The Why of Psi

The Why of Psi

Workshop Presenters:

for CertiPHIers Cooperative…

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  U of M

Outline for the Course

- Thermal Bridge Theory
- Principles of thermal bridge modeling
- Flixo orientation/walkthrough
- Module 0 Warm up
- Module 1 EQ Layers
- Module 2 Wall Corner
- Module 3 Brick Ledge
- Module 4 Lintel

The Why of Psi

Thermal Bridge Theory

- Thermal bridge definition, types of TBs, and why controlling them is critical for super-insulated buildings.

- Typical thermal bridge details and design techniques to reduce thermal bridge heat loss.

- How to use and input psi values with the PHPP/ WUFI Passive

Section 1 – Background + Basics

What is a thermal bridge?

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Short answer:
A discontinuity in the thermal envelope.

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What types of discontinuities might there be in a thermal envelope?

Section 1 – Background + Basics

What is a thermal bridge?

Short answer:
A discontinuity in the thermal envelope.

What types of discontinuities might there be in a thermal envelope?

- Repetitive bridges (studs, floor joists, rafters)
- Material changes (windows, insulation)
- Penetrations (pipes, fasteners)
- Assembly junctions (roof to wall, wall to floor, etc)
- Corners

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Section 1 – Background + Basics

Repetitive TBs

Should be accounted for in calculation of assembly U-values in the PHPP

Point TBs (penetrations)

Usually use side calculators instead of thermal bridge modeling software. Examples: large fasteners in commercial facades, pipe penetrations)

Linear TBs (assembly junctions)

Three types:

1) Structural (ex – rim joists, prefab wall junctions)
2) Geometric (ex – wall corners, roof ridge)
3) Combination (ex – wall to roof, wall to slab)

Section 1 – Background + Basics

Repetitive TBs – entry in PHPP

Assembly no.	Building assembly description	Interior insulation?
6	Basement wall to cellar	

Heat transfer resistance [m²K/W] interior R_{si} : 0.13

exterior R_{se} : 0.13

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	t [in]	[mm]
1.	GWB	0.170		0.000		0.000	5/8	16
2.	Roxul ComfortBatt	0.035	Wood (softwood)*	0.130		0.000	3 1/2	89
3.	GWB	0.170		0.000		0.000	5/8	16
4.	Roxul ComfortBoard IS	0.036		0.000		0.000	0	0
5.		0.000		0.000		0.000		
6.		0.000		0.000		0.000		
7.		0.000		0.000		0.000		
8.		0.000		0.000		0.000		

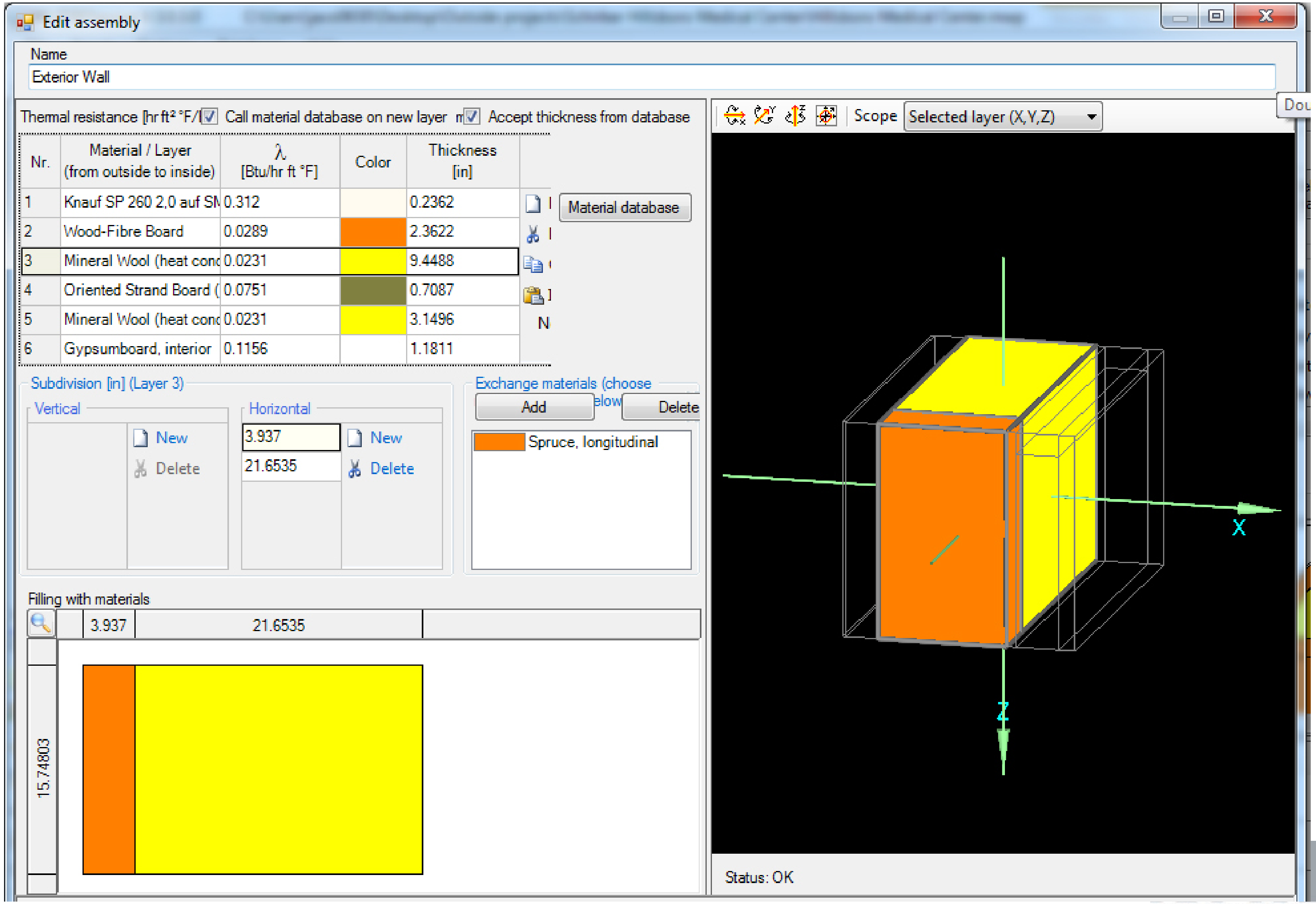
Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
85%	15.0%		12.1 cm
			4 3/4 in

U-value supplement W/(m²K)

U-Value: 0.431 W/(m²K)

R- 13.2

Section 1 – Background + Basics



Repetitive TBs – entry in WUFI Passive (static side only)

Section 1 – Background + Basics

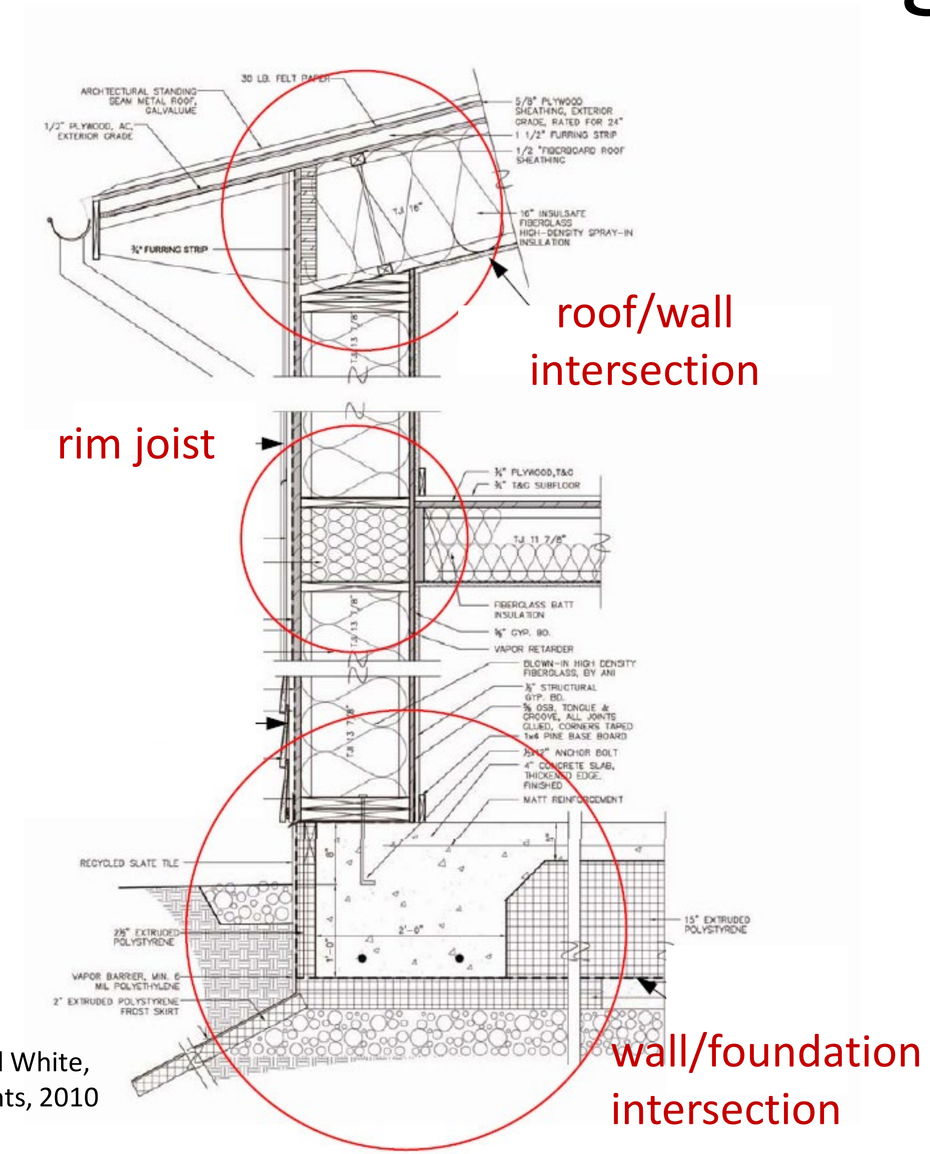


Image from David White, Right Environments, 2010

Circled areas are common linear thermal bridges.

