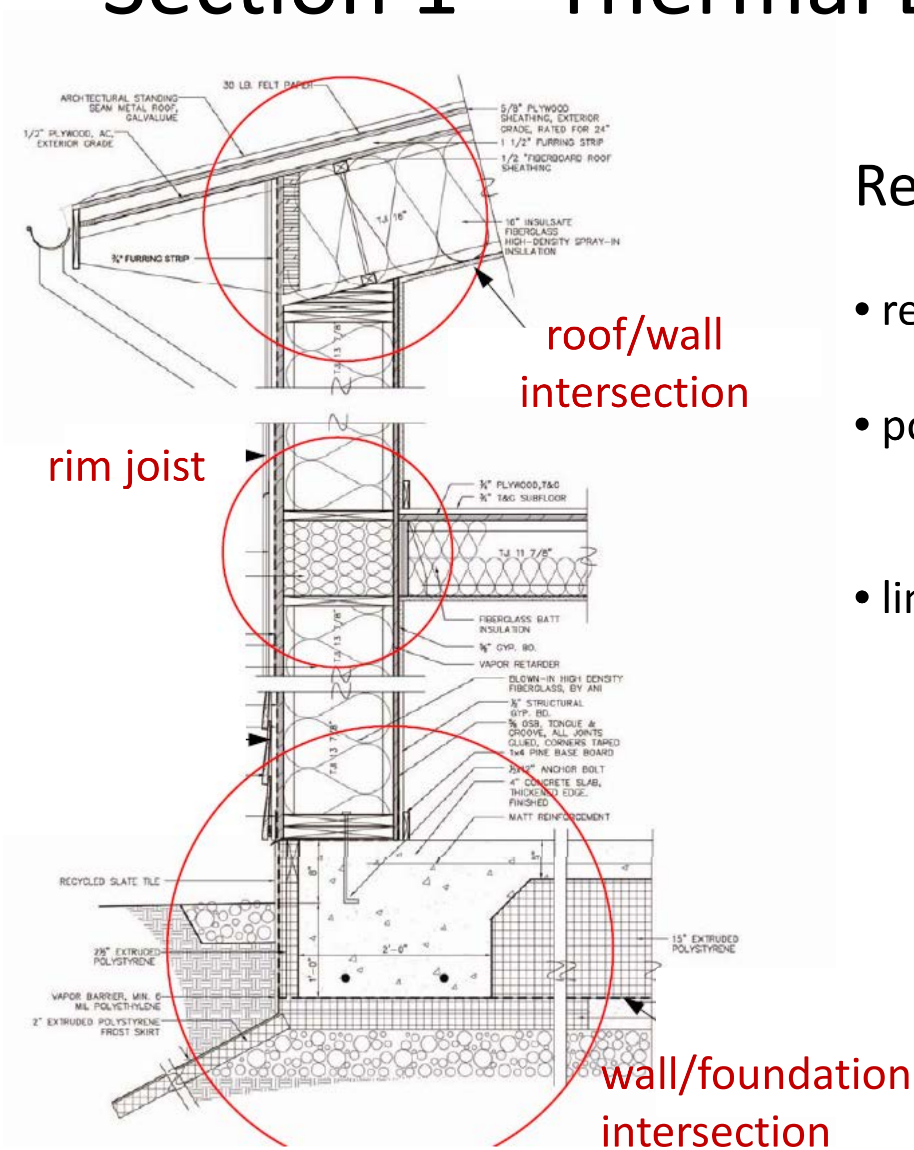
Thermal Bridges and Windows

Thermal Bridges and Windows

Outline

1. Thermal bridges - background
2. Common thermal bridge locations – residential
3. Common thermal bridge locations – commercial
4. Window performance - background
5. High performance residential windows
6. High performance commercial windows
7. Commercial window selection – Façade Design Tool

Section 1 – Thermal Bridge Background



Residential Thermal bridges

- repetitive bridges – already accounted for
- point bridges – generally, heat loss too small to consider
- linear bridges – heat loss should be calculated

Circled areas are common linear thermal bridges. Wall corners are also linear thermal bridges.

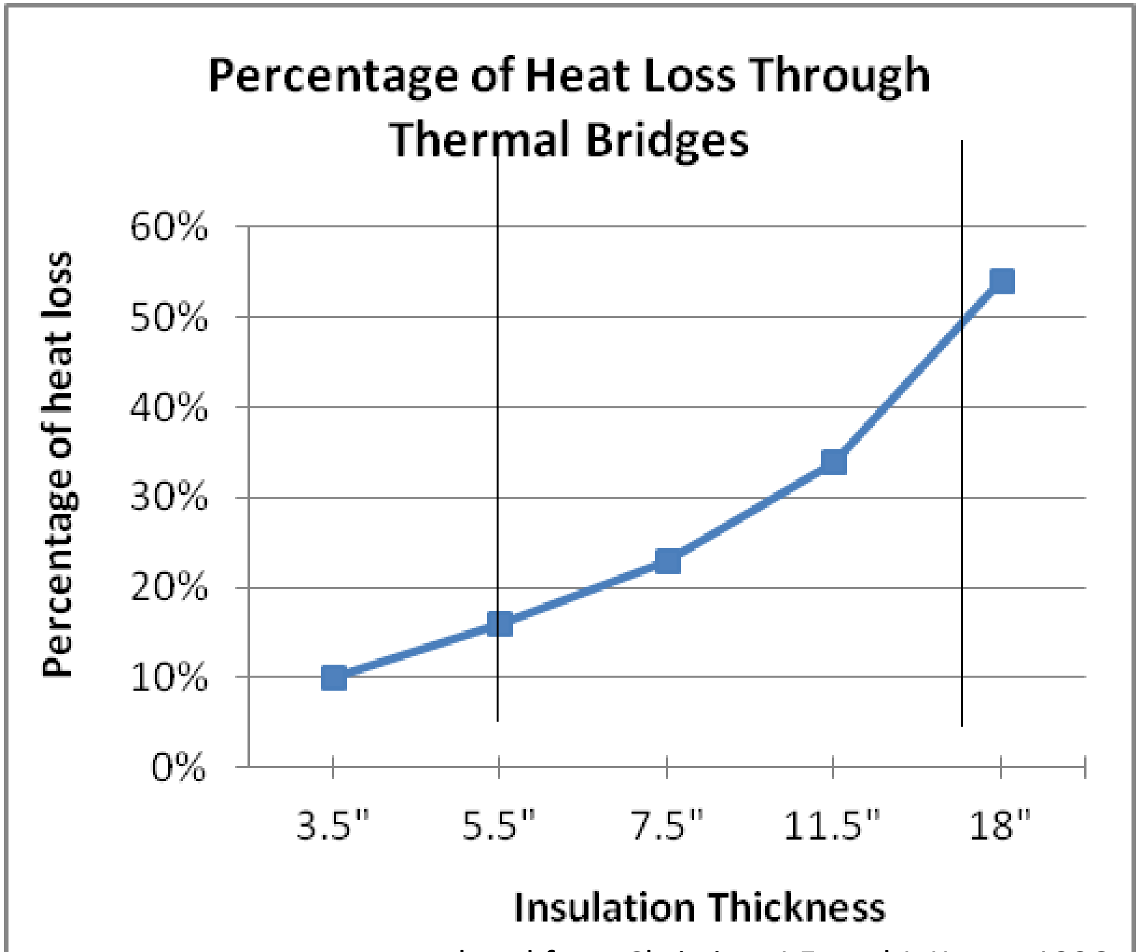
Image from David White, Right Environments, 2010

Section 1 – Thermal Bridge Background

Thermal bridges – do they matter?

- Thermal bridges make up a small portion of heat loss in a poorly insulated envelope - 16% in a typical insulated 2x6 wall.

- If same details from a standard stud wall were used to construct an R-45 wall, heat loss through thermal bridges would approach 50%.



extrapolated from Christian, J.E. and J. Kosny. 1996

Conclusion - For highly insulated envelopes, thermal bridges must be considered!

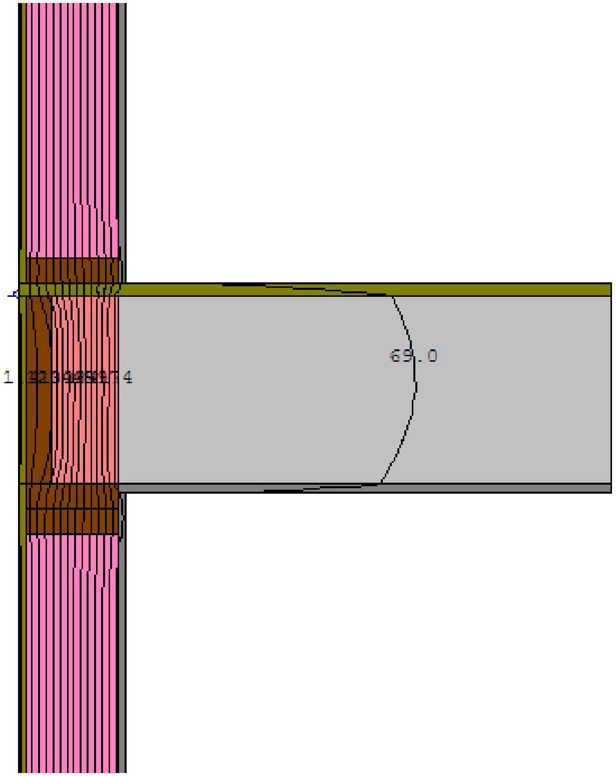
Section 1 – Thermal Bridge Background

- Heat loss through a linear thermal bridge is measured with a Ψ value
- A Ψ value is like a U-value for thermal bridges

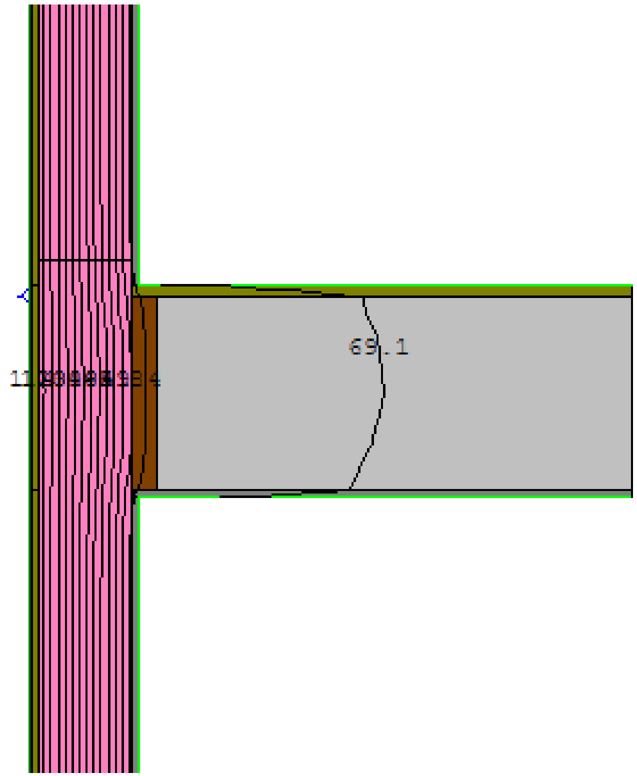
  U x A x dT = heat loss from a surface, of area A

  Ψ x L x dT = heat loss from a linear thermal bridge, of length L
- Ψ values </= 0.01 W/mK qualify as "thermal bridge free" according to Passive House. Values above this need to be accounted for in heat loss calculations, especially for high perf.
- To calculate Ψ values, a 2-D heat flow simulation model (such as THERM) is used.

Section 2 – Thermal Bridges Residential



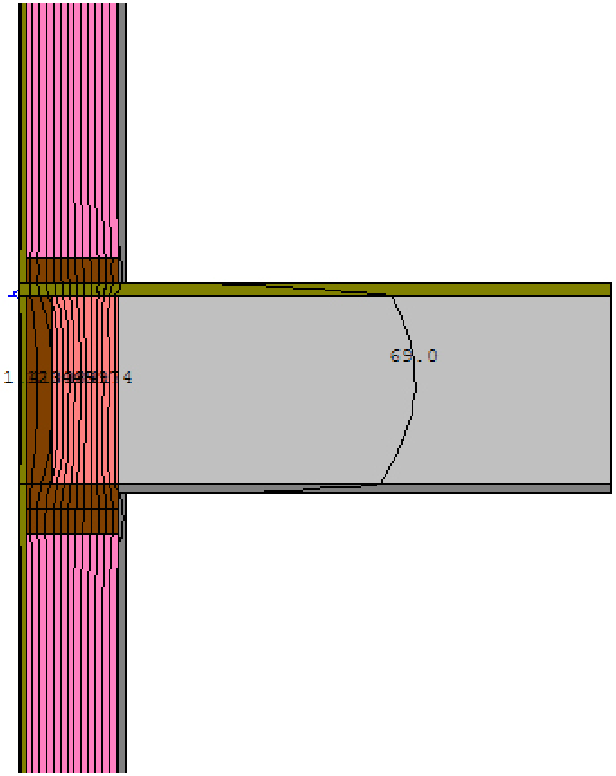
rim joist, fib. batt (R-15.5) : Ψ = 0.032 W/mK



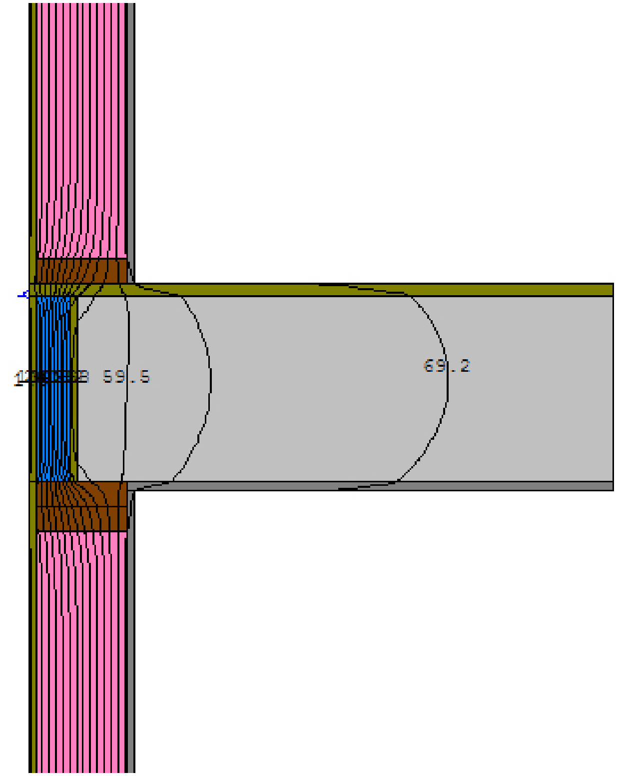
rim joist, balloon framing : Ψ = 0.0 W/mK

- As number of top and bottom plates grow, the psi value increases indicating increased heat loss. Typical 2x6 rim joist has heat loss **3x** the 0.01 W/mK limit.
- STEP 1 – Avoid elements that bridge from interior to exterior

Section 2 – Thermal Bridges Residential



rim joist, fib. batt (R-15.5) : Ψ = 0.032 W/mK

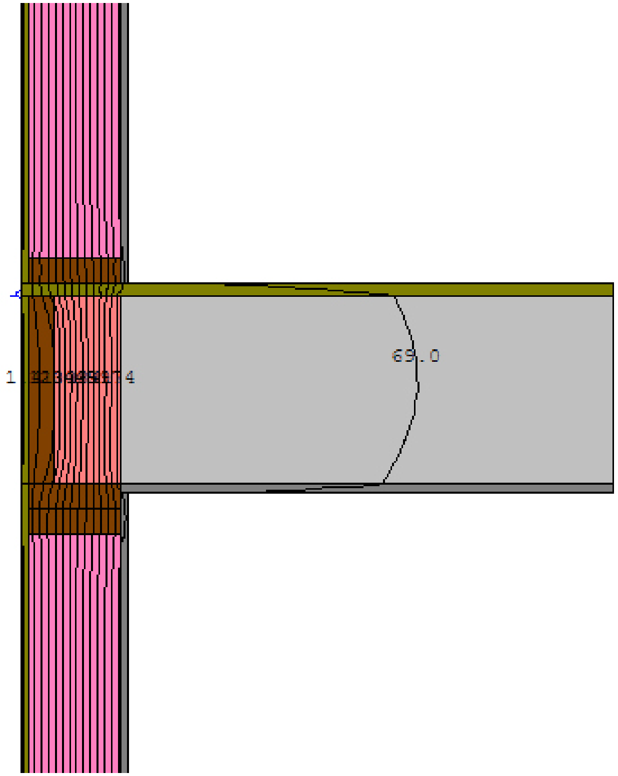


rim joist, rim board (R-12):Ψ = 0.086 W/mK

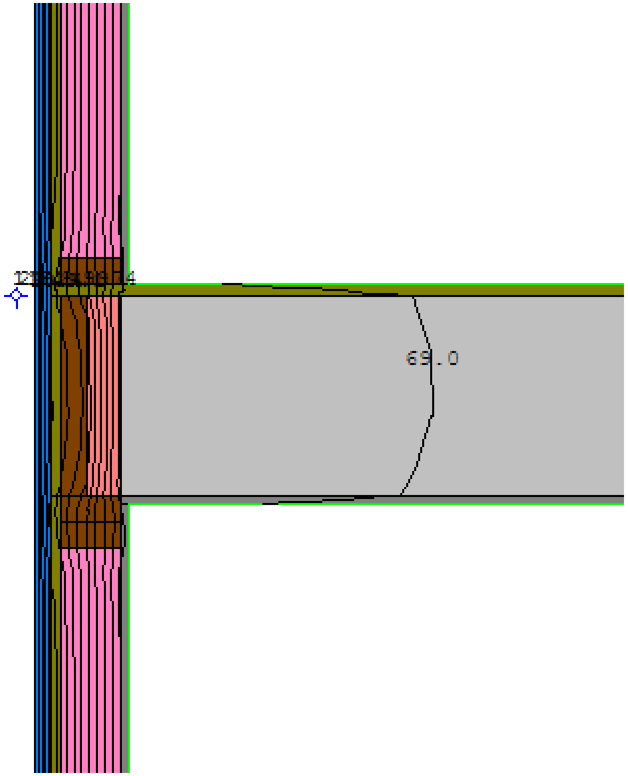
- Rim joist thermal bridge - challenging to achieve the Ψ = 0.01 W/mK target.
- Maintaining continuity and alignment of insulation layers is a good first step.

