.09	0.13	0.05	0.01
	Shade	U-Value	7.2	7.5	7.0	6.9	7.2
	Between	SHGC	0.18	0.11	0.15	0.1	0.06
Winter	Interior	U-Value	8.1	9.0	8.9	9.0	9.3
	Shade	SHGC	0.18	0.15	0.16	0.15	0.13
	Exterior	U-Value	8.1	9.5	9.3	9.5	9.5
	Shade	SHGC	0.18	0.09	0.14	0.05	0.01
	Shade	U-Value	8.1	8.4	8.4	8.4	8.4
	Between	SHGC	0.18	0.11	0.14	0.1	0.06

Kawneer 1600 SHGC



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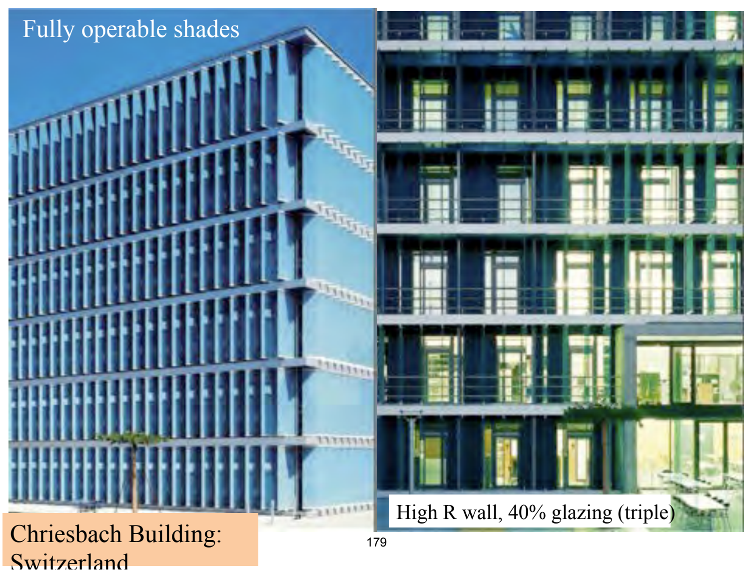
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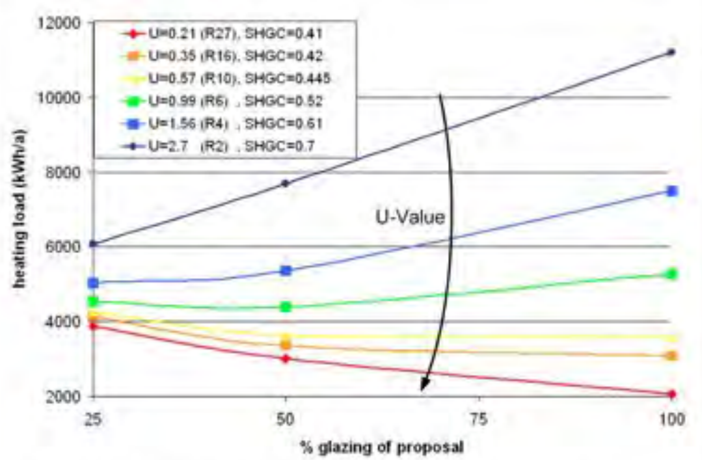

Figure 3.3.1 b): Heating load vs. % glazing of proposal for various windows.

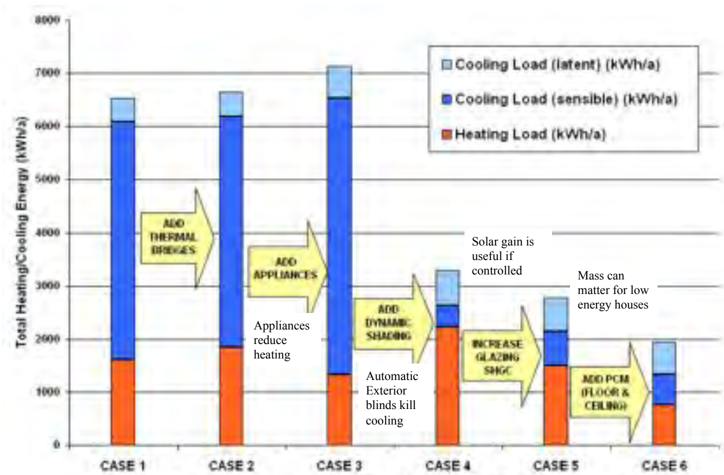

Figure 3.6.1 b: ESP-r simulation results for the refined house model.

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