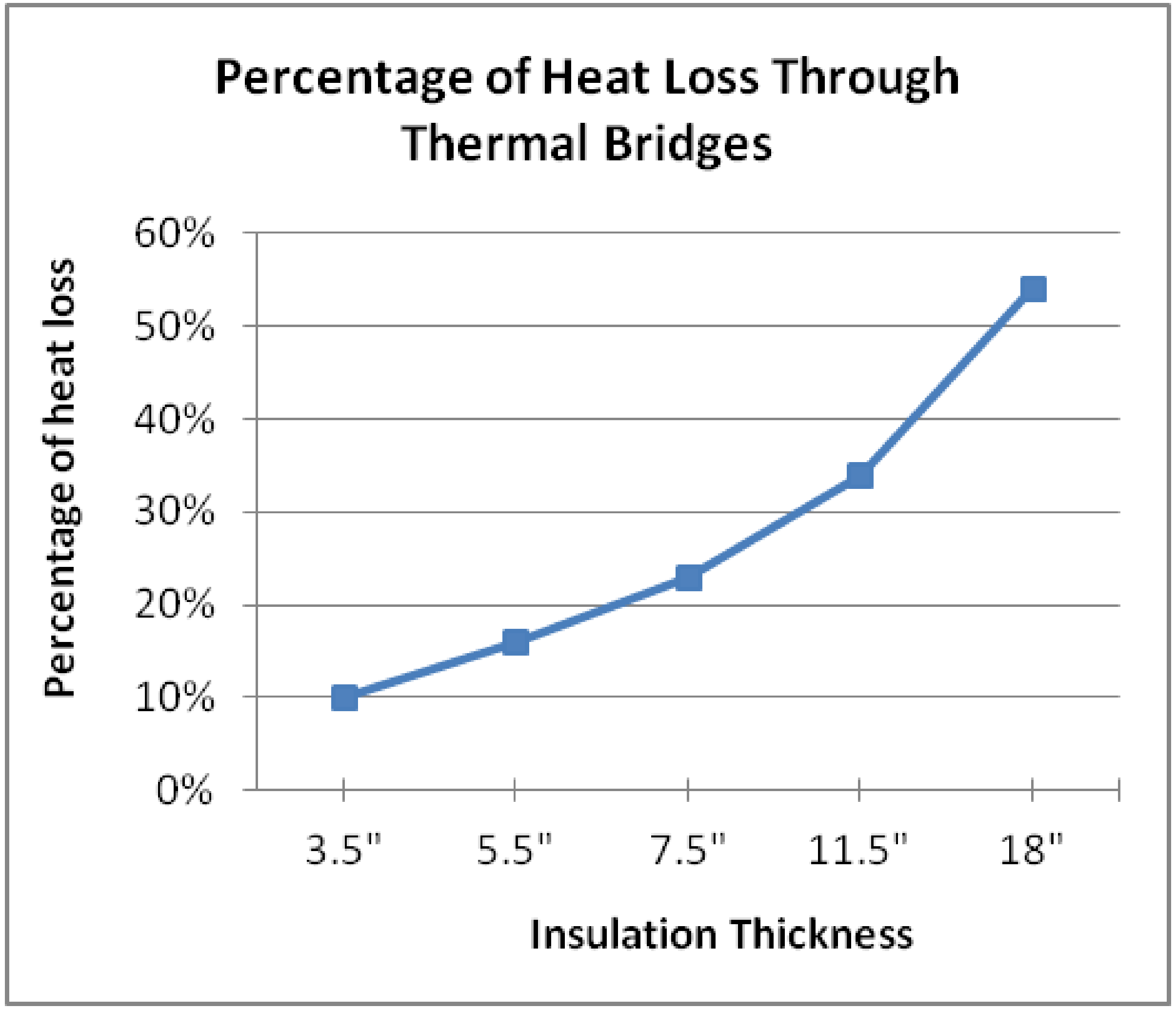
- The wall/foundation intersection is a combination linear TB (structural/geometric)
- The roof/wall intersection is also a combination (structural/geometric)
- The rim joist is purely a structural linear TB

Section 1 – Background + Basics

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 climbs past 35%.



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

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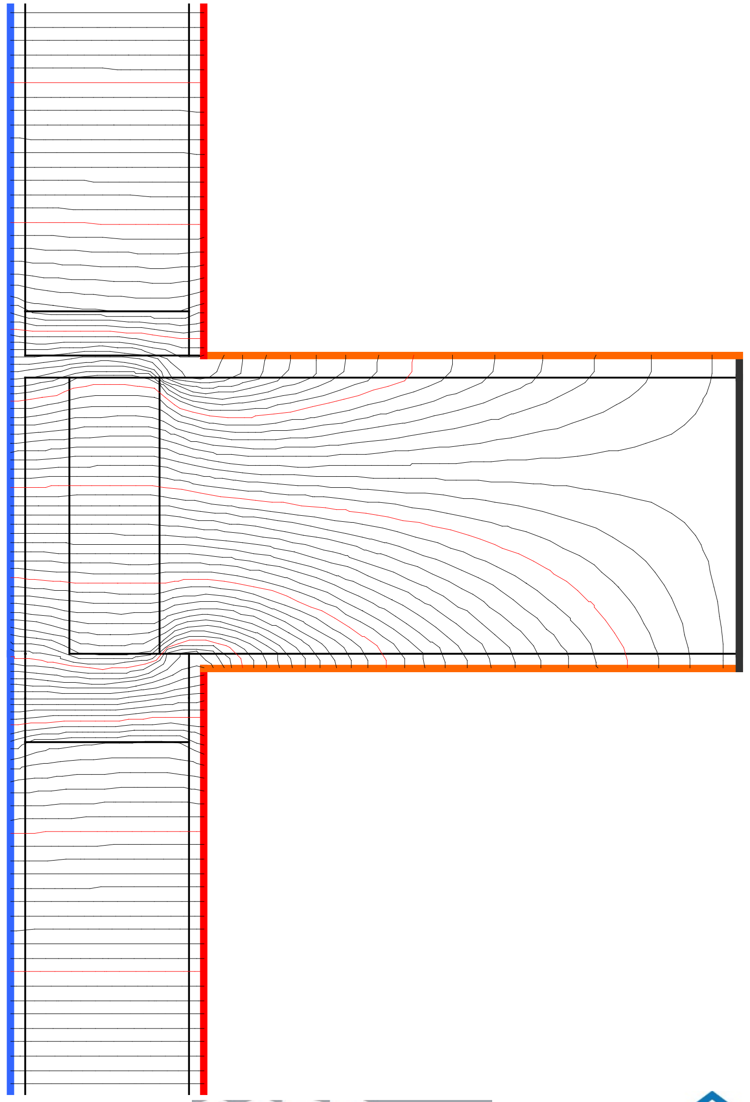
Section 1 – Background + Basics

How is that possible?

1. As insulation levels increase, less heat is transmitted, but the remaining heat flow through the uninsulated portions of the envelope makes up a greater percentage of that remainder.

2. Heat begins to move laterally in the assembly. Heat finds the quickest path out – generally through the TB's. They can transport more than their "fair share".



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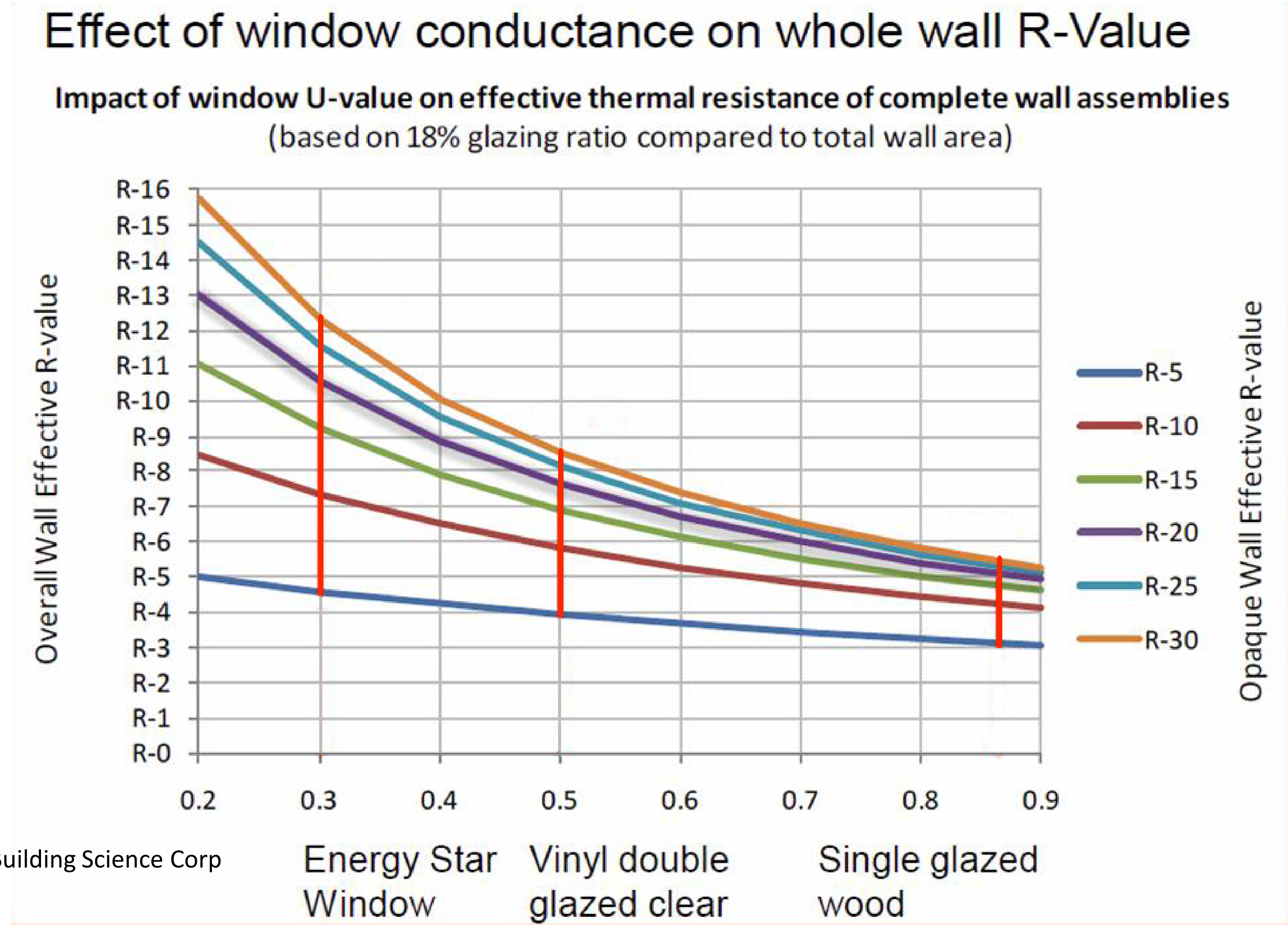
Section 1 – Background + Basics