STEP 2 – Align insulation layers

Section 2 – Thermal Bridges Residential



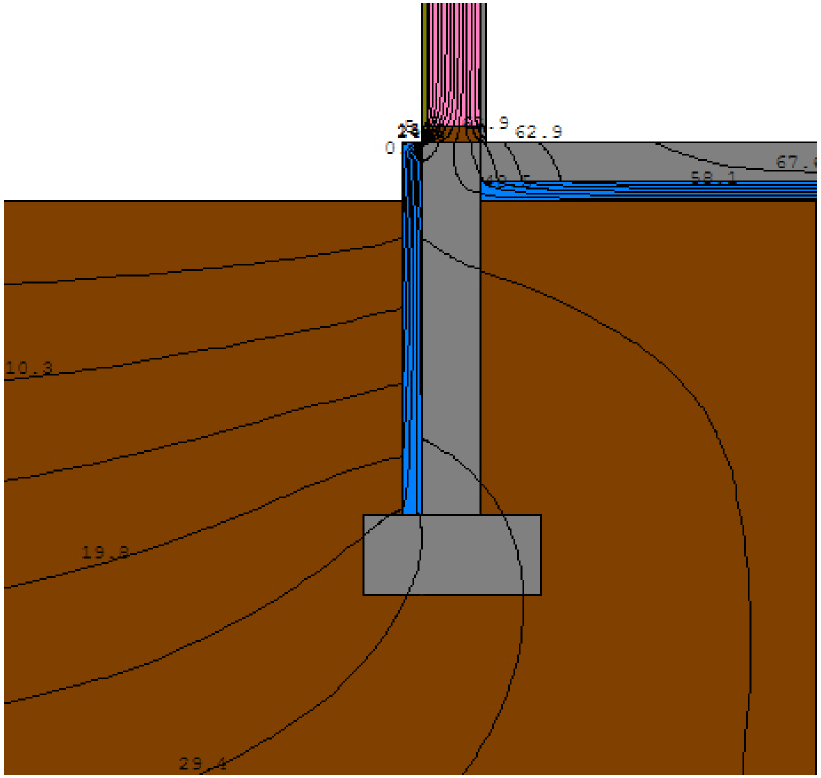
rim joist, 2x6 wall w fib batt (R-14.6):
Ψ = 0.032 W/mK



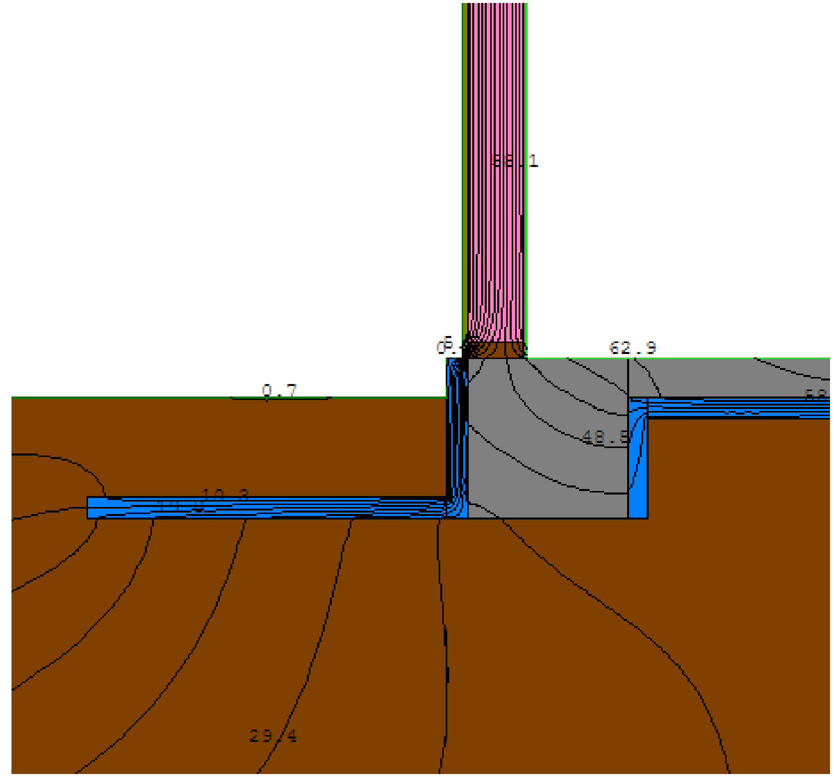
rim joist, 2x4 wall w 1” exterior XPS (R-14.9):
Ψ = 0.025 W/mK

STEP 3 – Use continuous exterior insulation to isolate bridging elements like plates and studs

Section 2 – Thermal Bridges Residential



stem wall: Ψ = 0.198 W/mK

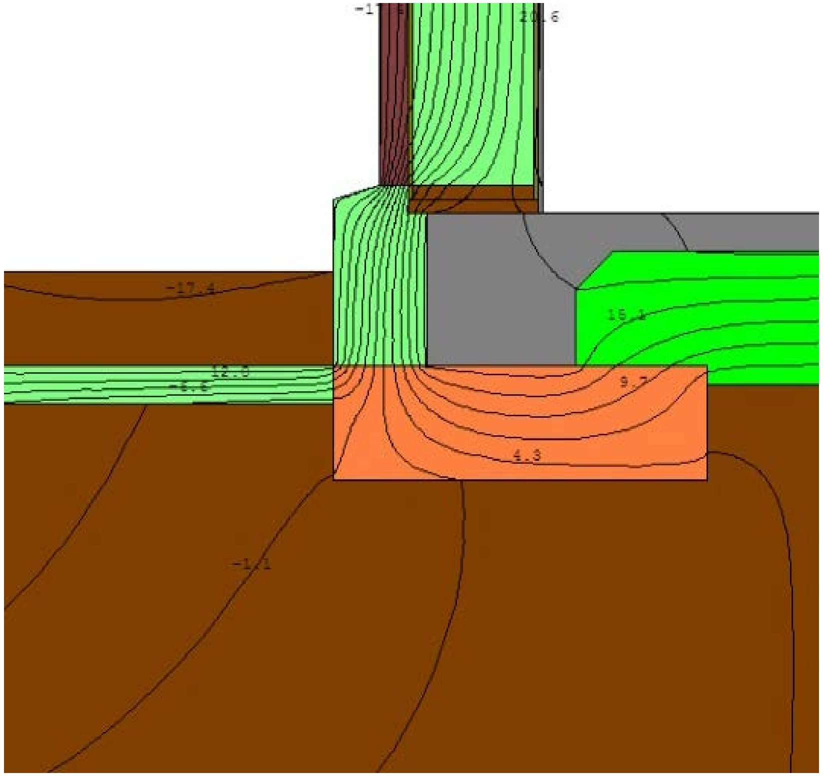


FPSF: Ψ = 0.374 W/mK

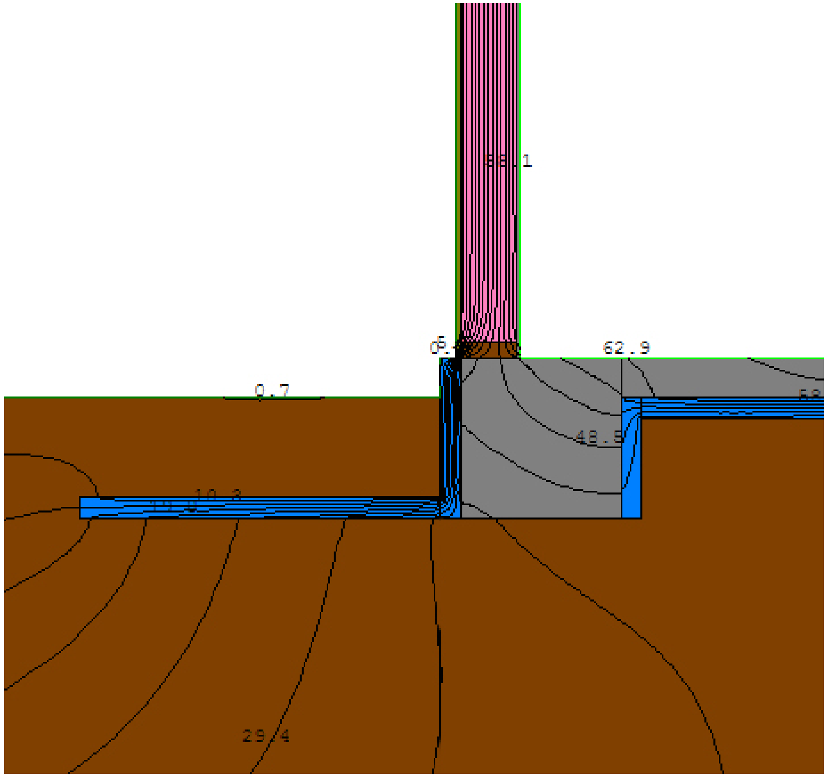
- Thermal bridge at the foundation is typically the largest and most challenging to address.
- The concrete stem wall and footing acts as a radiation fin.

STEP 4 – Avoid accidental "radiation fins".

Section 2 – Thermal Bridges Residential



FPSF (well insulated): Ψ = 0.052 W/mK

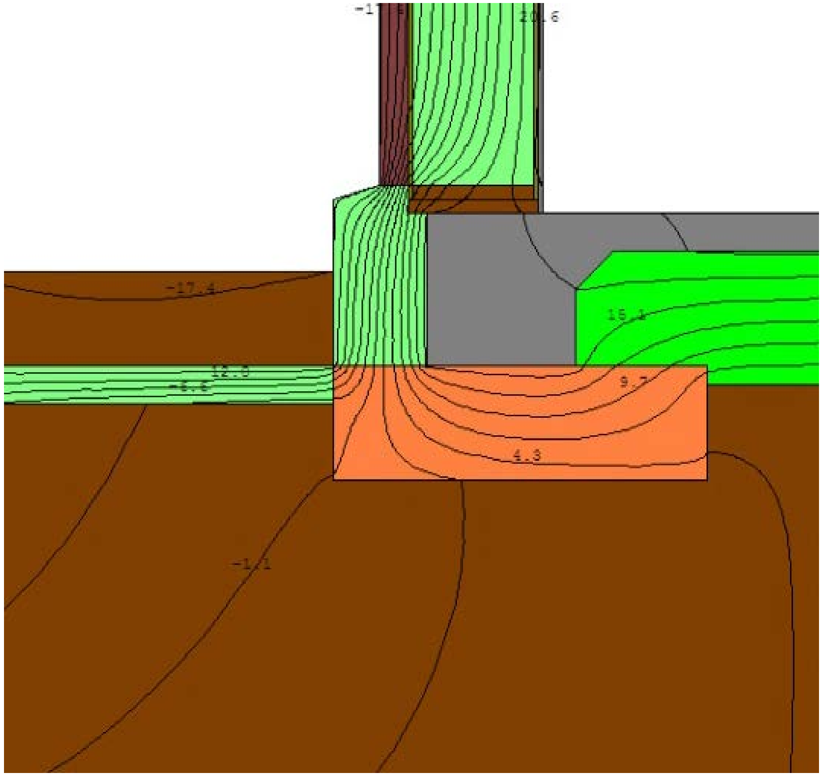


FPSF: Ψ = 0.374 W/mK

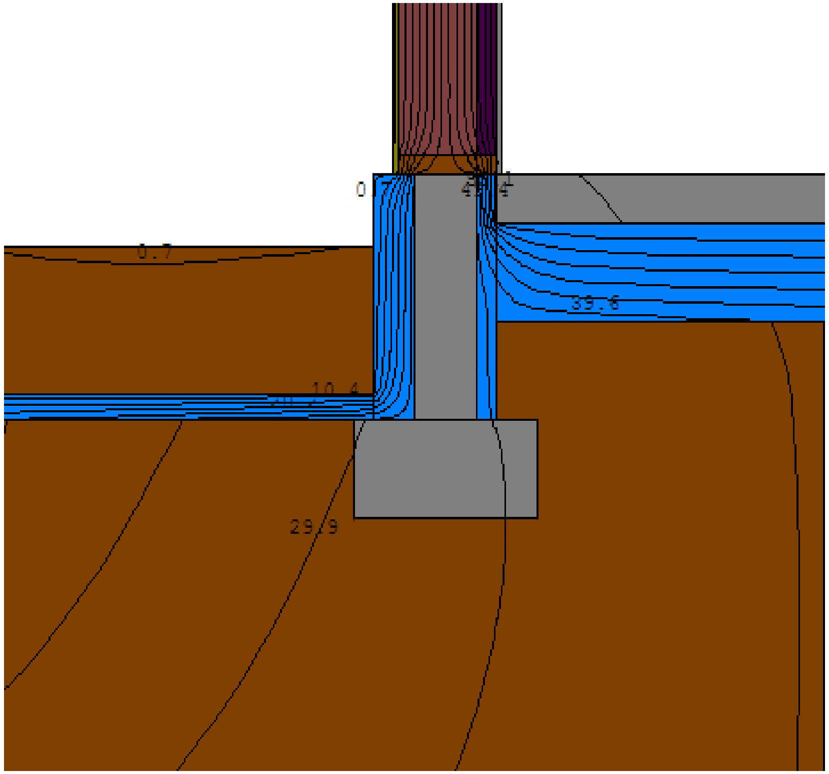
Thick layers of continuous insulation can improve the performance of the detail, but even a very well insulated FPSF is still **5x** higher than the 0.01 W/mK limit.

STEP 4 - Avoid accidental radiation fins - even well-insulated ones

Section 2 – Thermal Bridges Residential



FPSF (well insulated): Ψ = 0.052 W/mK



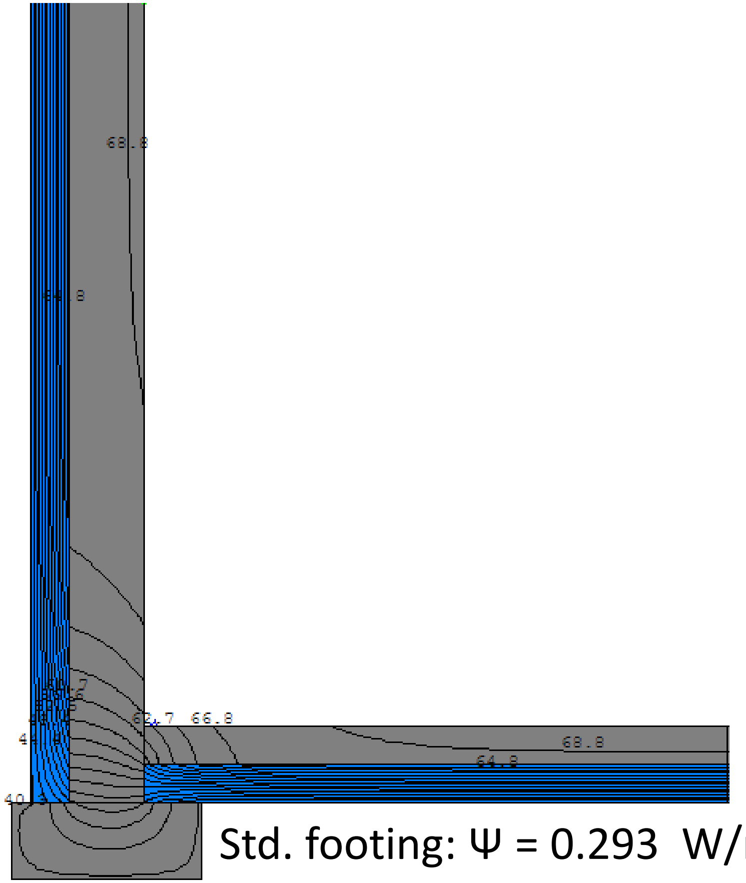
Thermally broken stem wall:Ψ = -0.007 W/mK

Thermally broken stem wall provides an insulated break between the stem wall and the floor slab, effectively cutting off the “radiation fin”.

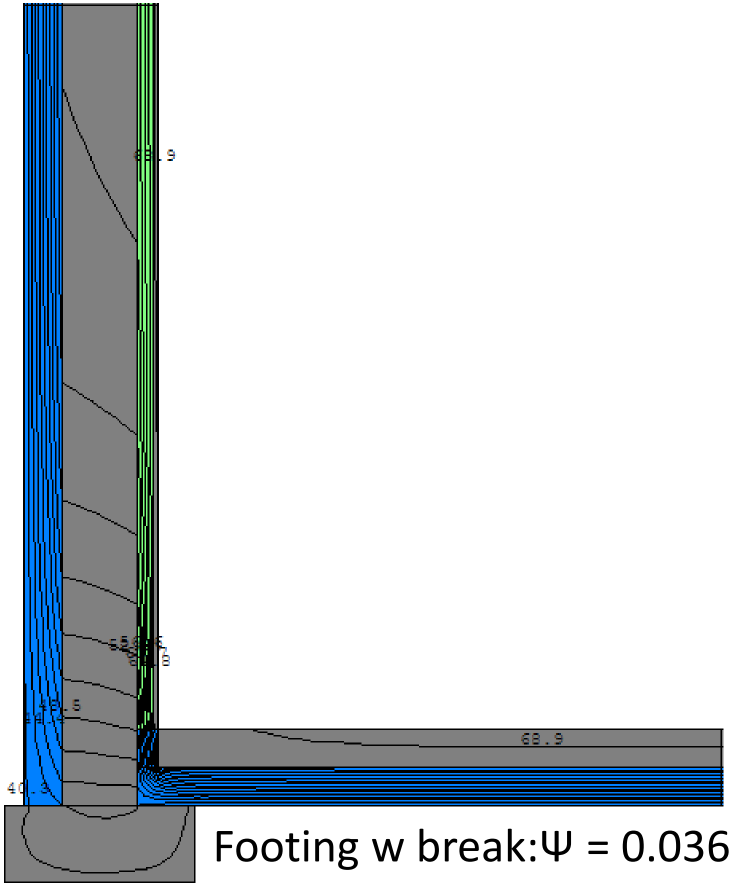
Also does better at aligning insulation layers at junction of stem wall and above grade wall.

STEP 5 – An insulated break between the exterior wall and floor slab is necessary.

Section 2 – Thermal Bridges Residential



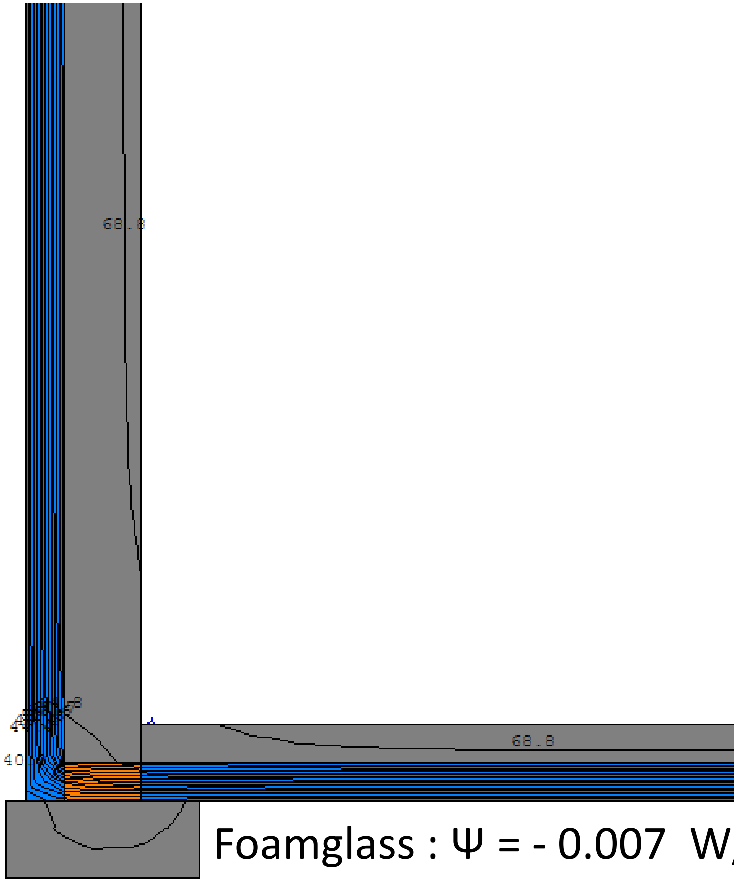
Std. footing: Ψ = 0.293 W/mK



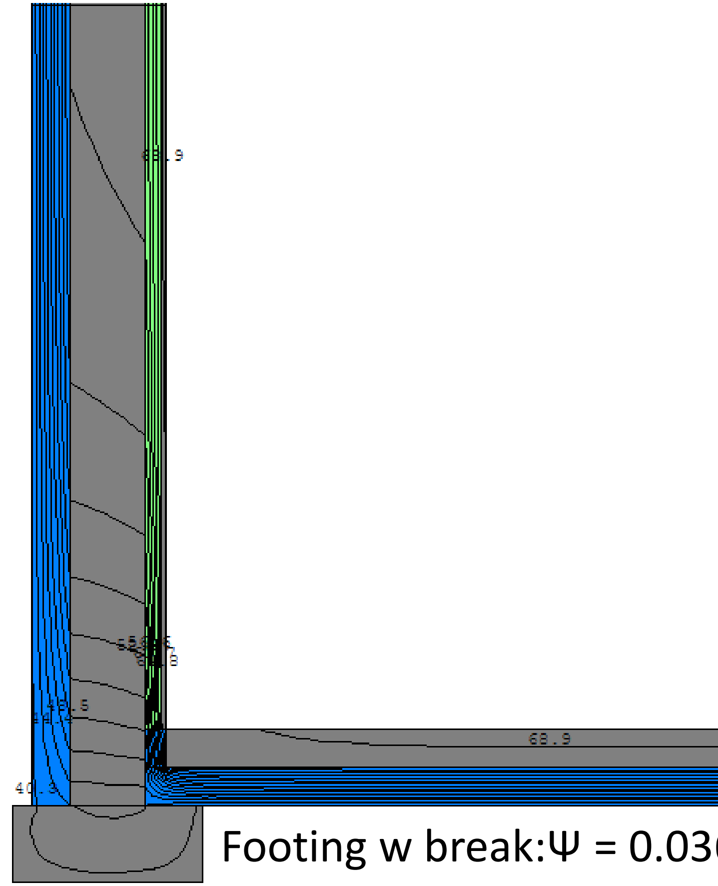
Footing w break:Ψ = 0.036 W/mK

Basement footings are another location to provide an insulated break between the foundation wall and the floor slab. A 2” thermal break reduces heat loss by almost a factor of 10. Doesn’t require insulation under the footing.