From Pembina Institute, Accelerating Market Transformation for High Performance Building Enclosures, 2016:

"Thermal bridging is underestimated… Morrison Hershfield has calculated that shelf angles, parapets, window perimeters, etc, can result in the underestimation of 20% to 70% of the total heat flow through walls."

Morrison Hershfield, Building Envelope Thermal Bridging Guide (2014)

Section 1 – Background + Basics



graph from Building Science Corp

Section 1 – Background + Basics

- 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 (0.0057 Btu/hr ft F)

- To calculate Ψ values, a 2-D heat flow simulation model (such as THERM or Flixo) is used.

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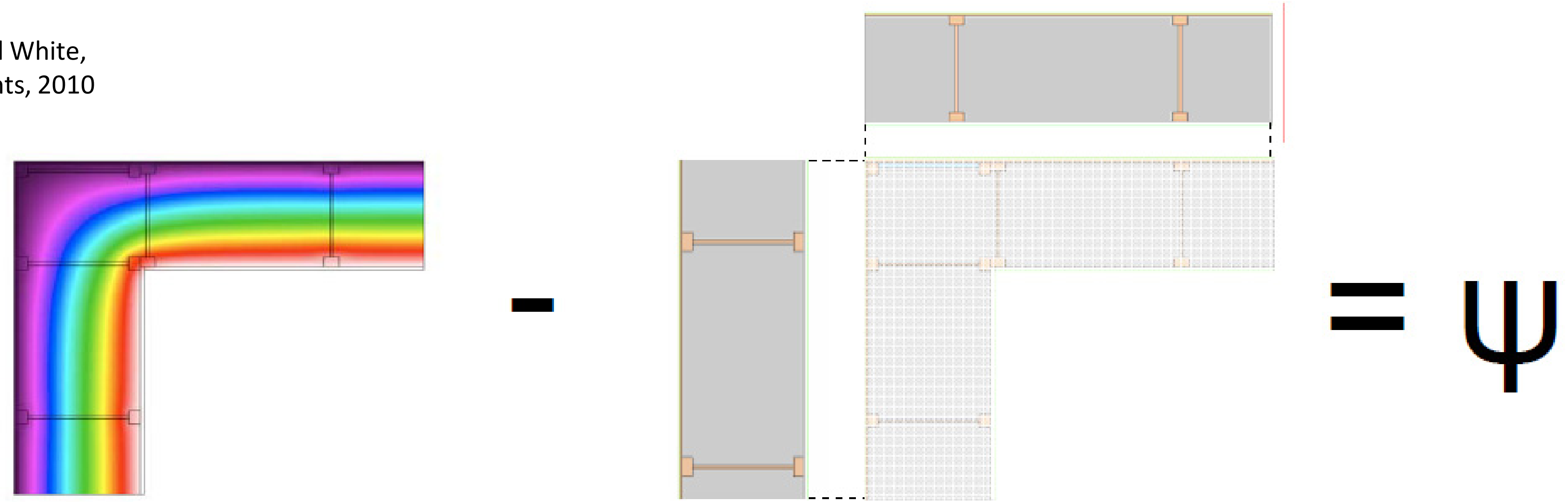
Section 1 – Background + Basics

Image from David White,
Right Environments, 2010



As used in the PHPP and WUFI Passive, the thermal bridge heat loss is conceptually the difference between the “true” heat loss, calculated using 2-dimensional simulation (THERM or Flixo), and the heat loss calculated using the typical U·A method (U x A x deltaT = heat loss (or gain))

Section 1 – Background + Basics

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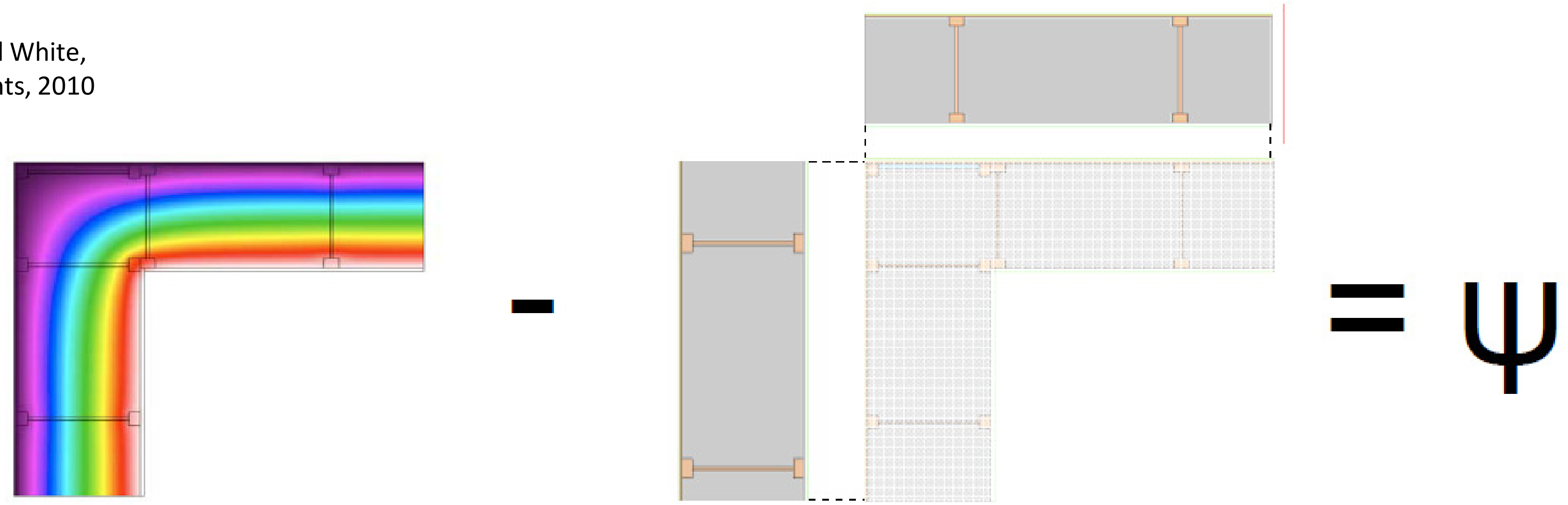

$$\text{“2D heat loss”} - U_1L_1 - U_2L_2 = \Psi$$

Section 1 – Background + Basics

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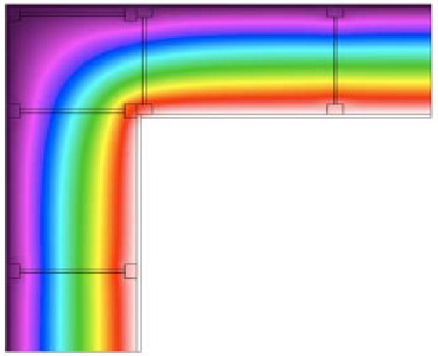
Right Environments, 2010



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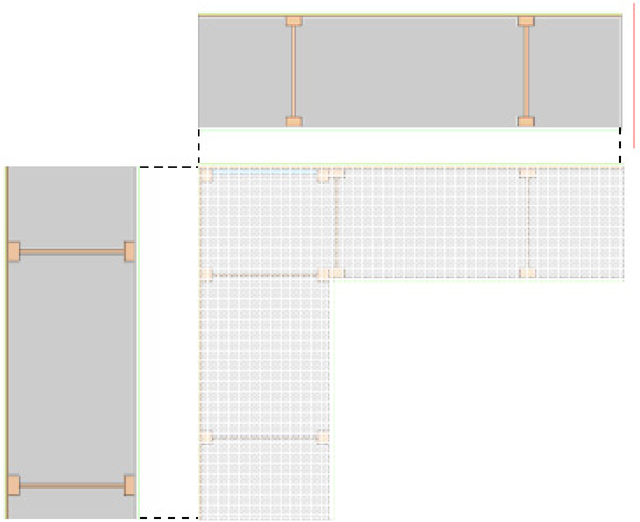

$= \Psi$

$$\text{"2D heat loss"} - U_1L_1 - U_2L_2 = \Psi$$

$$L2d - U_1L_1 - U_2L_2 = \Psi$$

Section 1 – Background + Basics

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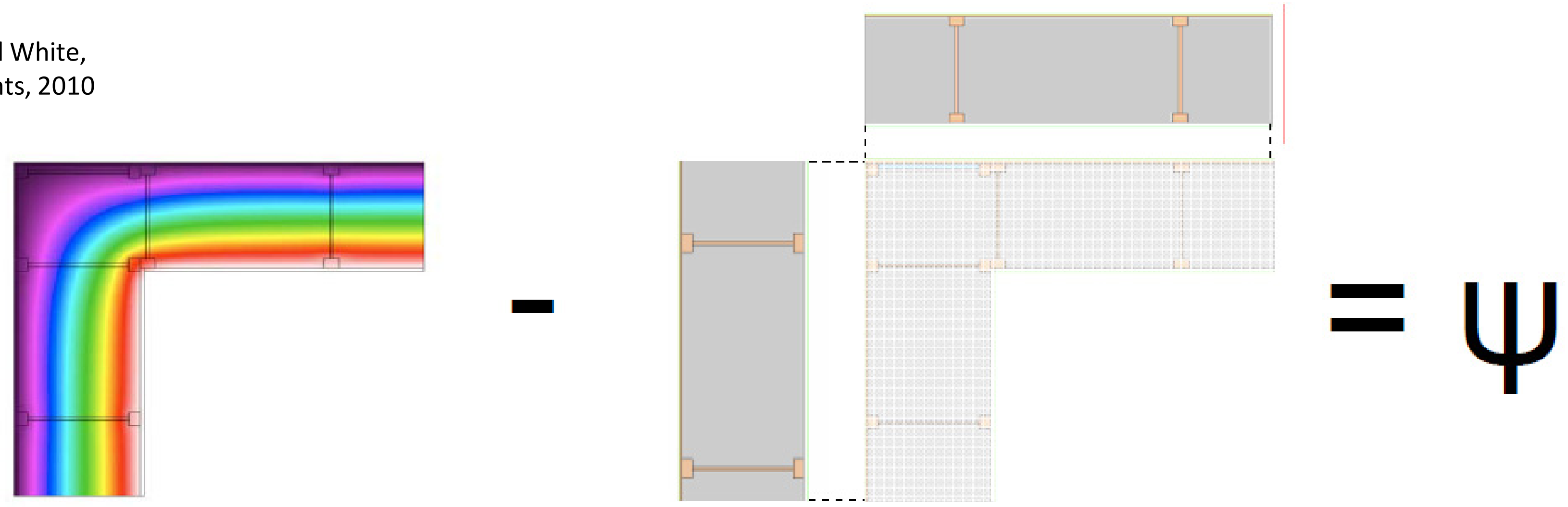
Right Environments, 2010



$$\text{“2D heat loss”} - U_1L_1 - U_2L_2 = \Psi$$

$$L2d - U_1L_1 - U_2L_2 = \Psi$$

$$\phi/\Delta T - U_1L_1 - U_2L_2 = \Psi \quad \text{(as in Flixo)}$$

Section 1 – Background + Basics

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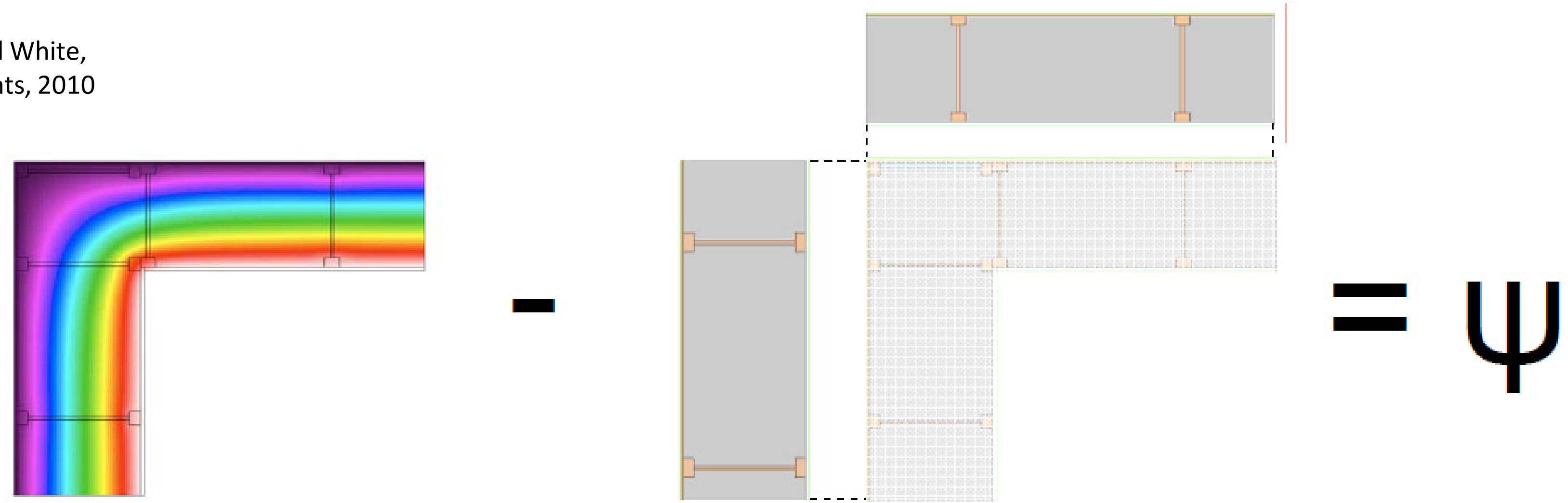
Right Environments, 2010

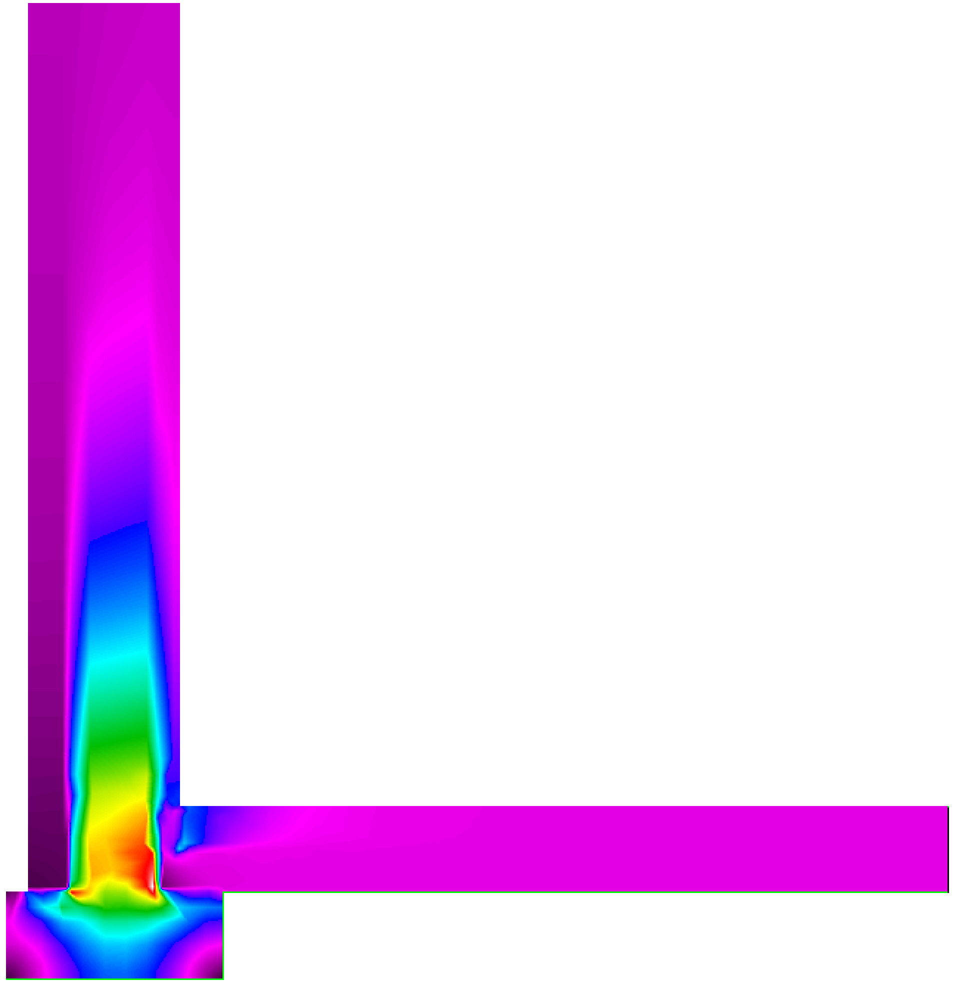


As used in the PHPP and WUFI Passive, the psi value is always based on a comparison of heat flows - a comparison between the actual heat flow and the estimated heat flow. **In this sense, psi is a correction factor.**