Section 2 – Thermal Bridges Residential



Foamglass : Ψ = - 0.007 W/mK



Footing w break:Ψ = 0.036 W/mK

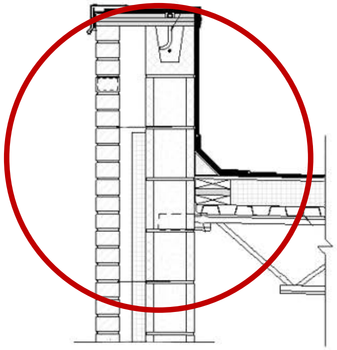
Another option – use Foamglass

Insulating cellular glass, designed for use in masonry construction:

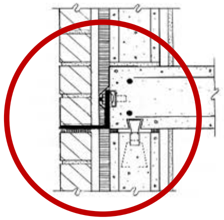
Compressive strength = 400psi, R-value = 2.5/inch

Section 3 – Thermal Bridges Commercial

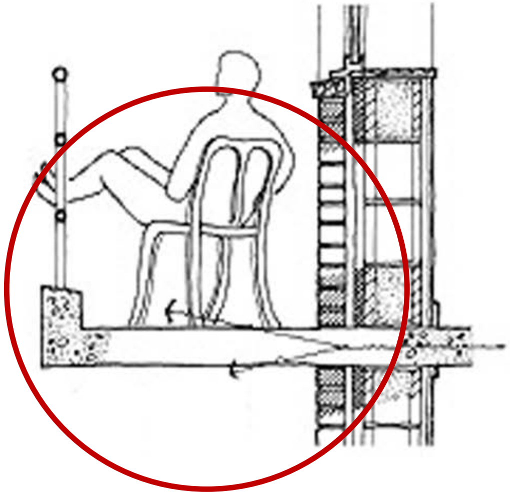
parapets



relieving angles



balconies



Thermal bridges

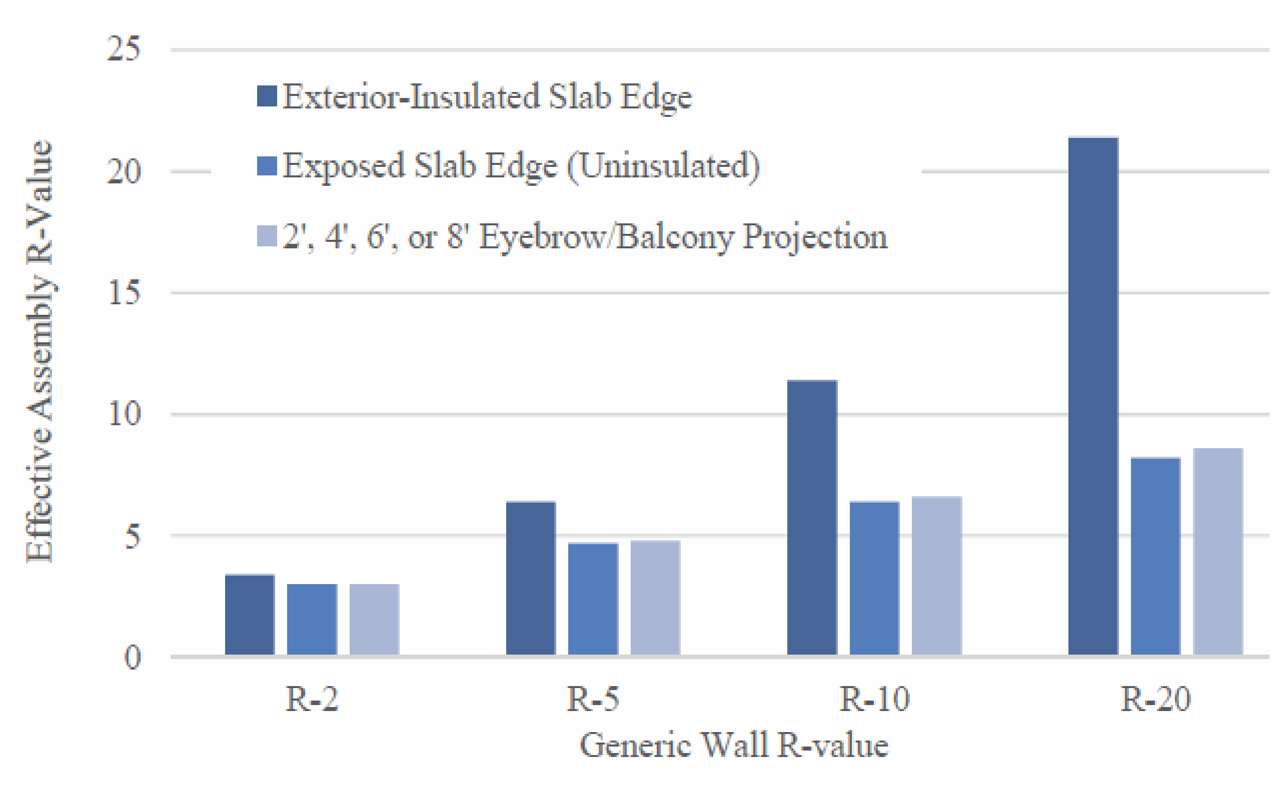
- repetitive bridges – already accounted for
- point bridges – can be larger in commercial construction
- linear bridges – heat loss should be calculated

Circled areas are common linear thermal bridges. Horizontal and vertical girts are also thermal bridges, though sometimes accounted for in R-value calculations.

Section 3 – Thermal Bridges Commercial

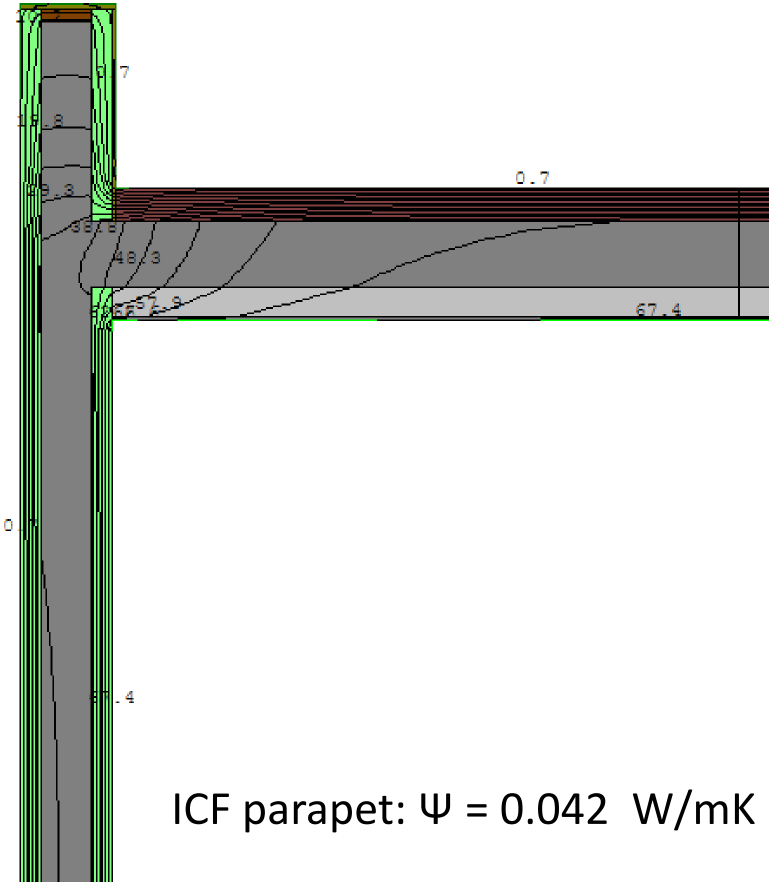
Commercial thermal bridges – do they matter?

- As R-value of the enclosure increases, the impact of thermal bridges grows larger.
- For an 8'8" tall wall insulated to R-20, the effective R-value drops to R-8.5 with an exposed slab edge or thermally unbroken balcony.
- Some typical commercial thermal bridges are really, really bad

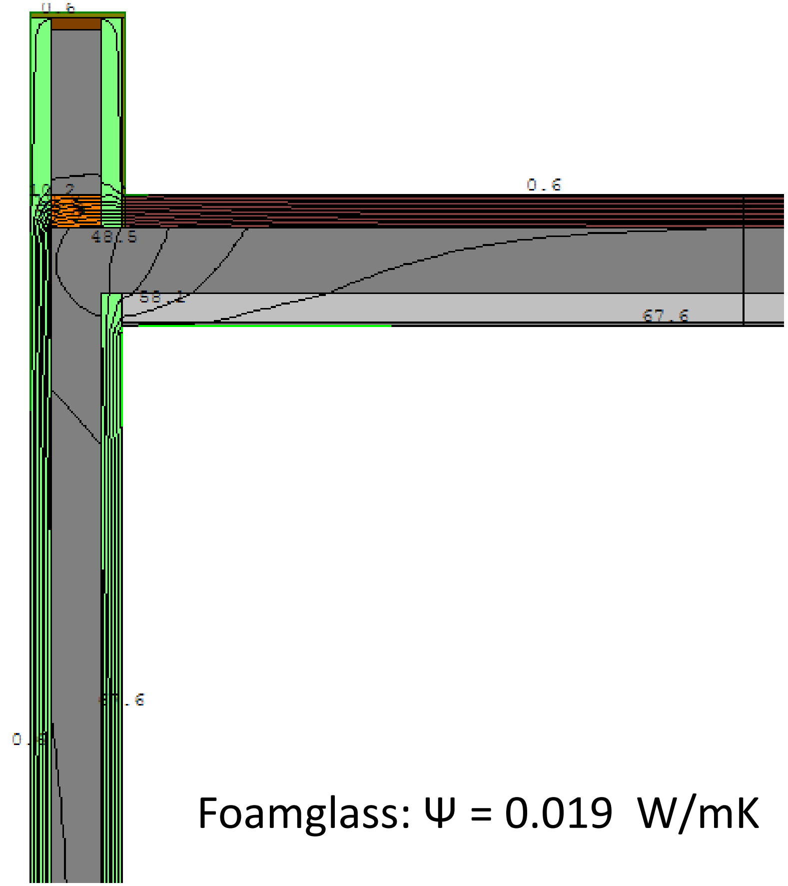


from Finch, G., Higgins, and Hanam, 2014

Section 3 – Thermal Bridges Commercial



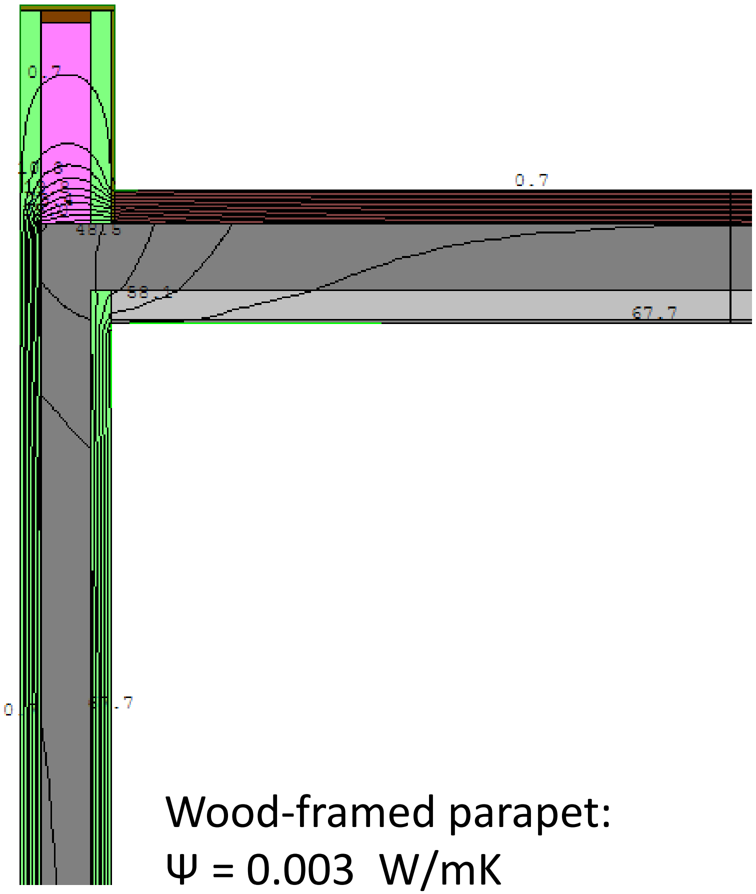
ICF parapet: Ψ = 0.042 W/mK



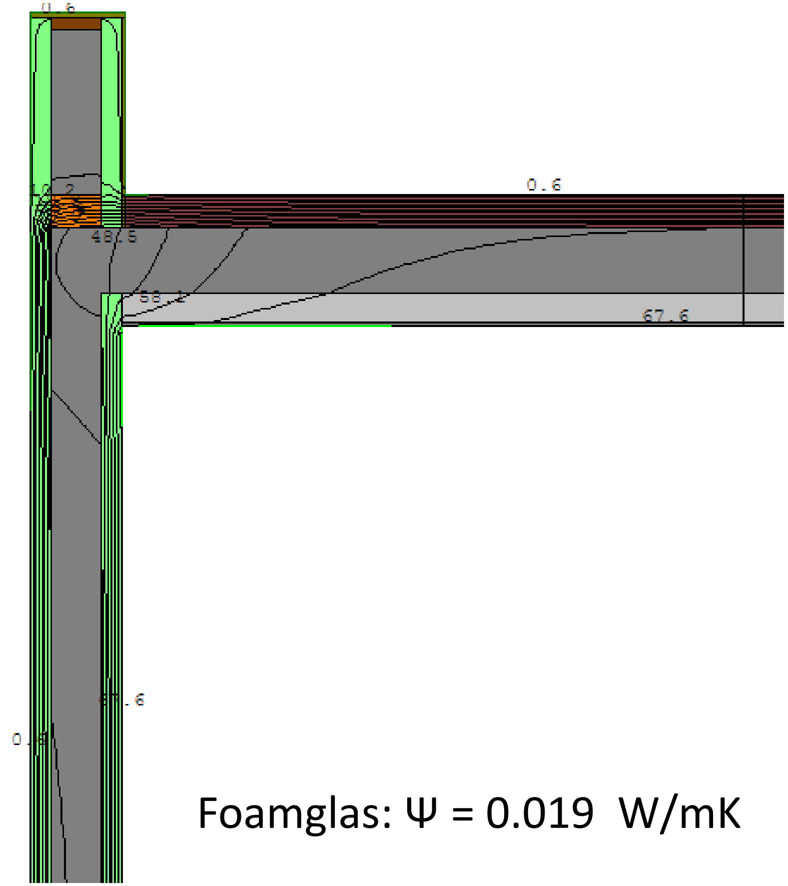
Foamglass: Ψ = 0.019 W/mK

Another good location to use Foamglas block, cuts heat loss by more than 50%.

Section 3 – Thermal Bridges Commercial



Wood-framed parapet:
Ψ = 0.003 W/mK



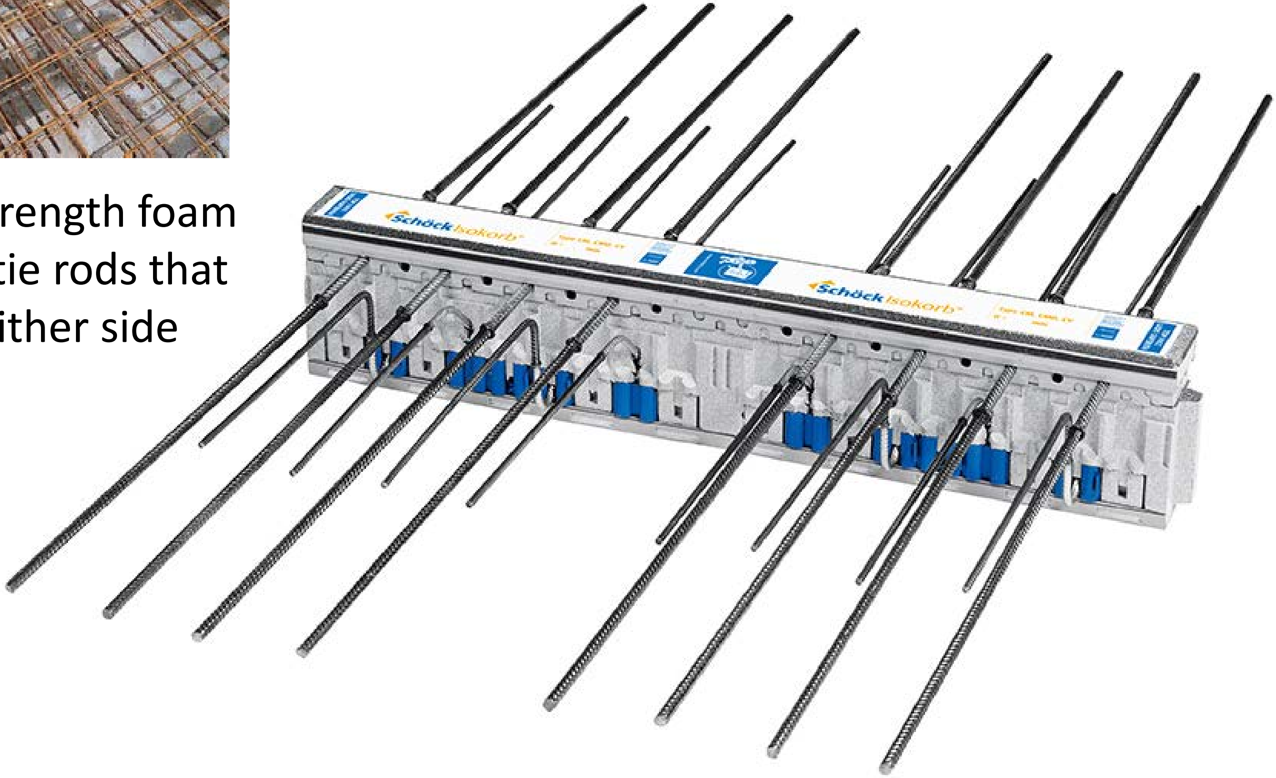
Foamglas: Ψ = 0.019 W/mK

But wood-framed parapet is the only detail to pass the 0.01 W/mK guideline.

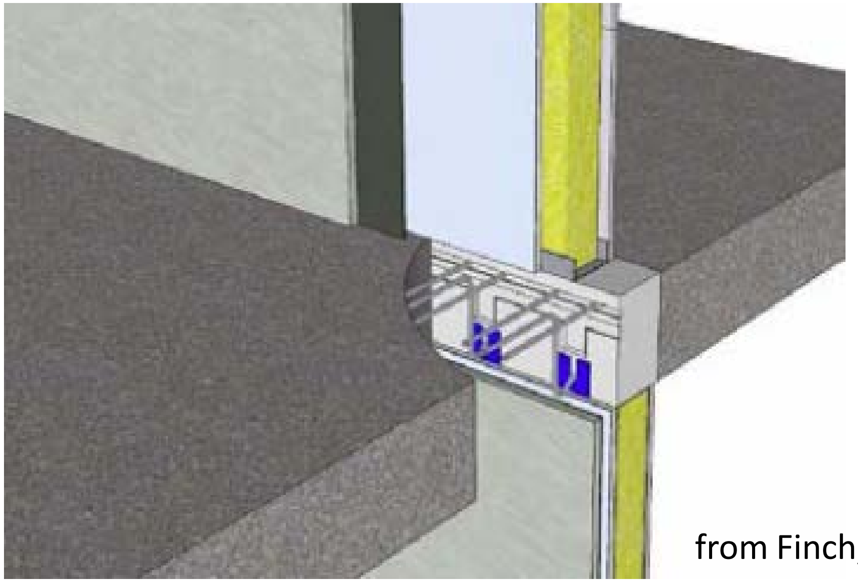
Section 3 – Thermal Bridges Commercial

Thermally broken balcony

A product with a high-strength foam core and stainless steel tie rods that connect with rebar on either side



Section 3 – Thermal Bridges Commercial



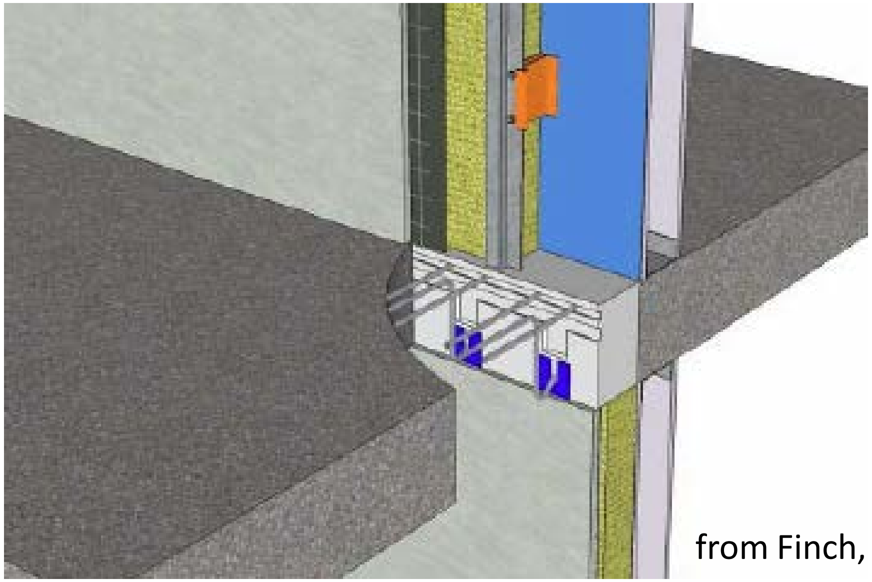
from Finch, G., Higgins, and Hanam, 2014

Steel stud insulated wall:

- Slab thermal break not incredibly important, too much heat lost through steel studs.