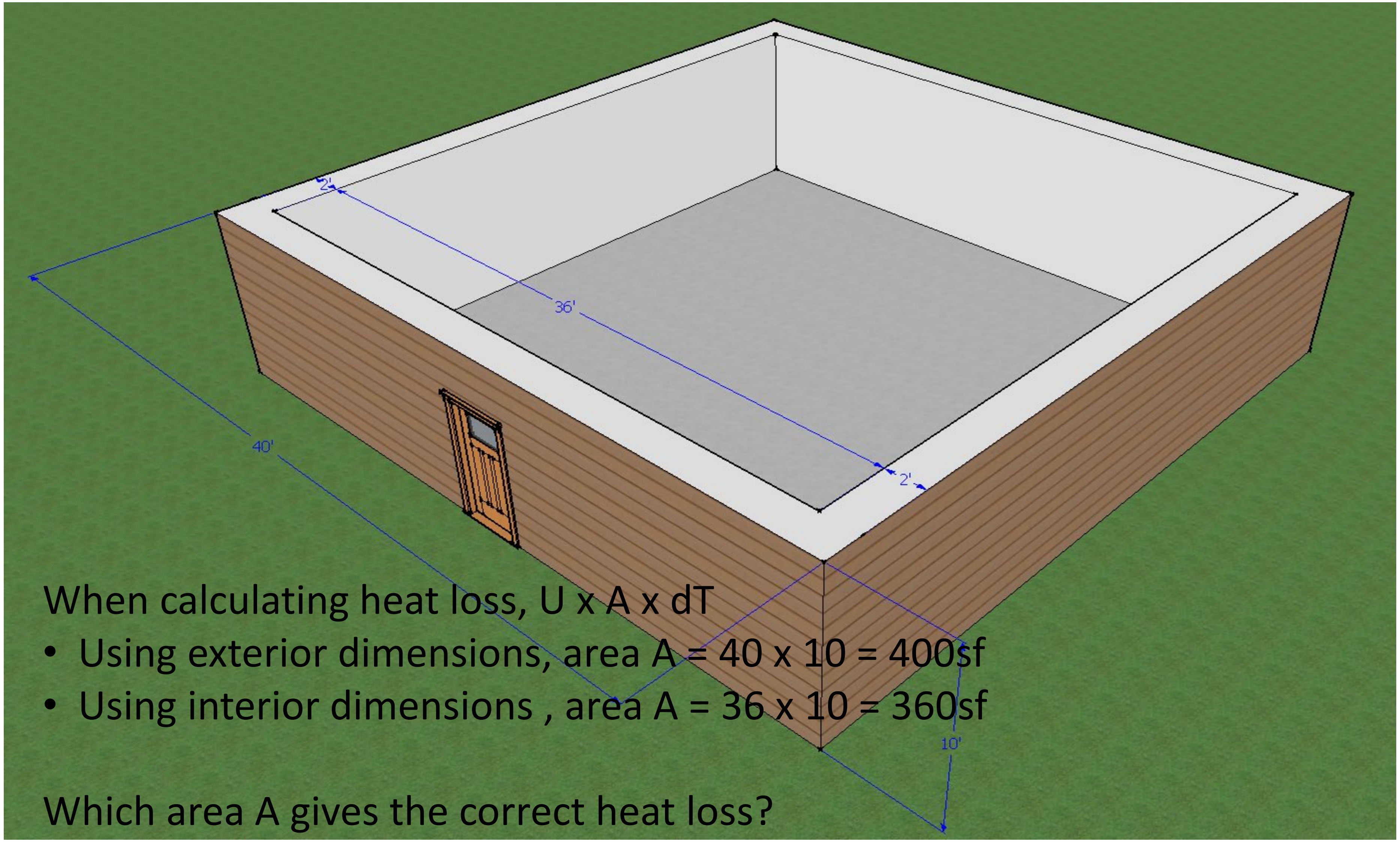
Section 1 – Background + Basics

Details coming up…

1. Wall corners
2. Rim joists
3. Footings
4. Parapets
5. Windows



Section 1 – Background + Basics

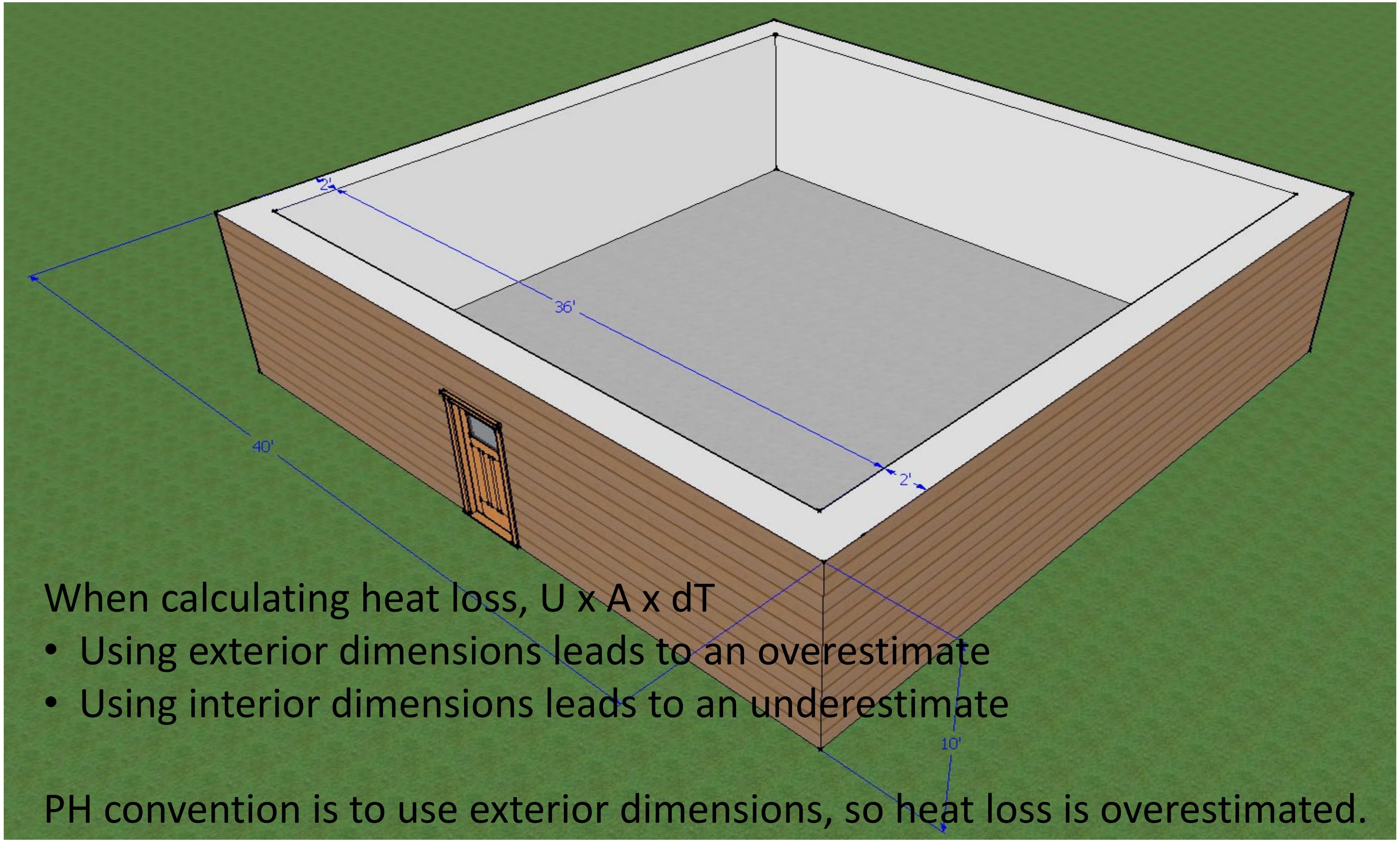


When calculating heat loss, U x A x dT

- Using exterior dimensions, area A = 40 x 10 = 400sf
- Using interior dimensions , area A = 36 x 10 = 360sf

Which area A gives the correct heat loss?

Section 1 – Background + Basics



When calculating heat loss, U x A x dT

- Using exterior dimensions leads to an overestimate
- Using interior dimensions leads to an underestimate

PH convention is to use exterior dimensions, so heat loss is overestimated.

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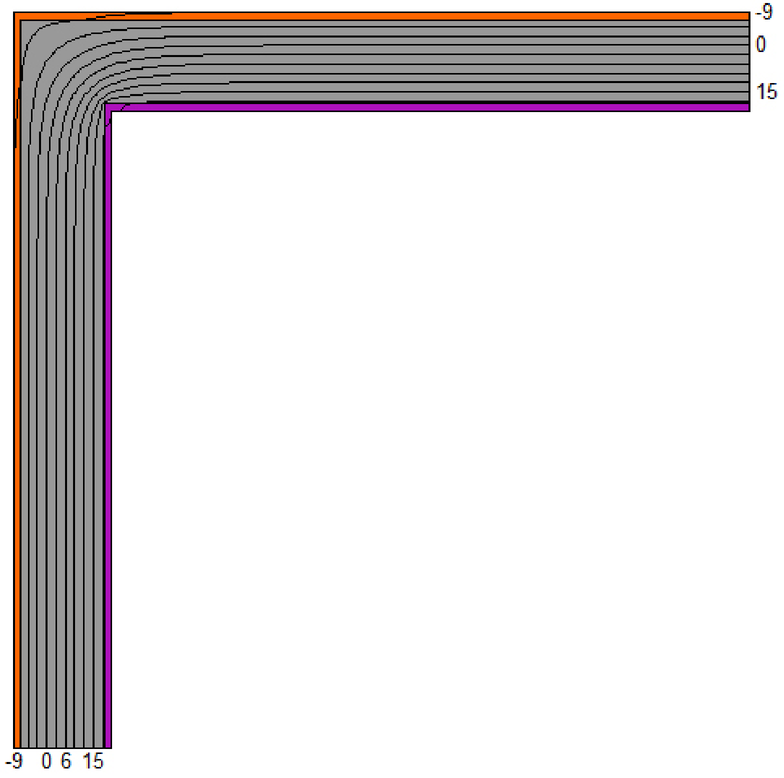
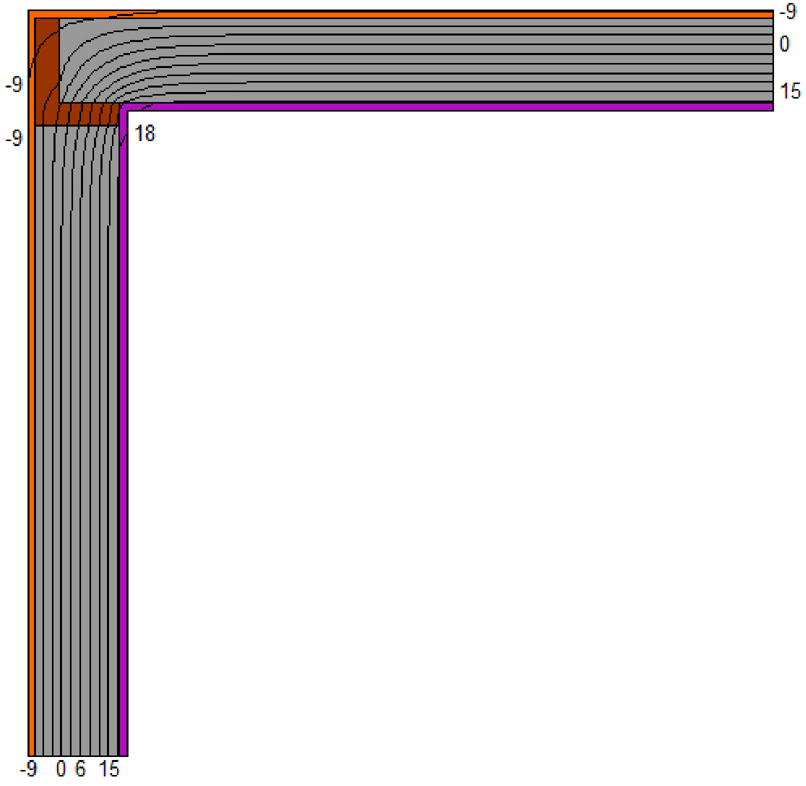
Section 2 – Common Linear Thermal Bridges





2x6 wall, no studs: Ψ = - 0.058 W/mK
(-0.034 Btu/hr ft F)

2x6 wall, 2-stud: Ψ = - 0.040 W/mK
(-0.023 Btu/hr ft F)

- By subtraction, negative psi values correct for overestimate of heat loss at exterior corners.
- The lower (more negative), the better. Higher psi values indicate increasing heat loss.
- Positive psi values above 0.01 W/mK indicate net heat transfer (heat gain in summer, heat loss in winter)that should be accounted for in PHPP.

Step 1 – Avoid bridging elements.

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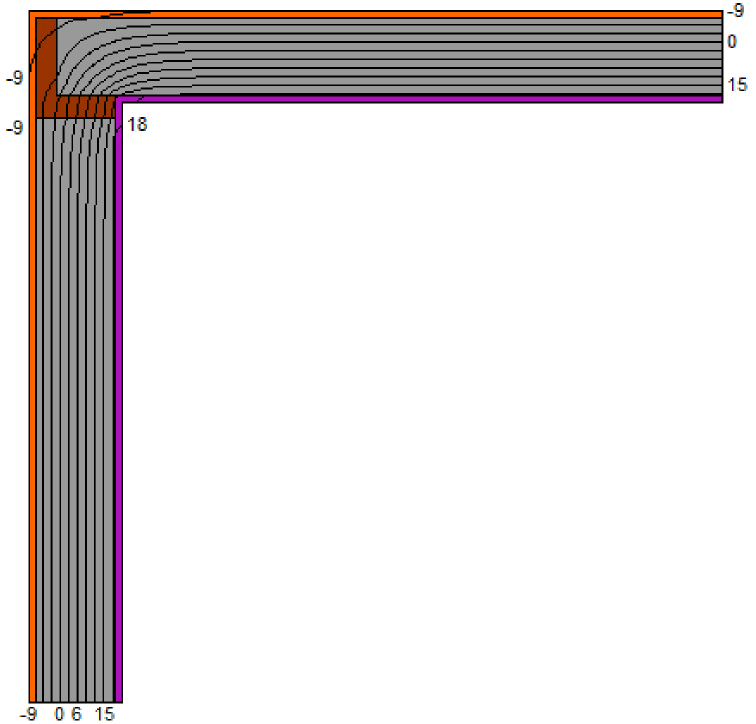
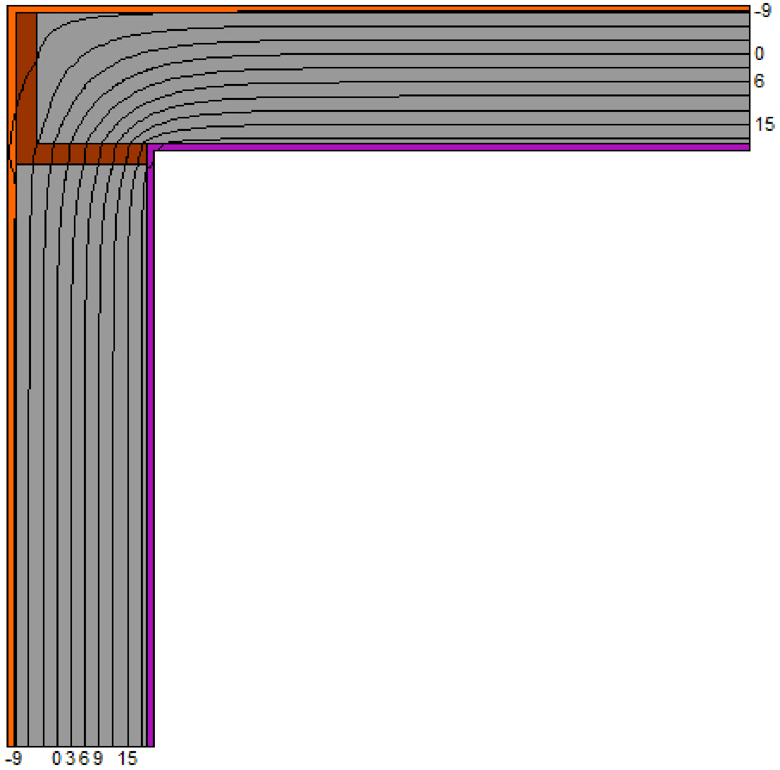
Section 2 – Common Linear Thermal Bridges



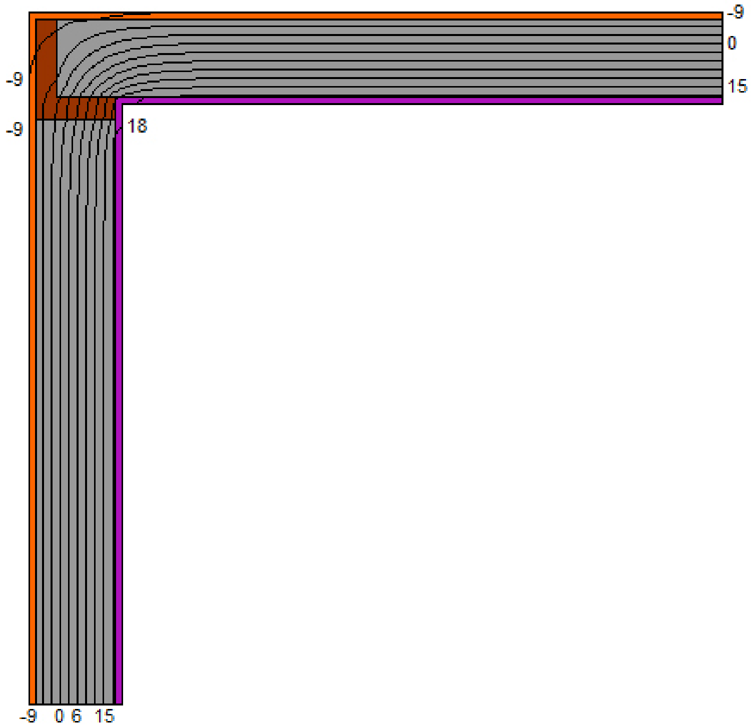


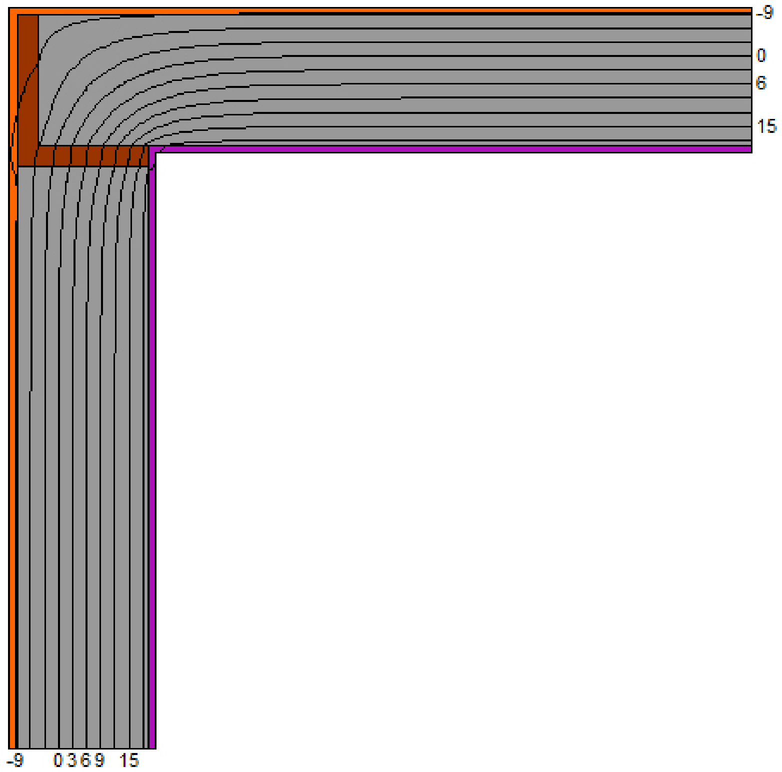
2x6 wall: Ψ = - 0.040 W/mK
(-0.023 Btu/hr ft F)

2x8 wall: Ψ = ?