Exterior Insulation Strategy	Effective R-Value (R_{SI}), No Thermal Break	Effective R-Values (R_{SI})	
		R-2.5 Thermal Break	R-5.0 Thermal Break
6" steel studs with R-20 batt insulation	R-4.2 (R_{SI} –0.74)	R-4.7 (R_{SI} –0.82) (12% improvement)	R-4.8 (R_{SI} –0.85) (14% improvement)

Section 3 – Thermal Bridges Commercial



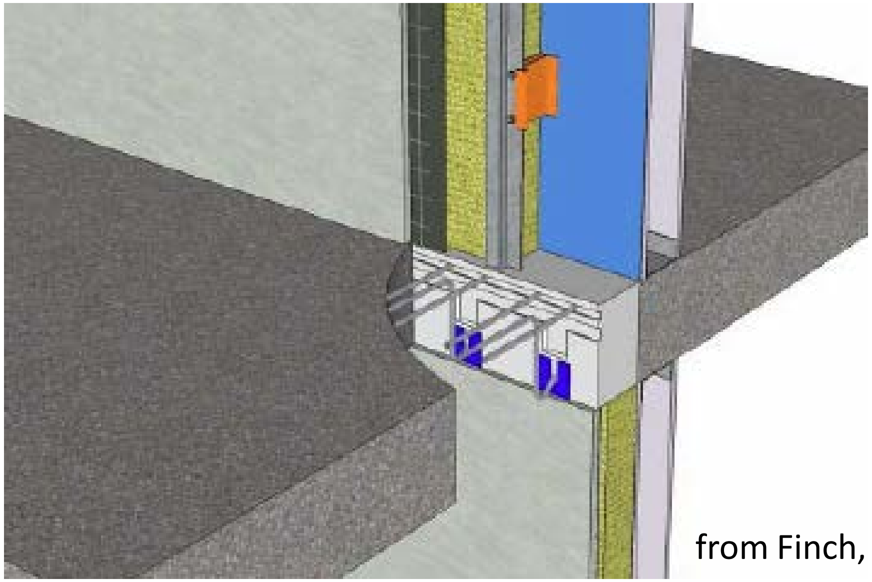
from Finch, G., Higgins, and Hanam, 2014

Steel stud, exterior insulation:

- With horizontal Z-girts, slab thermal break shows some benefit.

Exterior Insulation Strategy	Effective R-Value (R_{SI}), No Thermal Break	Effective R-Values (R_{SI})	
		R-2.5 Thermal Break	R-5.0 Thermal Break
Horizontal Z-girts @ 24" vertically, 4" MW (R-16) exterior + no insulation in S.S. @ 16" o.c.	R-6.5 (R_{SI} – 1.15)	R-8.2 (R_{SI} –1.44) (26% improvement)	R-8.6 (R_{SI} –1.52) (32% improvement)

Section 3 – Thermal Bridges Commercial



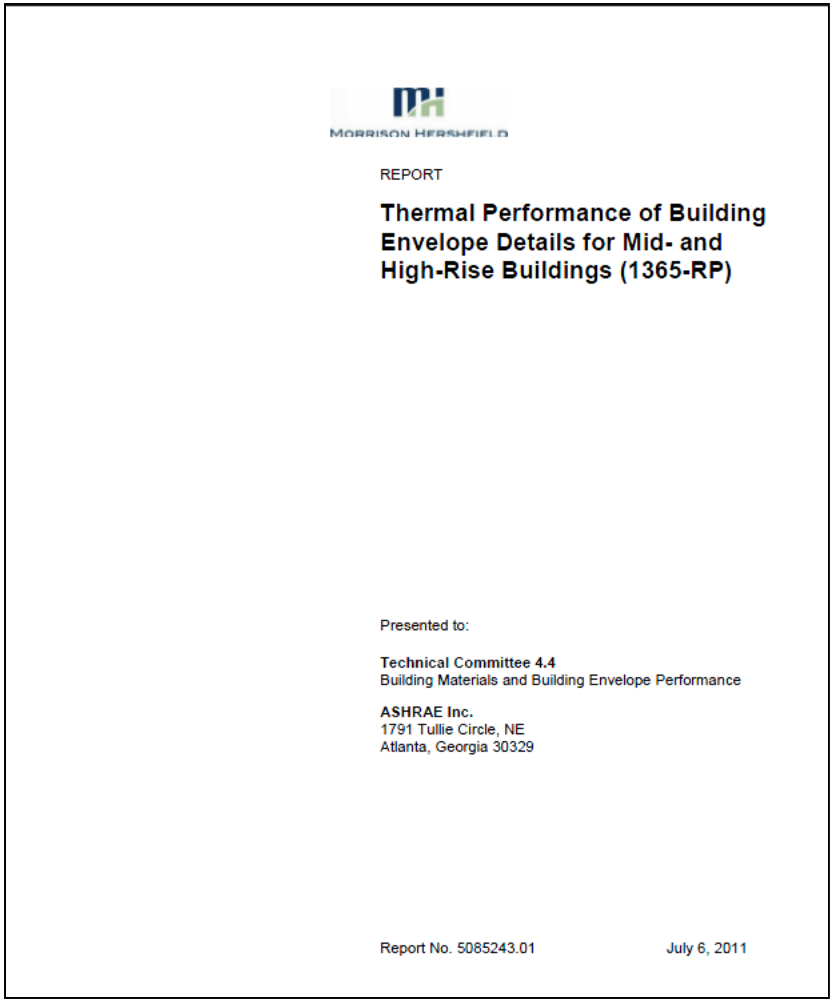
Steel stud, exterior insulation:

- Horizontal Z-girts still have too much heat loss, slab thermal break shows only minor improvement.
- Fiberglass clips (shown) increase R-value of the wall and make slab thermal break important and effective

from Finch, G., Higgins, and Hanam, 2014

Exterior Insulation Strategy	Effective R-Value (R_{SI}), No Thermal Break	Effective R-Values (R_{SI})	
		R-2.5 Thermal Break	R-5.0 Thermal Break
Nonconductive cladding clips 16"x24" spacing, 4" MW (R-16) exterior + no insulation in S.S. @ 16" o.c.	R-8.5 (R_{SI}– 1.50)	R-13.2 (R_{SI} –2.33) (55% improvement)	R-14.2 (R_{SI} –2.50) (67% improvement)
Horizontal Z-girts @ 24" vertically, 4" MW (R-16) exterior + no insulation in S.S. @ 16" o.c.	R-6.5 (R_{SI} – 1.15)	R-8.2 (R_{SI} –1.44) (26% improvement)	R-8.6 (R_{SI} –1.52) (32% improvement)

Section 3 – Thermal Bridges Commercial


MORRISON HERSHFIELD

REPORT

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

Presented to:

Technical Committee 4.4
Building Materials and Building Envelope Performance

ASHRAE Inc.
1791 Tullie Circle, NE
Atlanta, Georgia 30329

Report No. 5085243.01 July 6, 2011

ASHRAE 1365, by Morrison Hershfield

Thermal bridging for commercial assemblies.

40 building details for mid and high-rise construction:

- Exterior Insulated Steel Stud Assemblies
- Slab and Floor Edges
- Parapets
- Glazing and Wall Intersections
- Poured-In-place Concrete Assemblies
- Conventional Curtain Wall Spandrel Panels
- Sliding Doors and Windows

Section 4 – High Performance Windows

Some basics…

U-value – inverse of R-value

R-3 window = U-0.33

R-5 window = U-0.2

SHGC – "solar heat gain coefficient". Percentage of solar heat that is passed through the window.

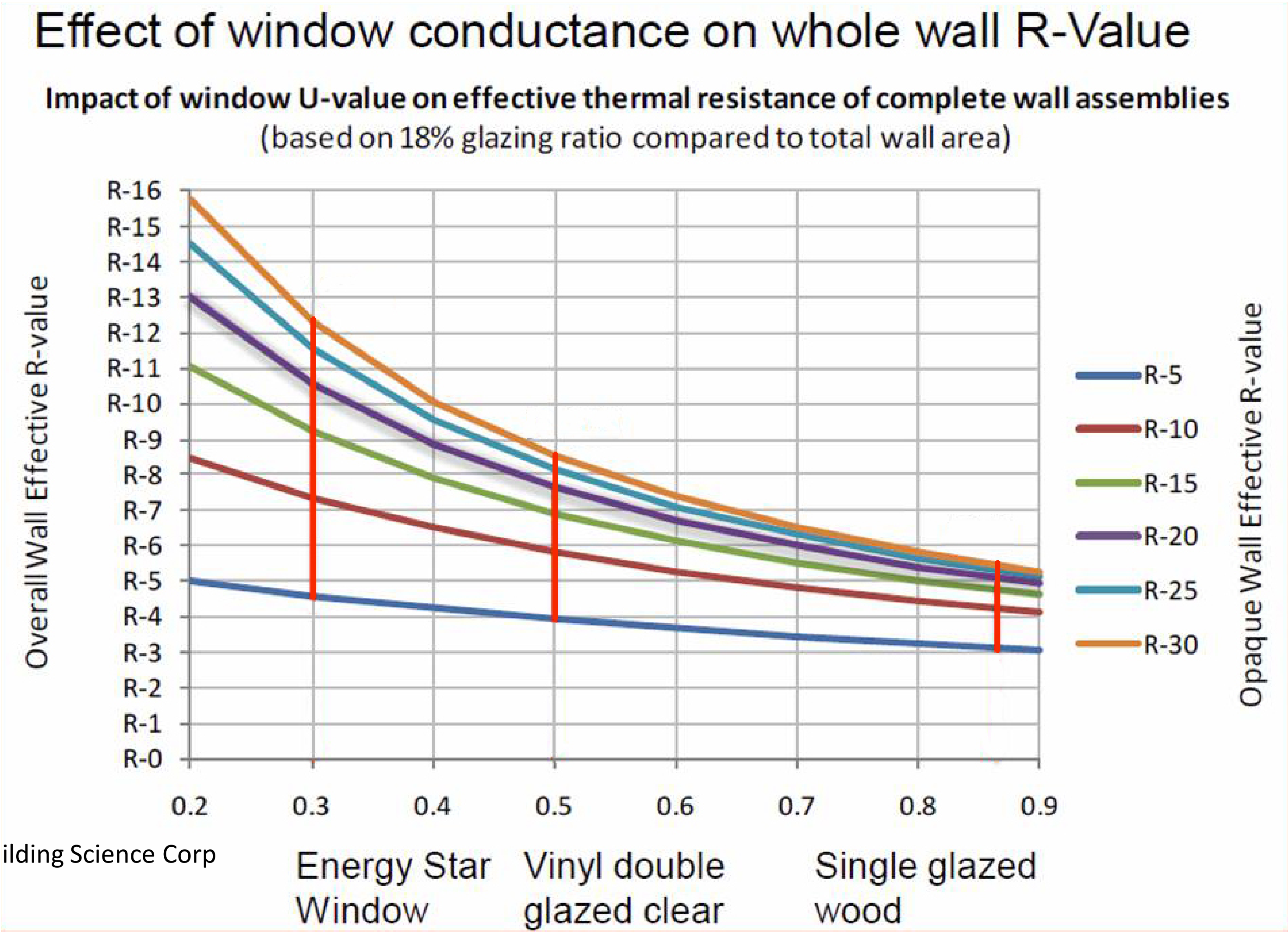
SHGC 0.3 means 30% of solar heat is admitted.

VT – "visible transmittance". Percentage of visible light that is passed through the window.

VT-0.4 means 40% of visible light is admitted.

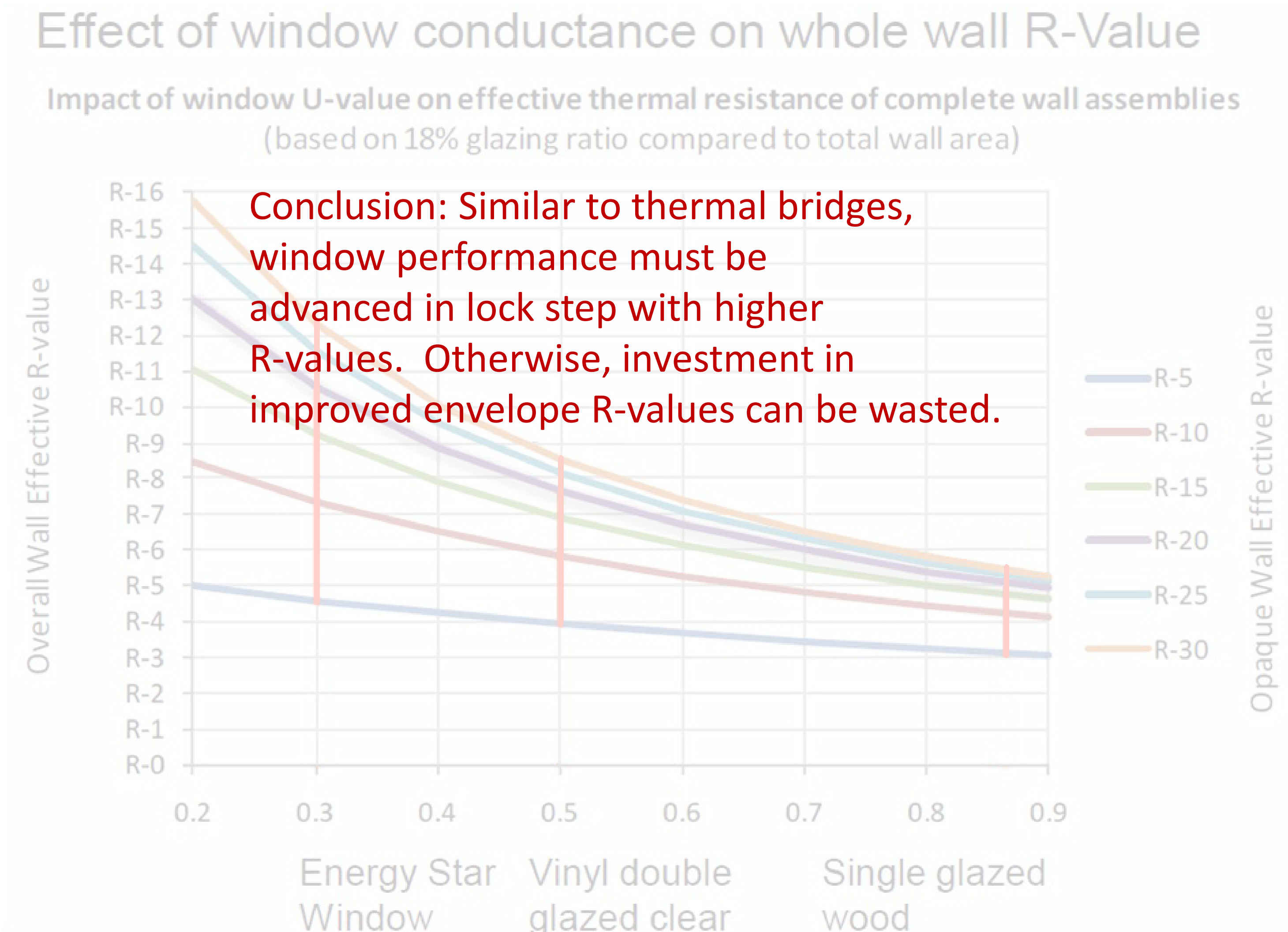
The VT, SHGC and U-values we'll be discussing are whole window values, not center of glass. This is an important distinction, and takes into the account the effects of the frame

Section 4 – High Performance Windows



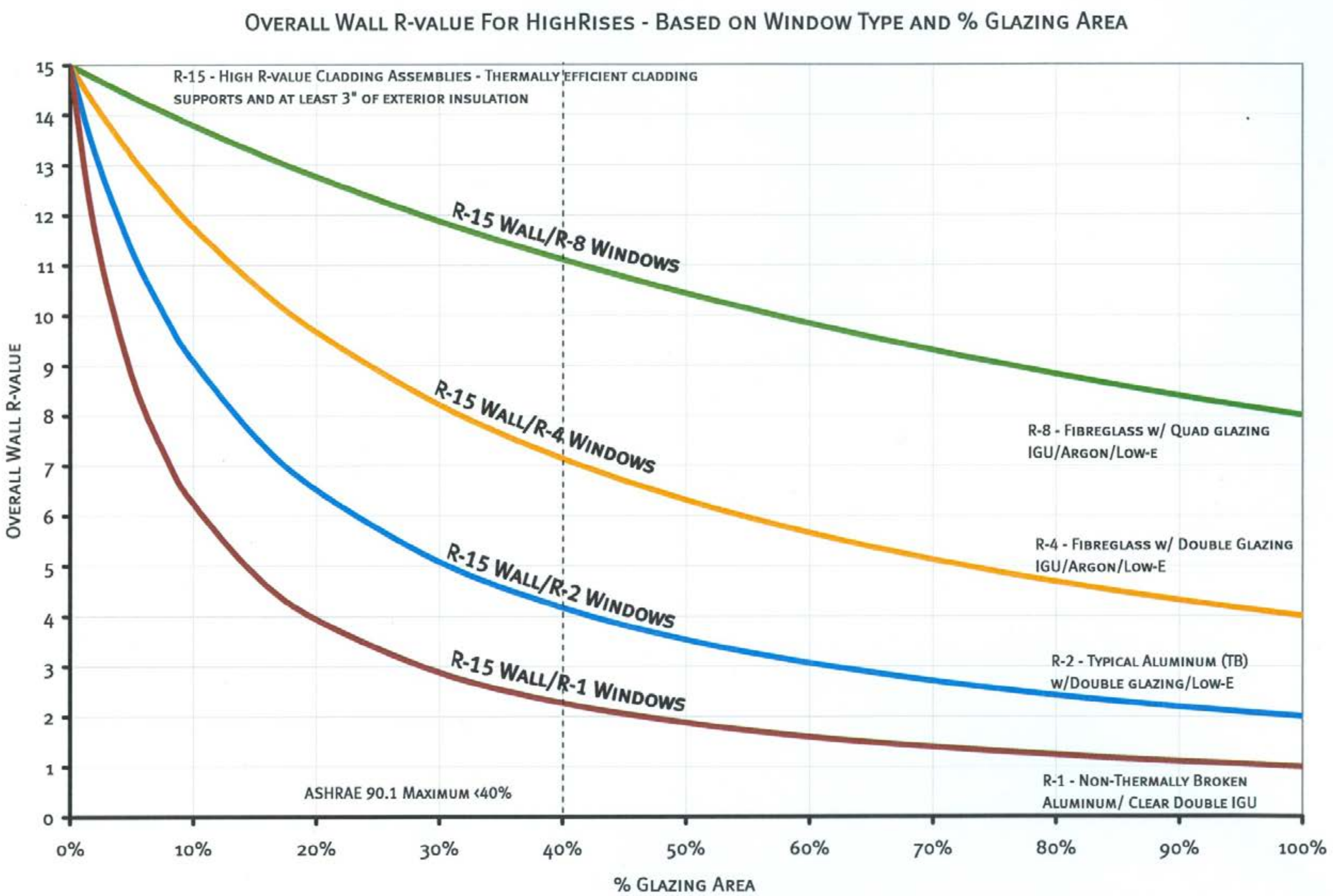
graph from Building Science Corp

Section 4 – High Performance Windows



Conclusion: Similar to thermal bridges, window performance must be advanced in lock step with higher R-values. Otherwise, investment in improved envelope R-values can be wasted.

Section 4 – High Performance Windows

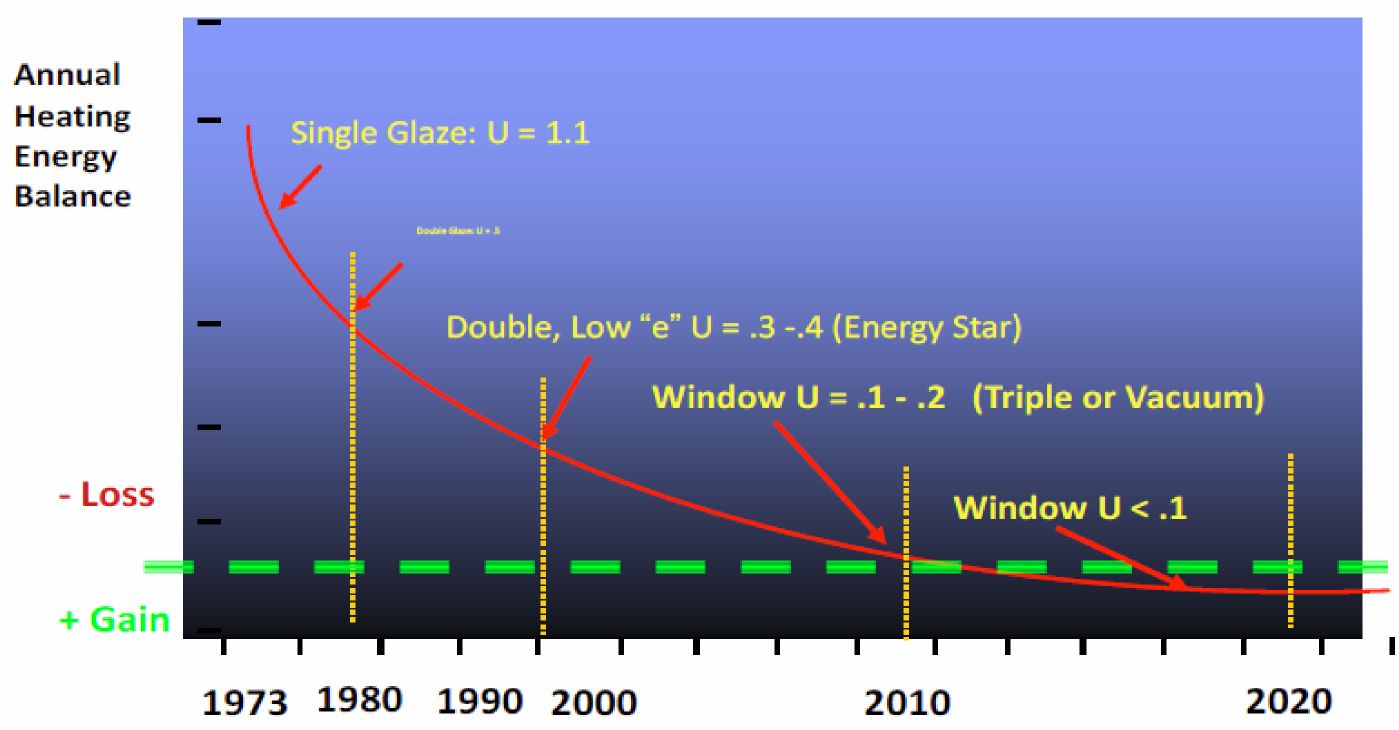


Section 5 – Residential Windows

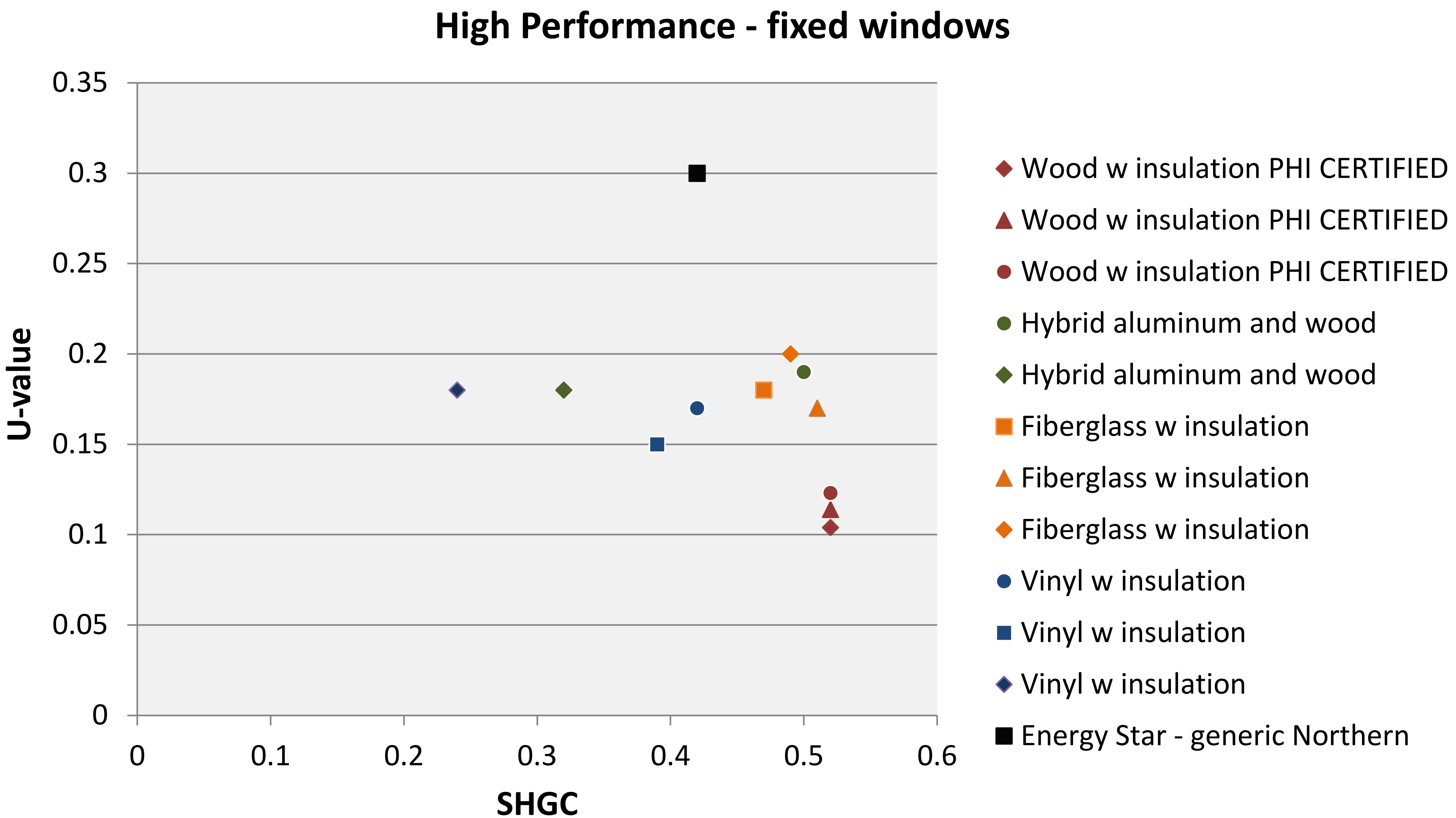
Residential Windows – important attributes (from energy perspective)

- U-value
- SHGC (solar heat gain coefficient)
- It's the combination of low U-value and high SHGC that is desirable for south-facing windows in cold climates (and also hard to find)

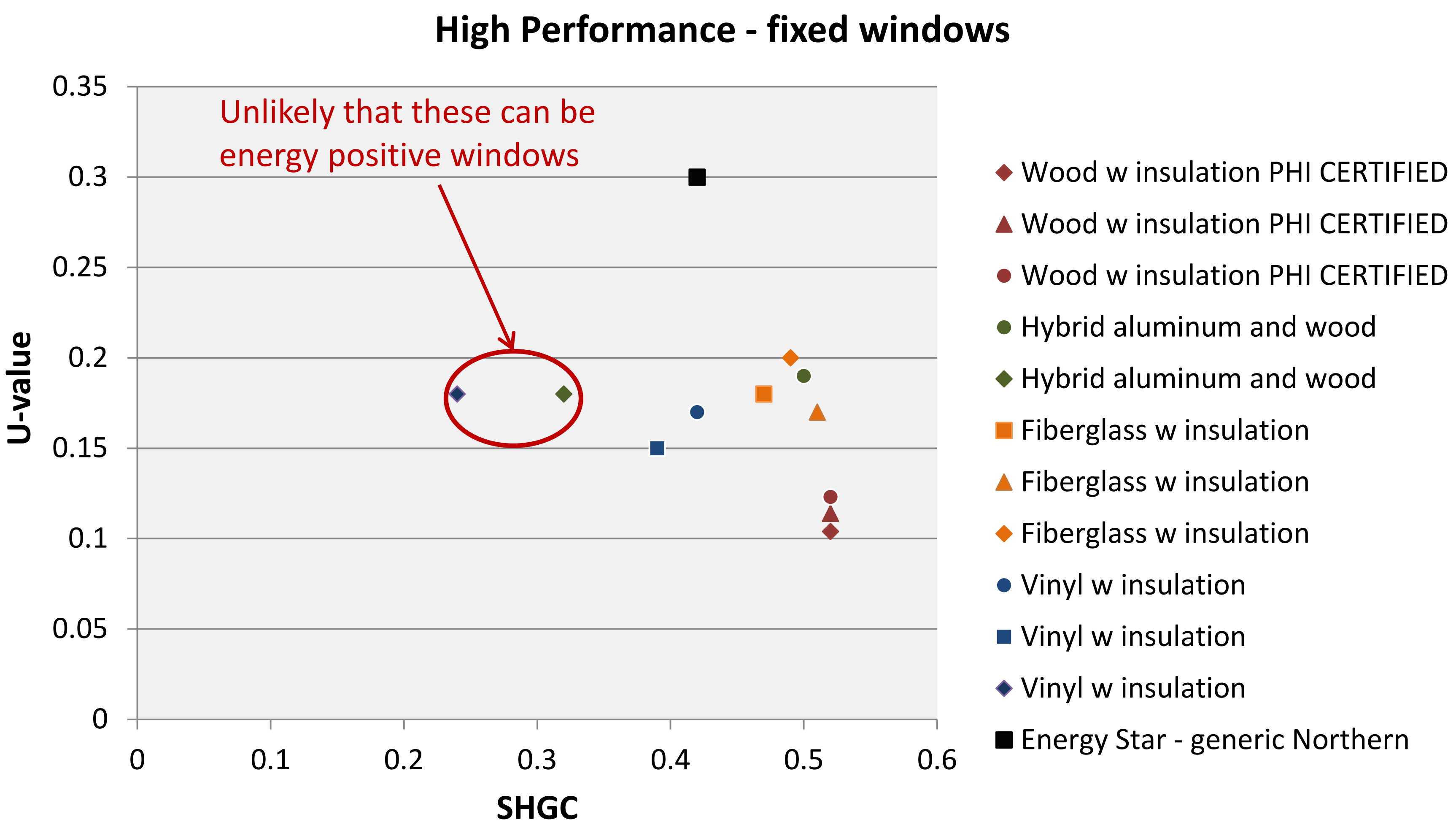
In general, windows with U-0.1 – U-0.2 can become energy positive depending on their SHGC and shading.



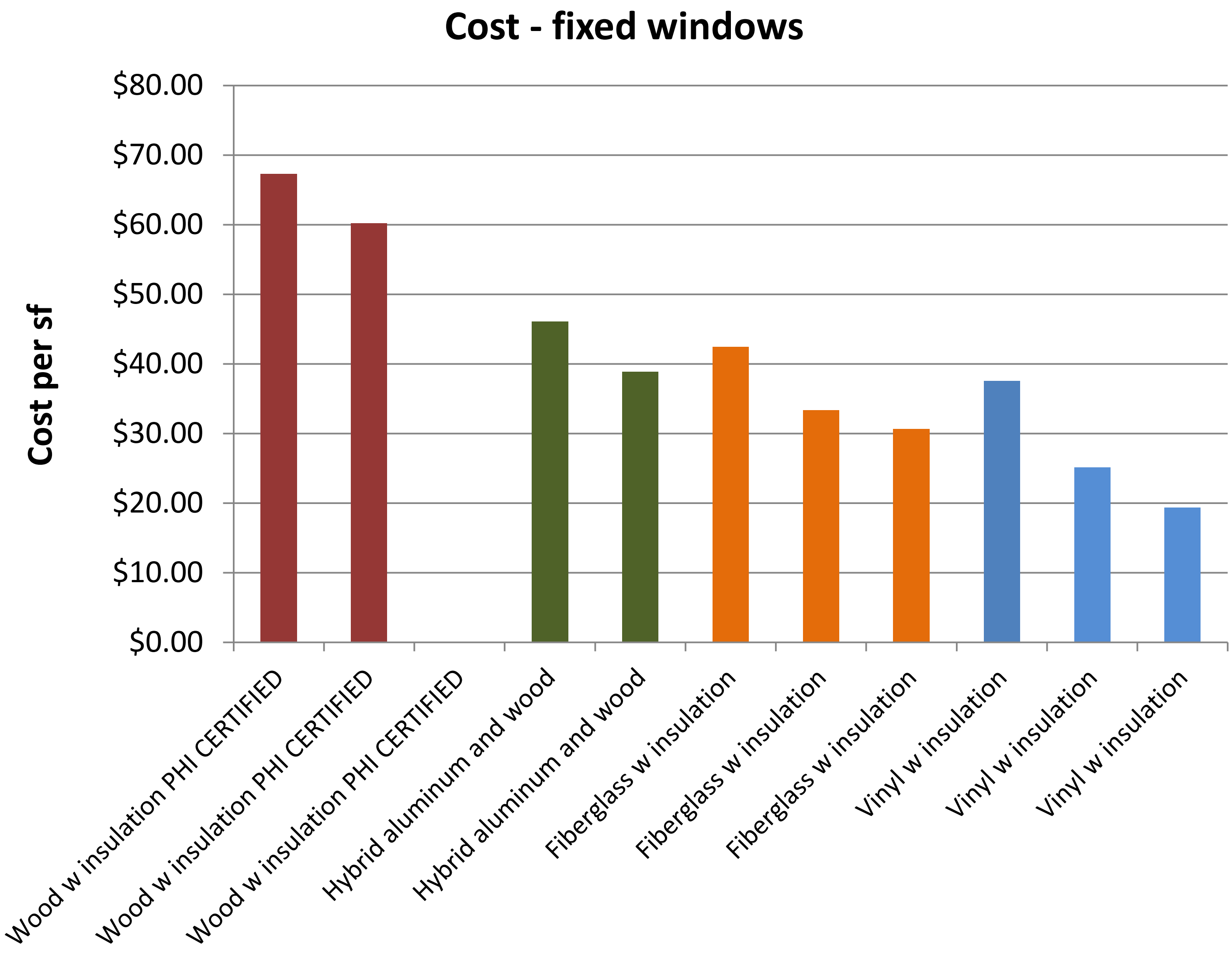
Section 5 – Residential Windows



Section 5 – Residential Windows

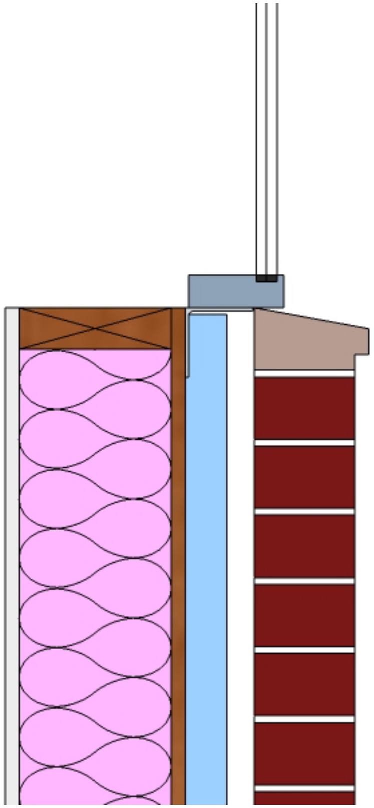


Section 5 – Residential Windows



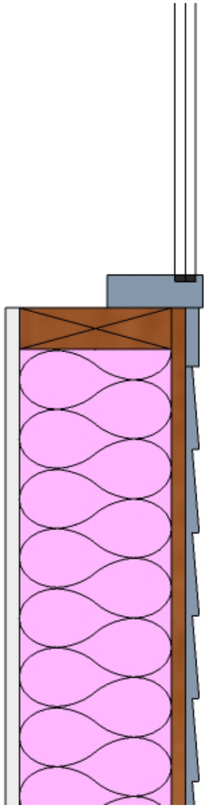
Solid wood w insulation, hybrid aluminum/wood, insulated fiberglass, insulated vinyl

Section 5 – Residential Windows



Window positioned outside of thermal envelope, Ψ = 0.10 W/mK

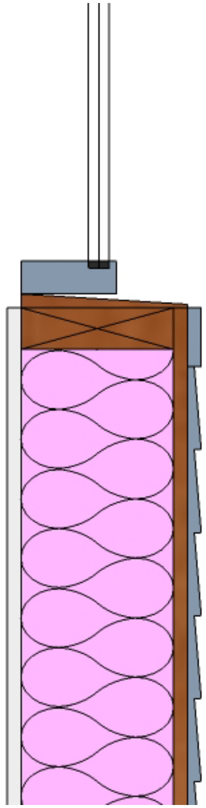
Effectively, R-value of window reduced by 20 - 30% depending on window size



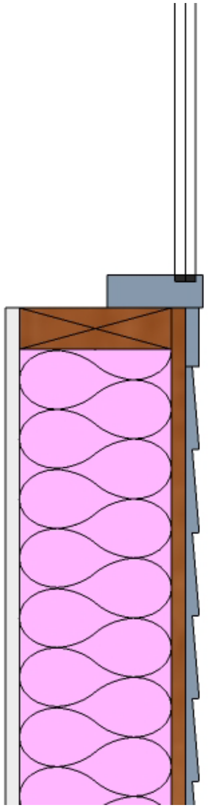
Window positioned on edge of thermal envelope, Ψ = 0.04 W/mK

R-value of window reduced by 5 - 10% depending on window size

Section 5 – Residential Windows



Window centered in plane of insulation, Ψ = 0.02 W/mK
R-value of window is essentially preserved



Window positioned on edge of thermal envelope, Ψ = 0.04 W/mK
R-value of window reduced by 5 - 10% depending on window size

Section 6 – Commercial Windows

While heating loads dominate residential construction energy use…

Figure 2-17. Total energy end uses for different building types

Data are given for the entire existing U.S. building stock (old and new buildings throughout the U.S.). Data have been normalized using a site-source efficiency of 0.33 for electricity end uses and 1.0 for natural gas end uses. Source: EIA, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*, Oct. 1998, Table EU-2, p. 311.

Principal Building Activity	Heating	Cooling	Lighting	Equipment	Ventilation	Refrig.	Water Heating	Cooking	Other
Education	26%	11%	37%	3%	4%	2%	14%	1%	2%
Food sales	5%	7%	19%	1%	2%	61%	2%	1%	1%
Food service	7%	13%	25%	2%	4%	22%	6%	18%	3%
Health care	14%	8%	30%	12%	5%	4%	16%	3%	9%
Lodging	11%	12%	34%	6%	2%	3%	25%	3%	4%
Mercantile and service	21%	12%	48%	6%	5%	2%	3%	1%	3%
Office	11%	13%	40%	21%	7%	1%	4%	1%	2%
Public assembly	29%	10%	35%	4%	6%	3%	9%	2%	2%
Public order and safety	18%	12%	31%	11%	4%	0%	15%	0%	8%
Religious worship	43%	10%	27%	2%	5%	3%	6%	1%	2%
Warehouse and storage	22%	4%	41%	18%	1%	7%	3%	0%	5%

Section 6 – Commercial Windows

While heating loads dominate residential construction energy use…

Figure 2-17. Total energy end uses for different building types

Data are given for the entire existing U.S. building stock (old and new buildings throughout the U.S.). Data have been normalized using a site-source efficiency of 0.33 for electricity end uses and 1.0 for natural gas end uses. Source: EIA, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*, Oct. 1998, Table EU-2, p. 311.