What will happen to the psi value for the 2x8 wall?

Section 2 – Common Linear Thermal Bridges



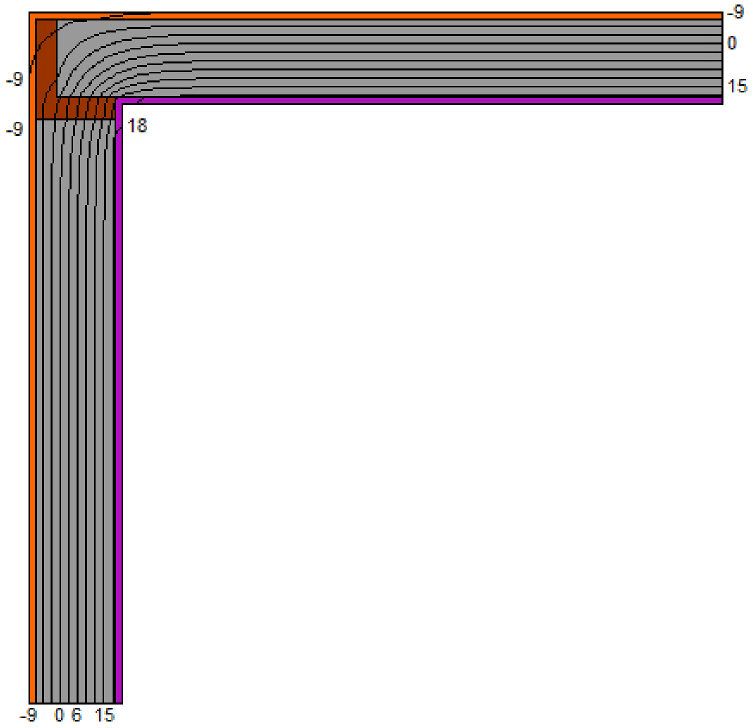


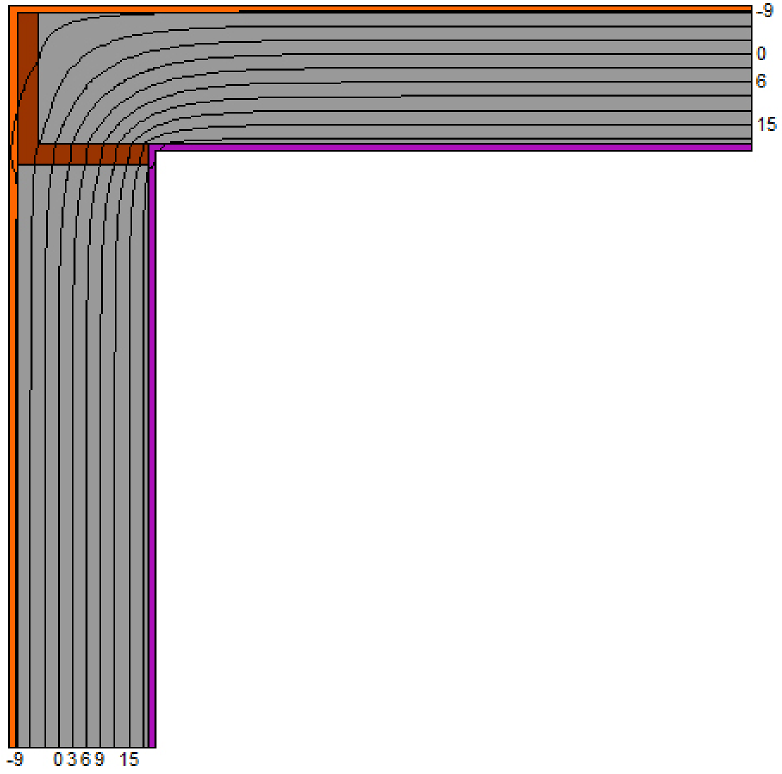
2x6 wall: Ψ = - 0.040 W/mK
(-0.023 Btu/hr ft F)

2x8 wall: Ψ = - 0.045 W/mK
(-0.026 Btu/hr ft F)

Is the 2x8 wall corner a "better" detail?

Section 2 – Common Linear Thermal Bridges





2x6 wall: Ψ = - 0.040 W/mK
(-0.023 Btu/hr ft F)

2x8 wall: Ψ = - 0.045 W/mK
(-0.026 Btu/hr ft F)

No.
A thicker wall section needs a larger correction factor due to larger overestimate of heat loss.

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Section 2 – Common Linear Thermal Bridges

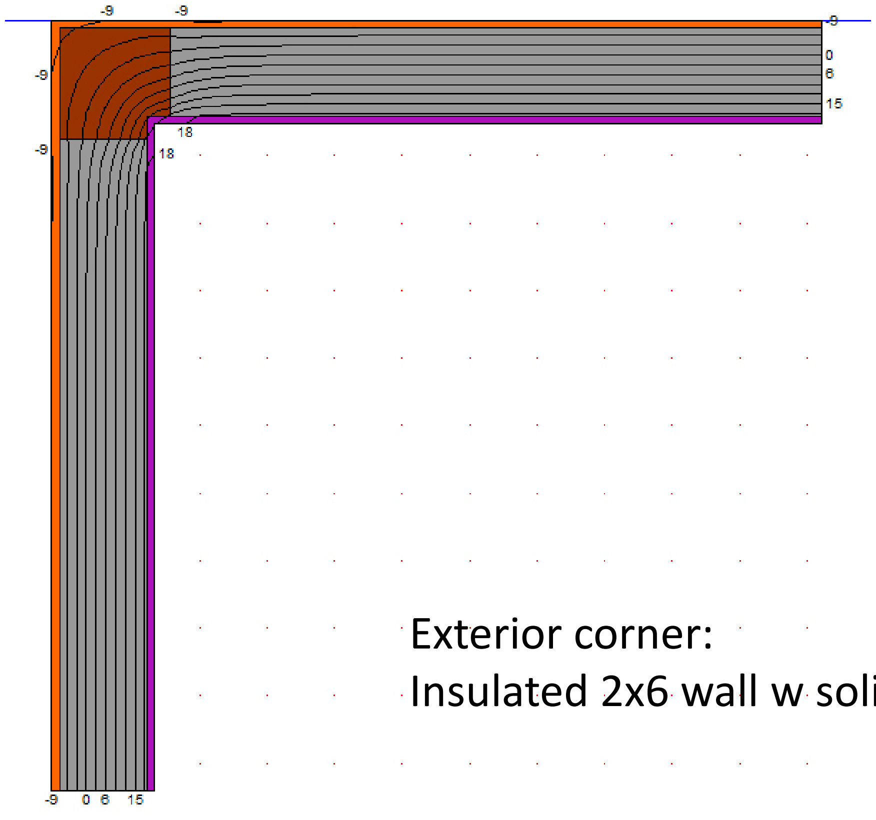
Is the psi value really an indicator of a detail’s thermal quality?

Section 2 – Common Linear Thermal Bridges

Is the psi value really an indicator of a detail's thermal quality?
Not really.

At geometric bridges, it does two things at once – it is both a correction factor and an indicator of heat flow – *but primarily a correction factor.*

Section 2 – Common Linear Thermal Bridges



Exterior corner:
Insulated 2x6 wall w solid post: Ψ = - 0.004 W/mK
(-0.002 Btu/hr ft F)

Is the psi value really an indicator of a detail's thermal quality?
Not really.

At geometric bridges, it does two things at once – it is both a correction factor and an indicator of heat flow – *but primarily a correction factor.*

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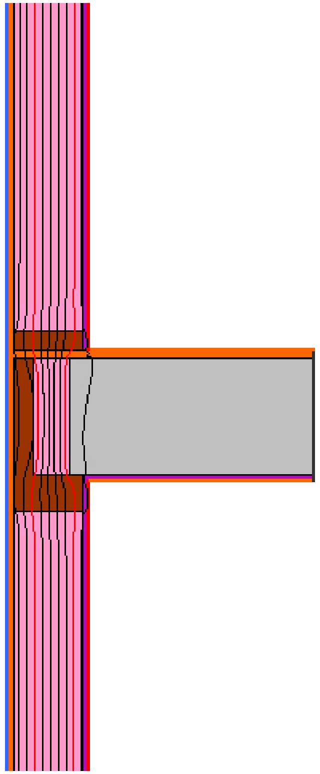

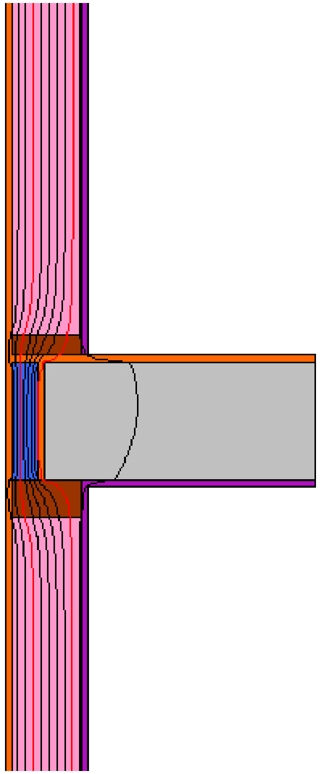

rim joist, fib. batt (R-11) : Ψ = 0.089 W/mK (0.051 Btu/hr ft F)

rim joist, rim board (R-11): Ψ = 0.129 W/mK (0.075 Btu/hr ft F)