Principal Building Activity	Heating	Cooling	Lighting	Equipment	Ventilation	Refrig.	Water Heating	Cooking	Other
Education	26%	11%	37%	3%	4%	2%	14%	1%	2%
Food sales	5%	7%	19%	1%	2%	61%	2%	1%	1%
Food service	7%	13%	25%	2%	4%	22%	6%	18%	3%
Health care	14%	8%	30%	12%	5%	4%	16%	3%	9%
Lodging	11%	12%	34%	6%	2%	3%	25%	3%	4%
Mercantile and service	21%	12%	48%	6%	5%	2%	3%	1%	3%
Office	11%	13%	40%	21%	7%	1%	4%	1%	2%
Public assembly	29%	10%	35%	4%	6%	3%	9%	2%	2%
Public order and safety	18%	12%	31%	11%	4%	0%	15%	0%	8%
Religious worship	43%	10%	27%	2%	5%	3%	6%	1%	2%
Warehouse and storage	22%	4%	41%	18%	1%	7%	3%	0%	5%

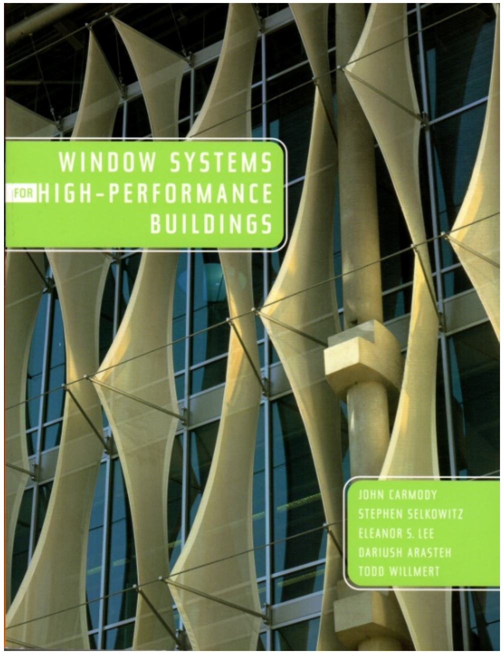
… Lighting is typically the most important for commercial-type buildings.

Section 6 – Commercial Windows

Commercial Windows – important attributes (from energy perspective)

- U-value – primarily impacts perimeter heating loads
- SHGC (solar heat gain coefficient) – primarily impacts cooling loads
- VT (visible transmittance) – primarily impacts lighting loads (and therefore cooling loads as well)

The combination of all three variables make "the best" commercial window very difficult to identify for any given building type, window area, and orientation. Energy modeling is necessary.



Some of the best guidance is available from the book - Window Systems for High-Performance Buildings

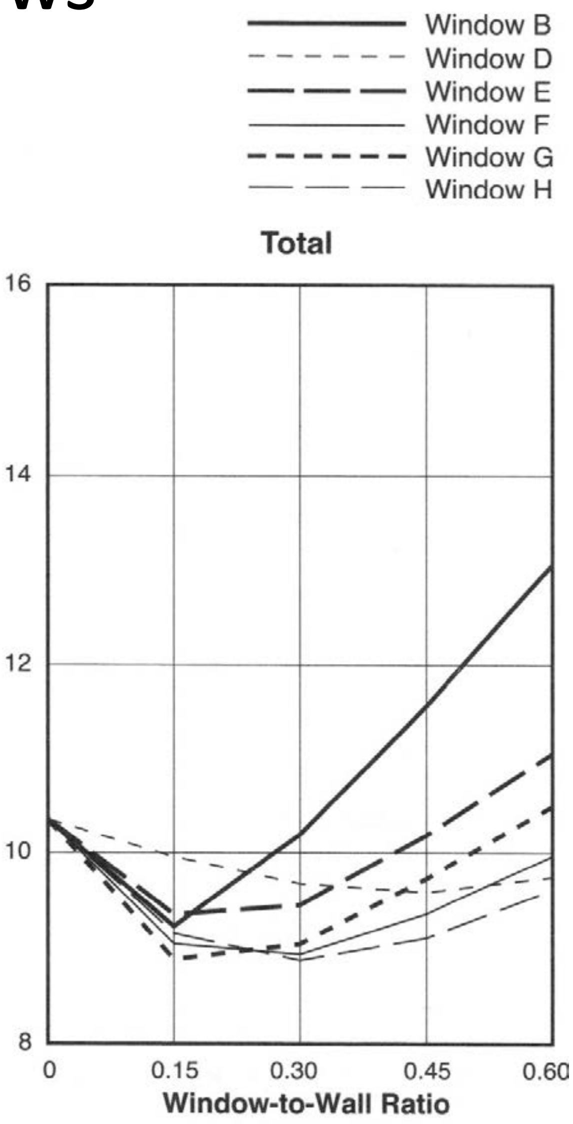
And website – www.commercialwindows.org

Section 6 – Commercial Windows

Commercial Windows – annual energy use as a function of window-to-wall ratio (WWR) for perimeter office zones

Where does the characteristic hockey stick shape come from?

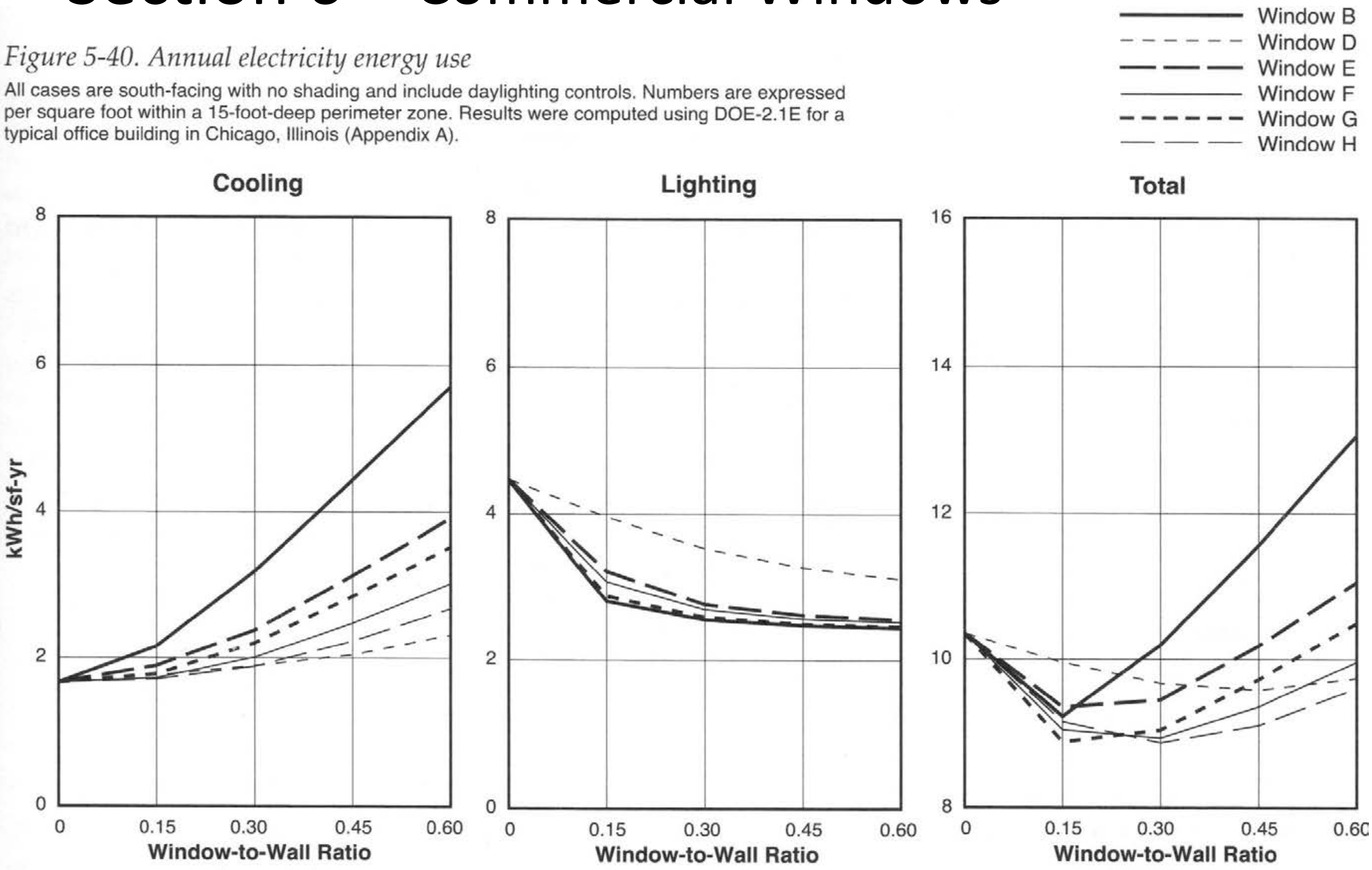
And why does it look so easy to achieve better performance than an insulated wall?



Section 6 – Commercial Windows

Figure 5-40. Annual electricity energy use

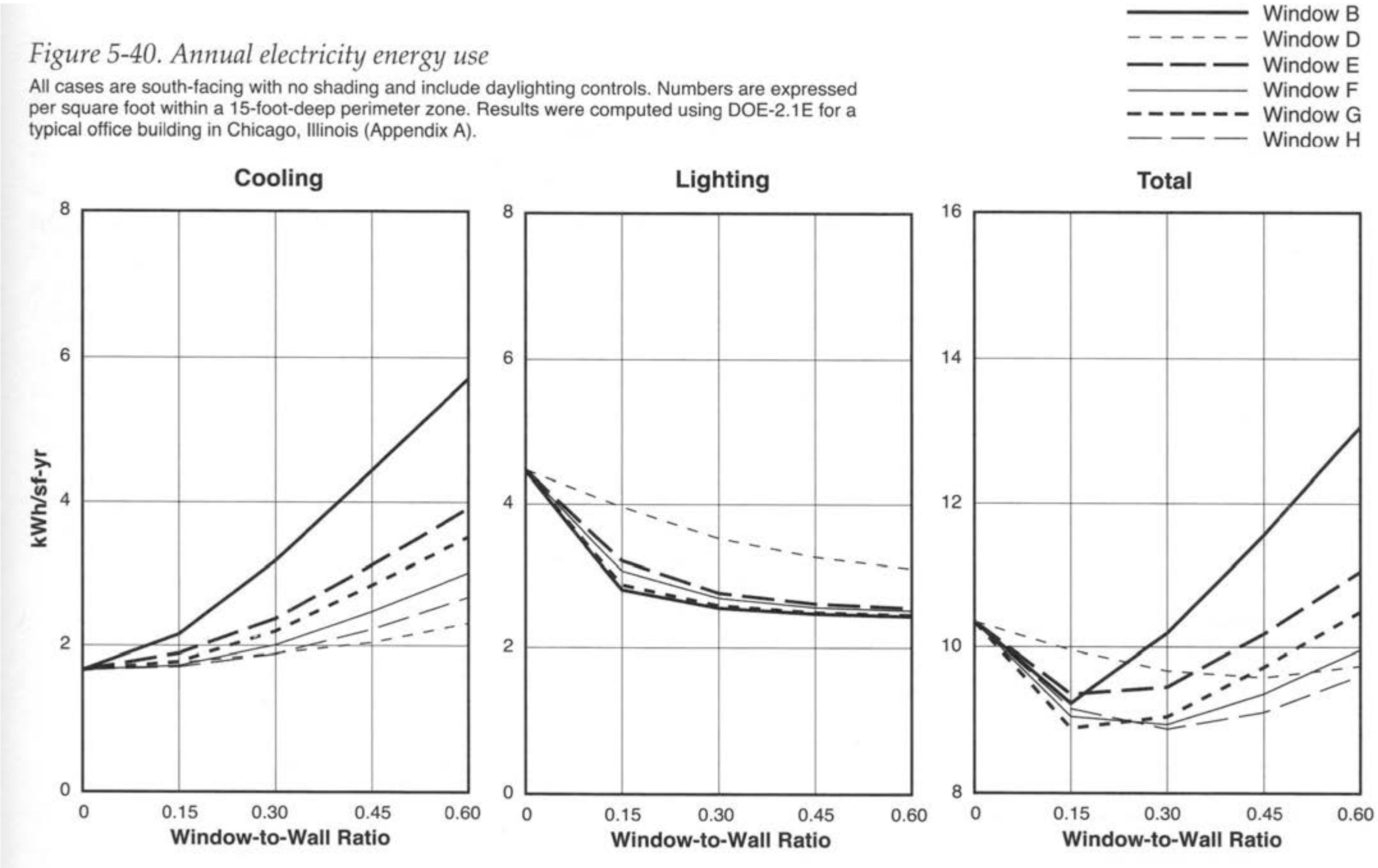
All cases are south-facing with no shading and include daylighting controls. Numbers are expressed per square foot within a 15-foot-deep perimeter zone. Results were computed using DOE-2.1E for a typical office building in Chicago, Illinois (Appendix A).



Section 6 – Commercial Windows

In general, the challenge is to reduce lighting energy use as far as possible before increasing heating and cooling loads begin to dominate.

Lower U-values and SHGC values allow us to delay the increasing impact of heating and cooling loads as long as possible.



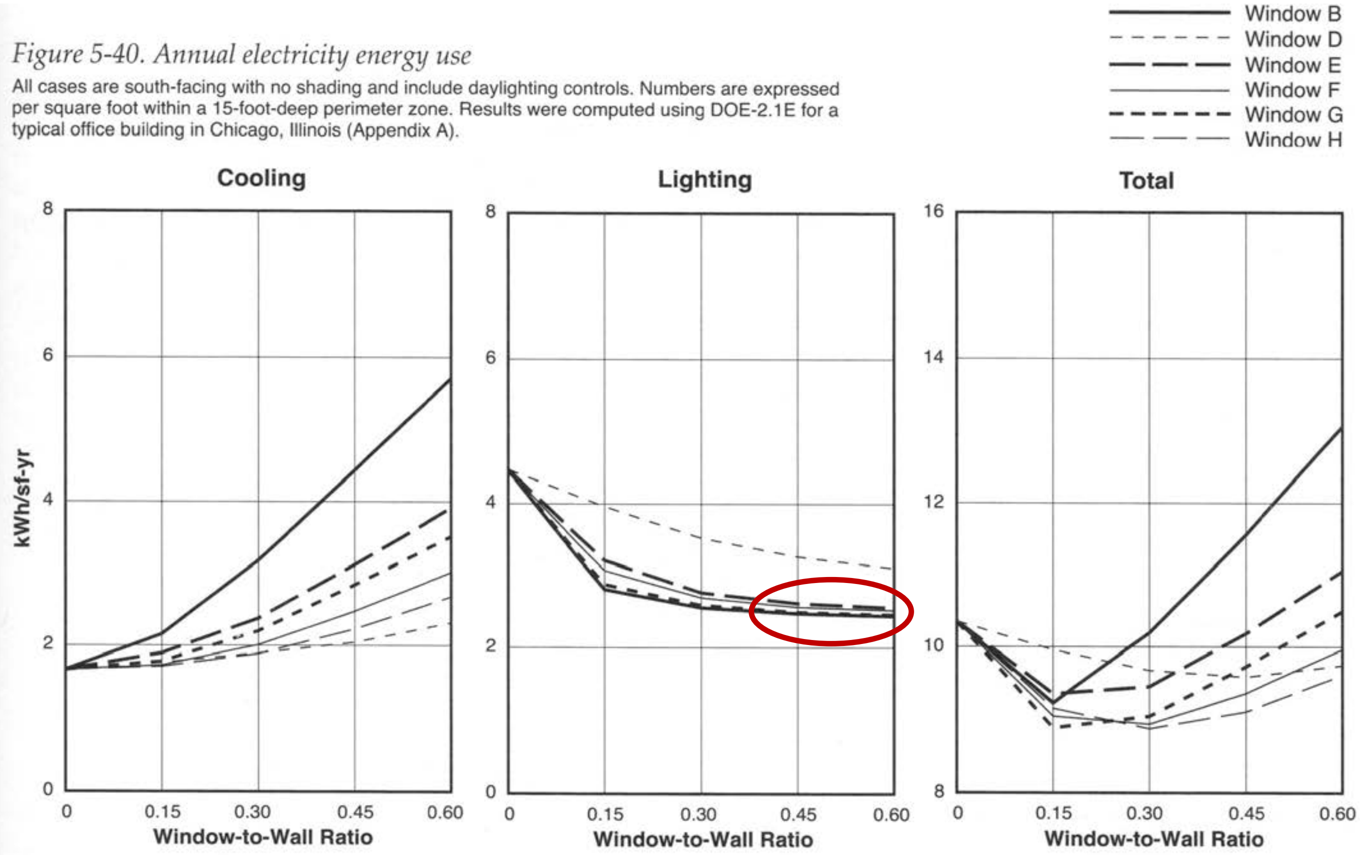
Section 6 – Commercial Windows

In general, the challenge is to reduce lighting energy use as far as possible before increasing heating and cooling loads begin to dominate.

At high WWR, the importance of VT values goes down.

Figure 5-40. Annual electricity energy use

All cases are south-facing with no shading and include daylighting controls. Numbers are expressed per square foot within a 15-foot-deep perimeter zone. Results were computed using DOE-2.1E for a typical office building in Chicago, Illinois (Appendix A).



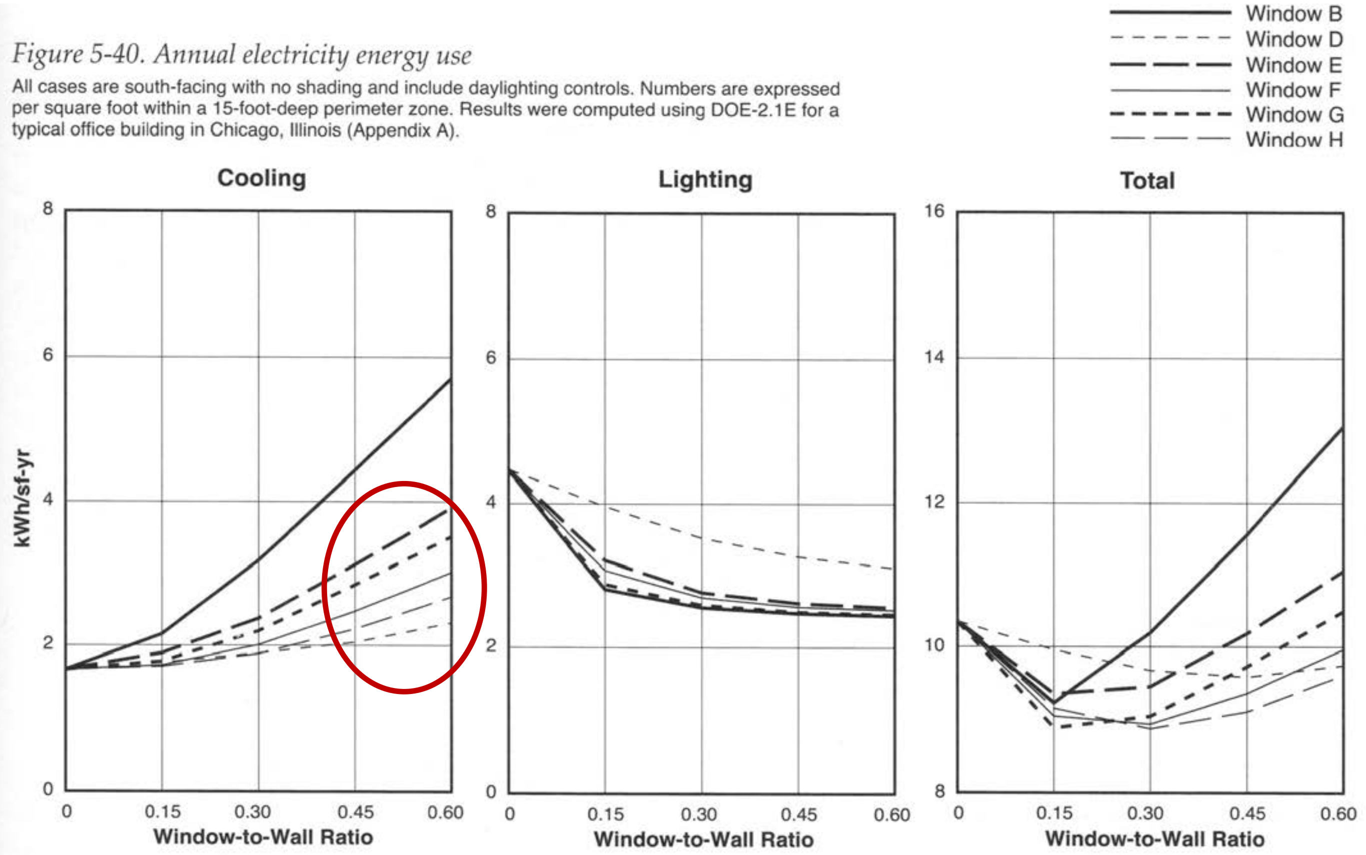
Section 6 – Commercial Windows

In general, the challenge is to reduce lighting energy use as far as possible before increasing heating and cooling loads begin to dominate.

But the importance of U-value and SHGC value goes up.

Figure 5-40. Annual electricity energy use

All cases are south-facing with no shading and include daylighting controls. Numbers are expressed per square foot within a 15-foot-deep perimeter zone. Results were computed using DOE-2.1E for a typical office building in Chicago, Illinois (Appendix A).



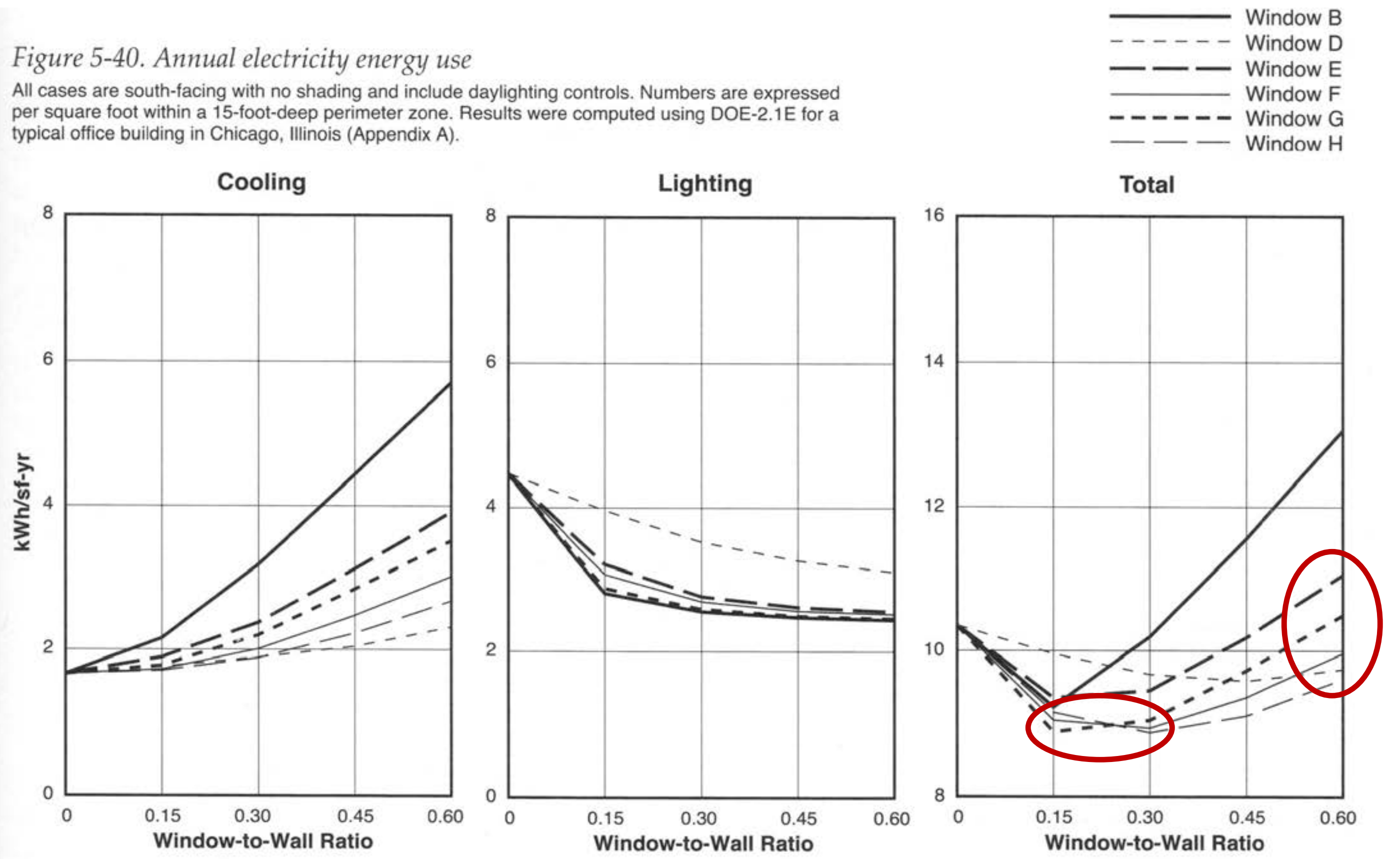
Section 6 – Commercial Windows

In general, the challenge is to reduce lighting energy use as far as possible before increasing heating and cooling loads begin to dominate.

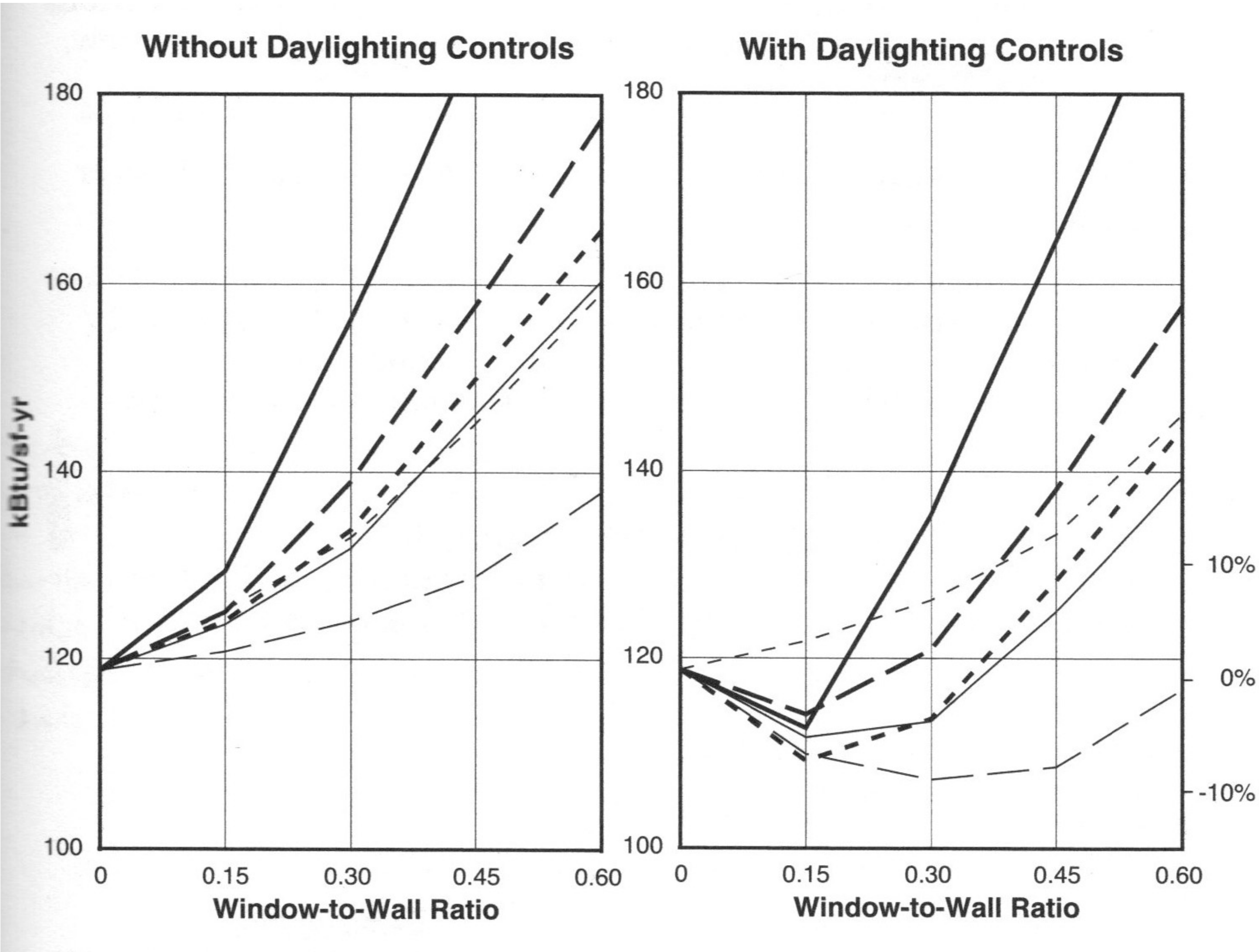
High WWR is rarely desirable from an energy standpoint.

Figure 5-40. Annual electricity energy use

All cases are south-facing with no shading and include daylighting controls. Numbers are expressed per square foot within a 15-foot-deep perimeter zone. Results were computed using DOE-2.1E for a typical office building in Chicago, Illinois (Appendix A).



Section 6 – Commercial Windows, E/W/S



Window B 2-glazing, clear
U-0.60 SHGC=0.60 VT=0.63

Window D 2-glazing, reflective
U-0.54 SHGC=0.17 VT=0.10

Window E 2-glazing, bronze tint
U-0.49 SHGC=0.39 VT=0.36

Window F 2-glazing, low-e
U-0.46 SHGC=0.27 VT=0.43

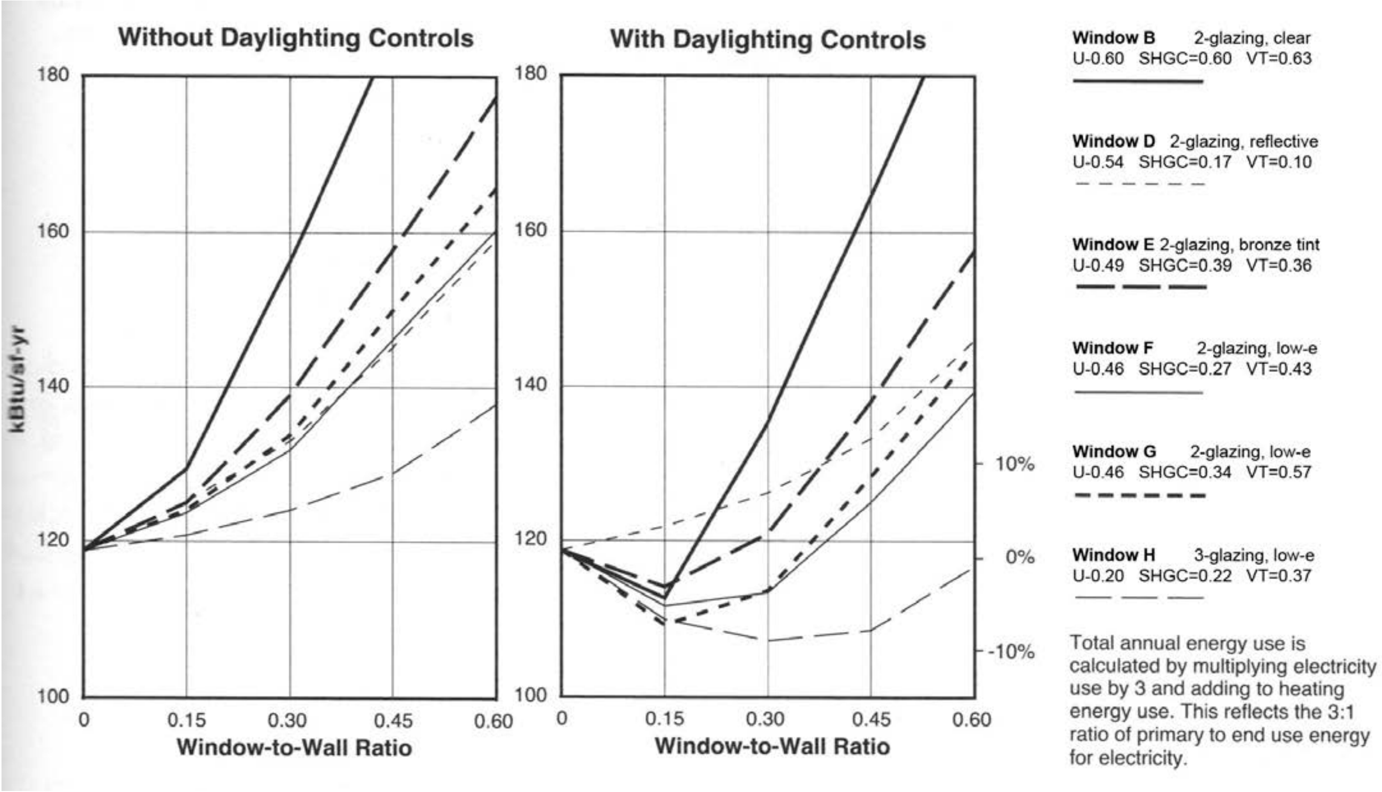
Window G 2-glazing, low-e
U-0.46 SHGC=0.34 VT=0.57

Window H 3-glazing, low-e
U-0.20 SHGC=0.22 VT=0.37

Total annual energy use is calculated by multiplying electricity use by 3 and adding to heating energy use. This reflects the 3:1 ratio of primary to end use energy for electricity.

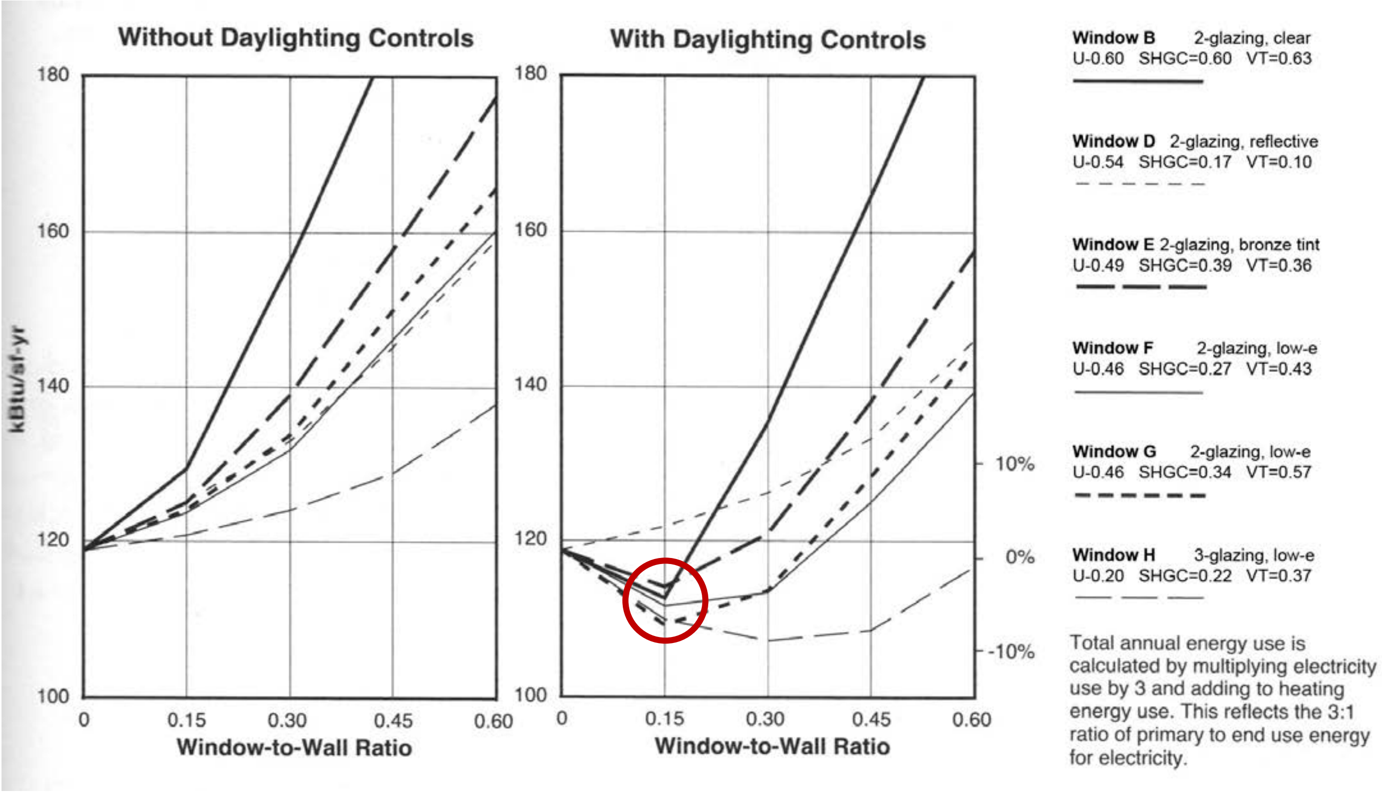
Section 6 – Commercial Windows, E/W/S

1) Without daylighting controls, there is no way to reliably "harvest" the lighting savings that windows offer, and energy use increases in every case.

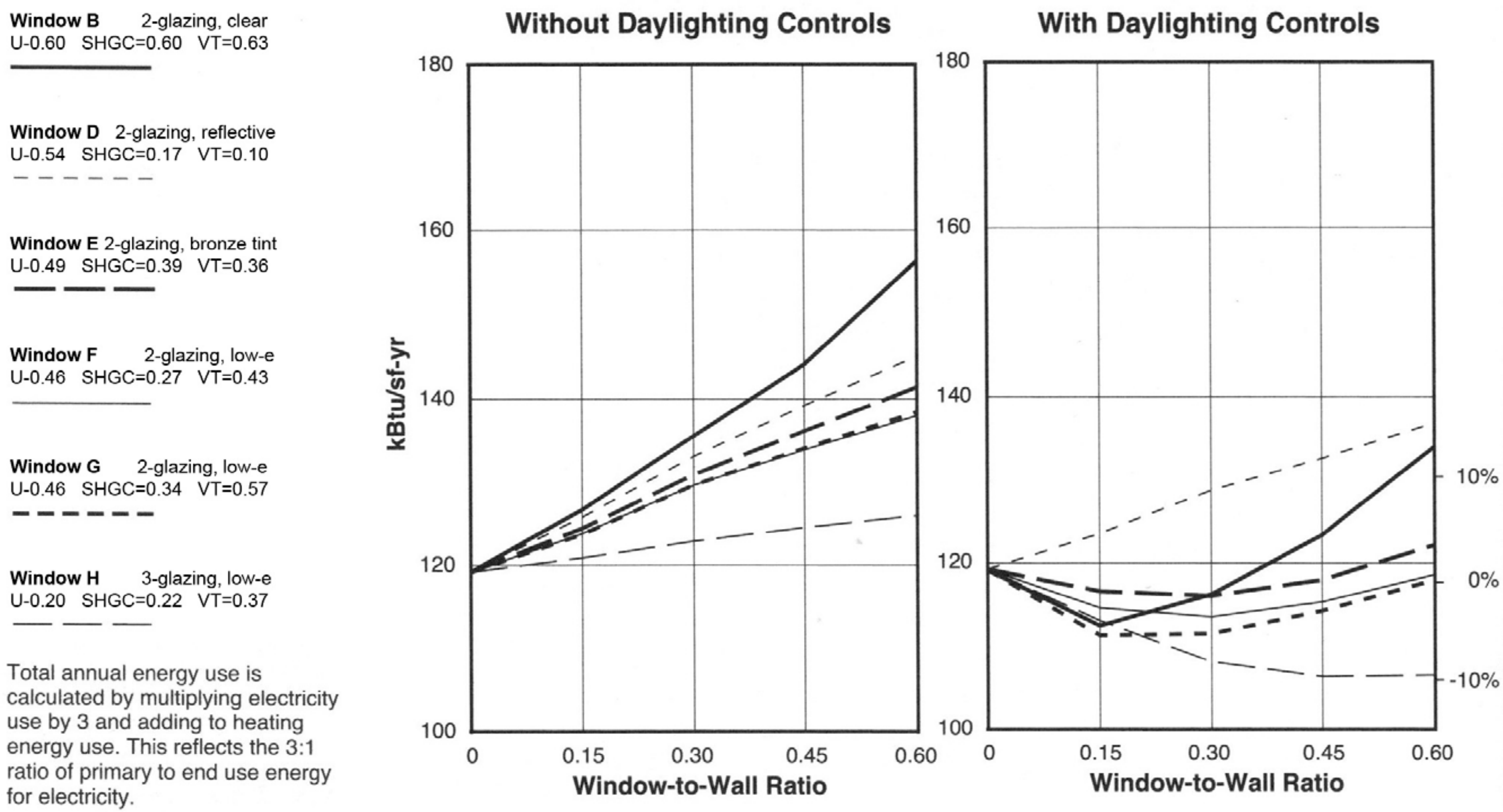


Section 6 – Commercial Windows, E/W/S

1) Without daylighting controls, there is no way to reliably "harvest" the lighting savings that windows offer, and energy use increases in every case.
2) Best WWR=0.15 for wide range of glazing types. Keep WWR small to avoid glare and unwanted solar heat gain due to low sun angles.



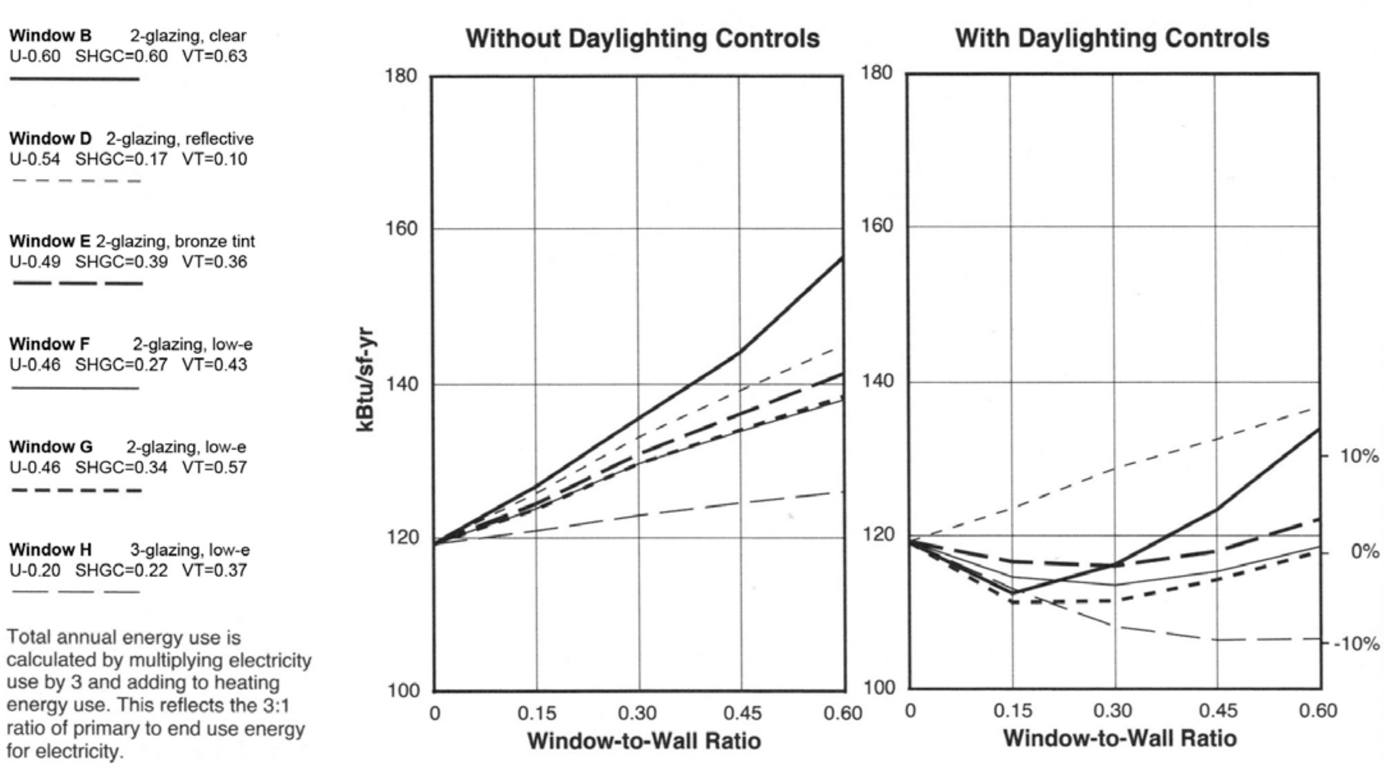
Section 6 – Commercial Windows, north



Total annual energy use is calculated by multiplying electricity use by 3 and adding to heating energy use. This reflects the 3:1 ratio of primary to end use energy for electricity.

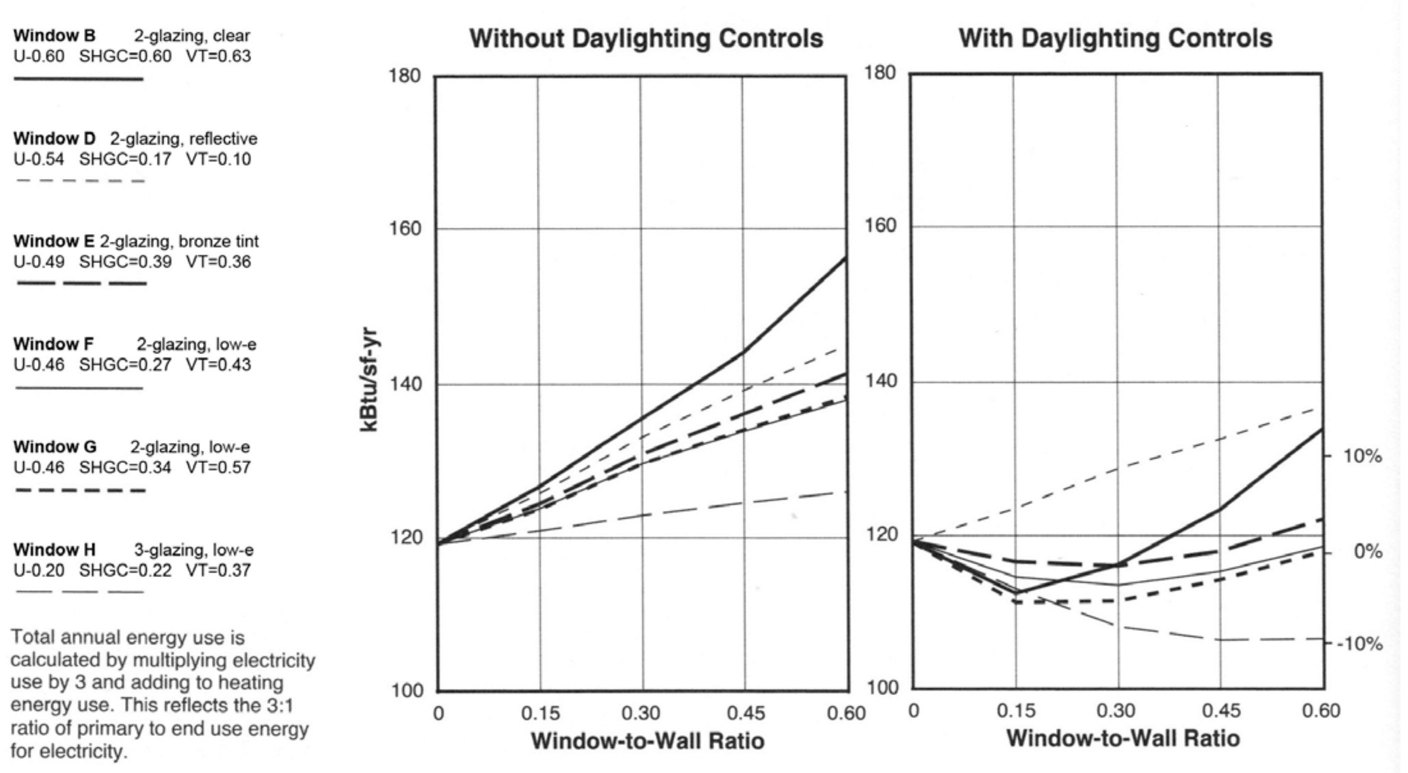
Section 6 – Commercial Windows, north

1) Again, daylighting controls are a necessity.



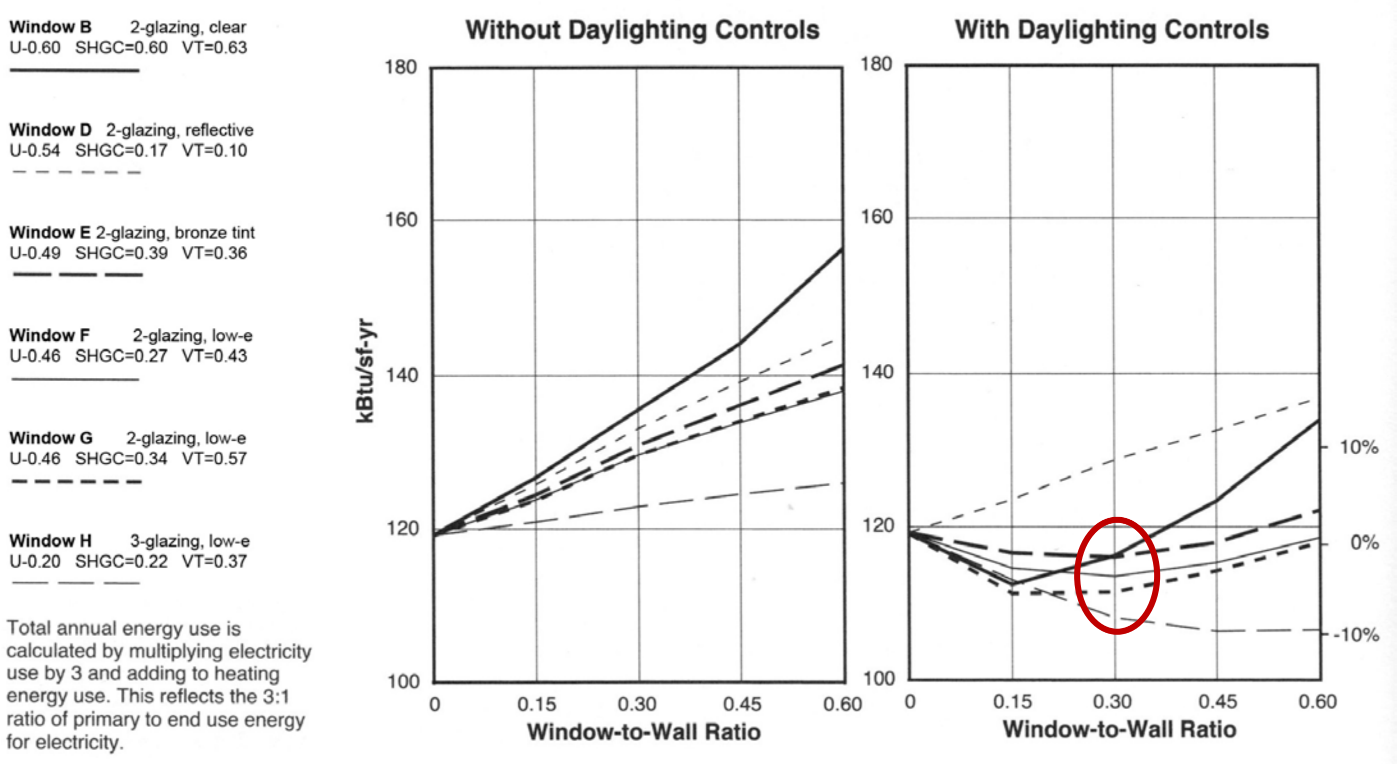
Section 6 – Commercial Windows, north

1) Again, daylighting controls are a necessity.
2) Lack of light means that VT is the most important attribute to reduce lighting loads. Lack of direct solar gain also means that SHGC values are irrelevant.



Section 6 – Commercial Windows, north

1) Again, daylighting controls are a necessity.
2) Lack of light means that VT is the most important attribute to reduce lighting loads. Lack of direct solar gain also means that SHGC values are irrelevant.
3) Best WWR = 0.3 for wide range of glazing types. With higher WWR, low U-value becomes important to minimize heat loss.



Section 6 – Commercial Windows

Best attempt to distill commercial window "rules of thumb"

orientation	daylighting controls	suggested window area	shading	window attributes
north	recommended	**moderate** 0.30WWR (for most glass types) 0.45 - 0.60 WWR (for 3-glaze)	not recommended	triple glazing low U-factor, high VT, SHGC not important
south	recommended	**small - moderate** 0.15WWR (for most glass types) 0.30WWR (for 3-glaze)	recommended for some window types and all window types with high WWR	triple glazing low U-factor, relatively low SHGC
east/west	recommended	**small** 0.15WWR (for most glass types)	recommended for some window types and all window types with high WWR	low SHGC is very important, low U-factor, high VT,

If project does not incorporate daylighting controls, best commercial windows are triple glazing – all the time, for every façade, for every WWR. Why? – w/out controls, daylighting savings are removed from the equation and energy savings are accomplished with lower U-values and SHGC values alone.

Section 6 – Commercial Windows

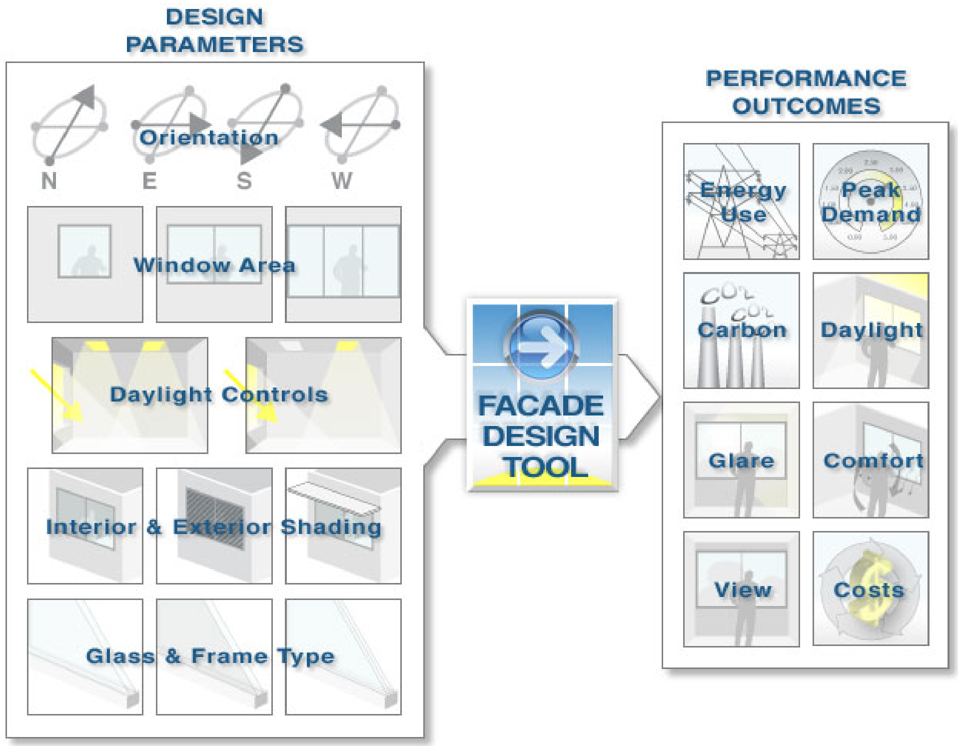
Façade design tool for commercial windows:
http://www.commercialwindows.org/

Section 6 – Commercial Windows

Facade Design Tool | Performance | Design | Window Technologies | Case Studies | Tools & Resources

FACADE DESIGN TOOL

The Facade Design Tool lets you choose the design conditions of a window and rank and compare the performance data in terms of annual energy, peak demand, carbon, daylight illuminance, glare, and thermal comfort. After a location, building type, and orientation have been selected, you have the choice to Refine & Explore or Compare the performance data of window design options that you define in terms of orientation, window area, daylight controls, interior shades, exterior shades, and window type.



Start using the Facade Design Tool

FACADE DESIGN TOOL

See the Facade Design Tool User's Guide for how to use the tool and for all information on design conditions and assumptions.

This site originally developed by the University of Minnesota and Lawrence Berkeley National Laboratory with support from the U.S. Department of Energy's Emerging Technologies Program.

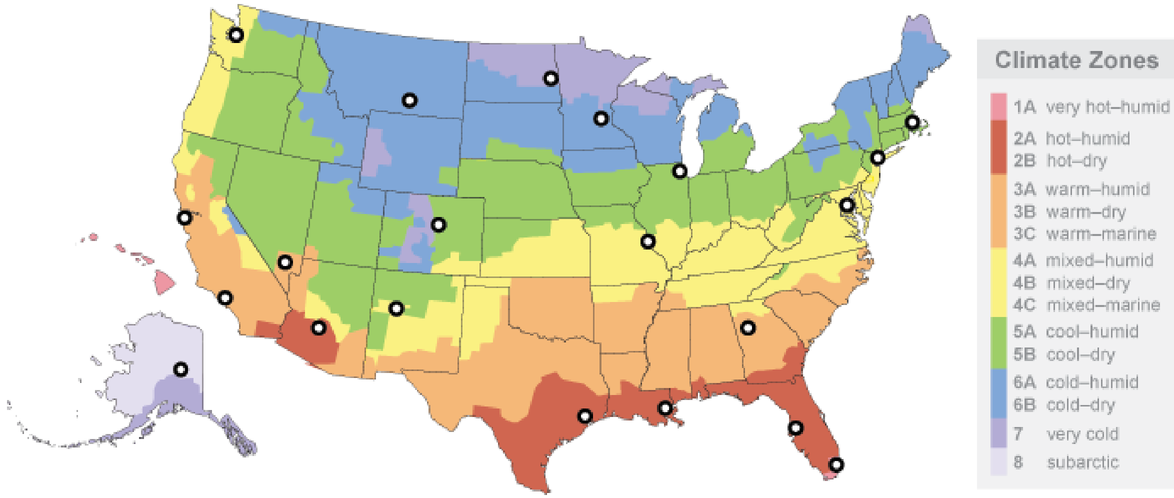
Section 6 – Commercial Windows

CHOOSE LOCATION & BUILDING TYPE

Select a location, building type, and facade orientation from the drop-down lists below. My city isn't listed»

"Refine & Explore" first lets you choose the available design parameters then you can refine and explore the ranked results. Use this exploratory method if parametrics are unknown or to determine the optimal design from various scenarios.

"Compare 5 Scenarios" lists the design parameters for 5 scenarios for a quick comparison. Use this comparison method if many of the design parametrics are previously determined.



Location [Select Location ▼]

Building Type [Select Building Type ▼]

Facade Orientation [Select Facade Orientation ▼]

REFINE & EXPLORE -OR- COMPARE 5 SCENARIOS

See the Facade Design Tool User's Guide for more specific information on how to use the tool.

This site originally developed by the University of Minnesota and Lawrence Berkeley National Laboratory with support from the U.S. Department of Energy's Emerging Technologies Program.

Section 6 – Commercial Windows

REFINE & EXPLORE ZONE RESULTS

Facade Design Tool Home | Minneapolis, Minnesota | Office | South

REFINE & EXPLORE | COMPARE RESULTS

Modify design parameters & explore the results.

Select up to 5 scenarios for detailed comparison.

Update Results

Expand Collapse

− Window Area
- ☑ 10%
- ☑ 20%
- ☑ 30%
- ☑ 40%
- ☑ 50%
- ☑ 60%

− Projections
- ☑ None
- ☑ 2' Overhang
- ☑ 4' Overhang

− Lighting Controls
- ☐ None
- ☑ Continuous Dimming

− Shading
- ☑ None
- ☑ Interior Blinds
- ☑ Exterior Blinds

− Glass Panes
- ☑ 1
- ☑ 2

Summary | **Energy** | Peak | Carbon | Daylight | Glare | Comfort

The Building		Glazing System					Light & Shade		Annual Energy Use (kBtu/sf-yr)
WWR	Building Projections	Glass	Panes	U-factor	SHGC	VT	Lighting Controls	Shades	kBtu/sf-yr
40	4' Overhang	I	3	0.13	0.32	0.6	Continuous	None	67.23
30	4' Overhang	I	3	0.13	0.32	0.6	Continuous	None	67.67
20	2' Overhang	G	2	0.24	0.38	0.7	Continuous	None	67.95
30	4' Overhang	G	2	0.24	0.38	0.7	Continuous	None	68.12
20	2' Overhang	I	3	0.13	0.32	0.6	Continuous	None	68.28
30	4' Overhang	H	2	0.24	0.27	0.64	Continuous	None	68.40
40	4' Overhang	H	2	0.24	0.27	0.64	Continuous	None	68.53
20	2' Overhang	H	2	0.24	0.27	0.64	Continuous	None	68.56
40	4' Overhang	G	2	0.24	0.38	0.7	Continuous	None	68.73
30	2' Overhang	H	2	0.24	0.27	0.64	Continuous	None	68.83
30	2' Overhang	I	3	0.13	0.32	0.6	Continuous	None	69.03
50	4' Overhang	I	3	0.13	0.32	0.6	Continuous	None	69.12
40	2' Overhang	H	2	0.24	0.27	0.64	Continuous	None	69.29
30	None	H	2	0.24	0.27	0.64	Continuous	None	69.38
40	2' Overhang	I	3	0.13	0.32	0.6	Continuous	None	69.38
30	2' Overhang	G	2	0.24	0.38	0.7	Continuous	None	69.63
20	None	H	2	0.24	0.27	0.64	Continuous	None	69.85
20	2' Overhang	B	2	0.47	0.7	0.79	Continuous	None	70.20
20	None	I	3	0.13	0.32	0.6	Continuous	None	70.48
40	4' Overhang	E	2	0.24	0.29	0.52	Continuous	None	70.52
30	None	I	3	0.13	0.32	0.6	Continuous	None	70.63
50	4' Overhang	H	2	0.24	0.27	0.64	Continuous	None	70.64
30	4' Overhang	E	2	0.24	0.29	0.52	Continuous	None	70.66
20	None	G	2	0.24	0.38	0.7	Continuous	None	70.73
40	None	J	3	0.12	0.21	0.34	Continuous	None	70.81

0 100 200 300 400 500