- 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

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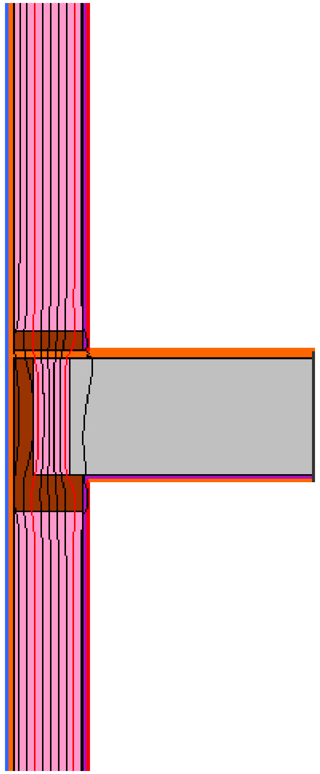
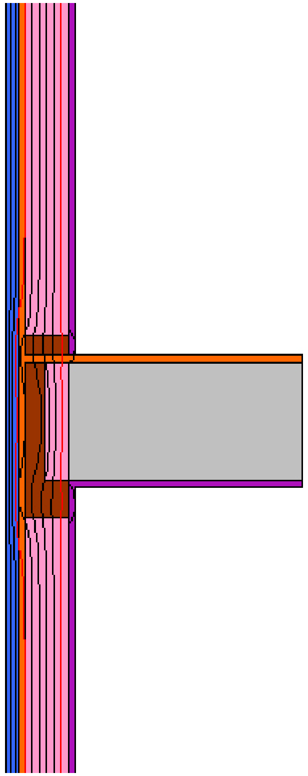
Section 2 – Common Linear Thermal Bridges



rim joist, fib. batt (R-11) : Ψ = 0.089 W/mK (0.051 Btu/hr ft F)

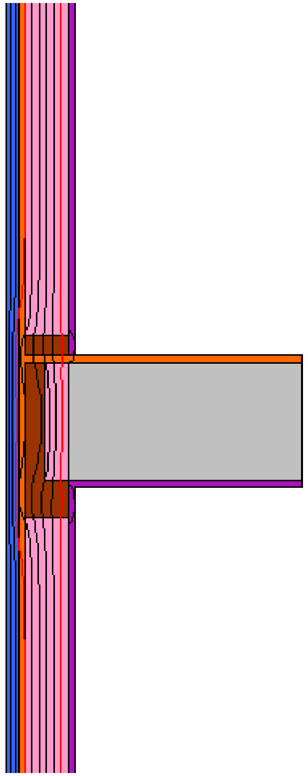


rim joist, 2x4 wall w 1” exterior XPS (R-13): Ψ = 0.047 W/mK (0.027 Btu/hr ft F)

- Exterior insulation helps control heat flow through uninsulated studs and plates.

STEP 3 – Use continuous exterior insulation to isolate bridging elements

Section 2 – Common Linear Thermal Bridges



rim joist, 2x4 wall w 1” exterior XPS (R-13):
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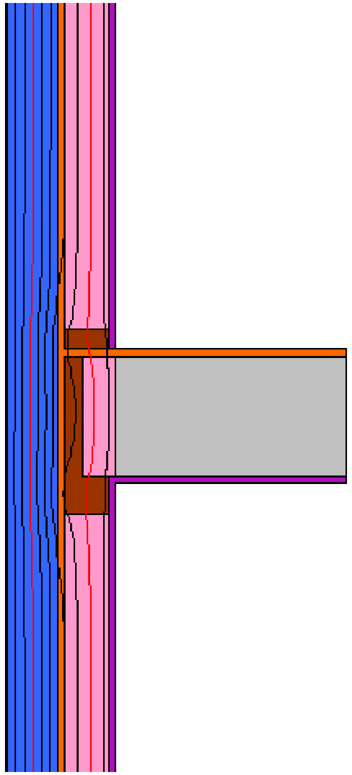
(0.027 Btu/hr ft F)



rim joist, 2x4 wall w 4” exterior XPS:
Ψ = 0.011 W/mK
(0.006 Btu/hr ft F)

Use enough exterior insulation, and the psi value can be driven down below 0.01 W/mK

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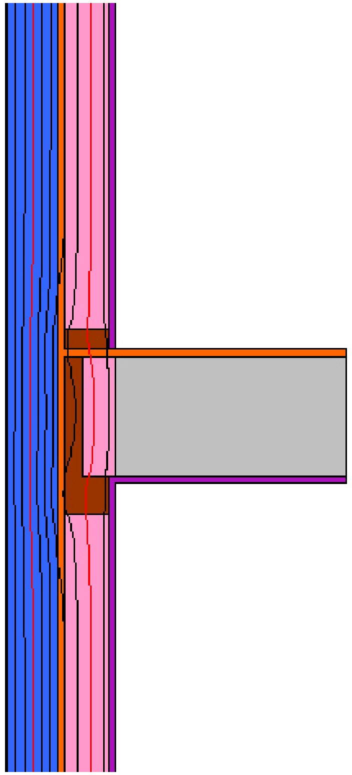
Section 2 – Common Linear Thermal Bridges



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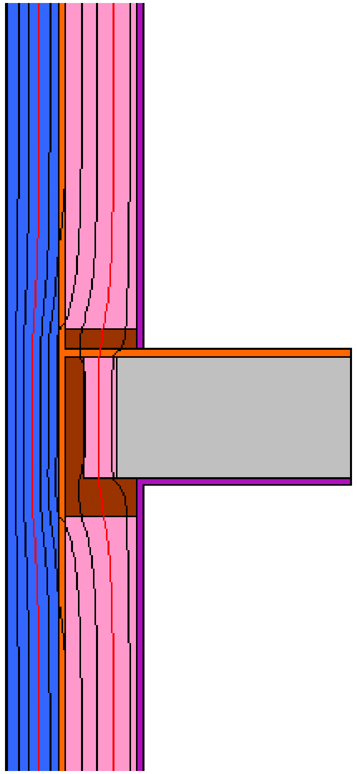
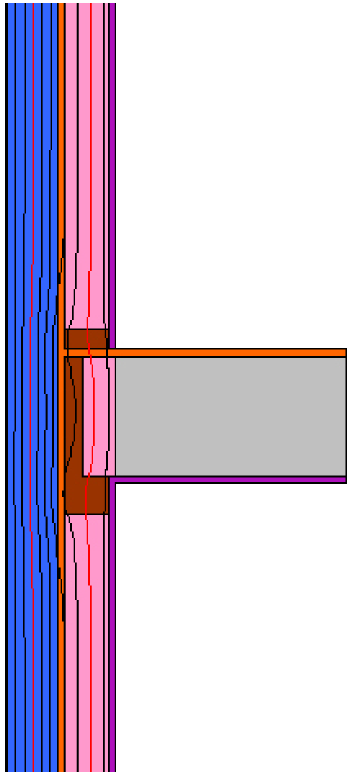


rim joist, 2x6 wall w 4” exterior XPS:
Ψ = ?

What’s going to happen to the psi value? Will it go up (get worse) or go down (get better)?

Section 2 – Common Linear Thermal Bridges



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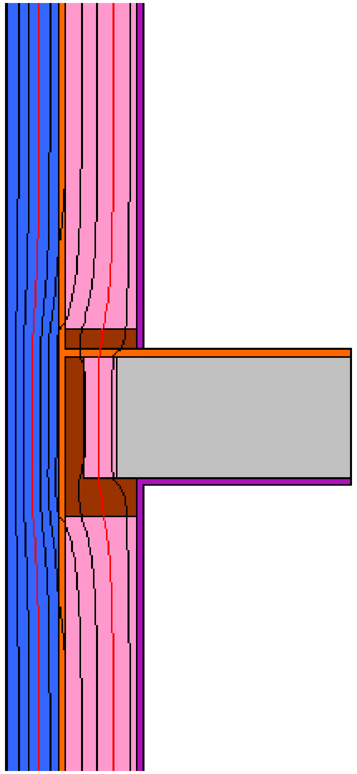
(0.006 Btu/hr ft F)



rim joist, 2x6 wall w 4” exterior XPS:
Ψ = 0.020 W/mK
(0.012 Btu/hr ft F)

Psi value is 2x higher with detail on the right. Why?
For the 2x6 wall, there’s now simply a larger difference between the higher R-value wall assembly and the rim joist R-value, which has remained the same.

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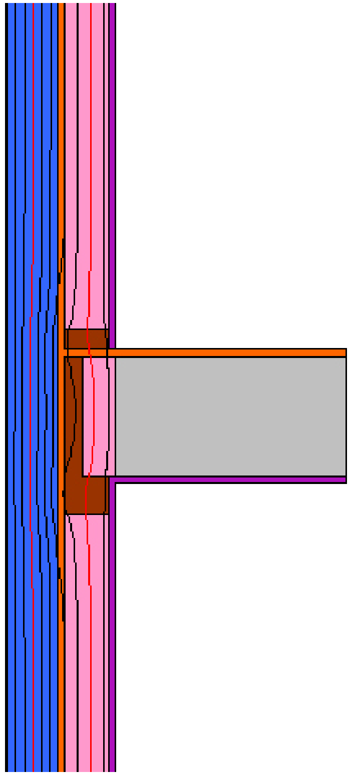
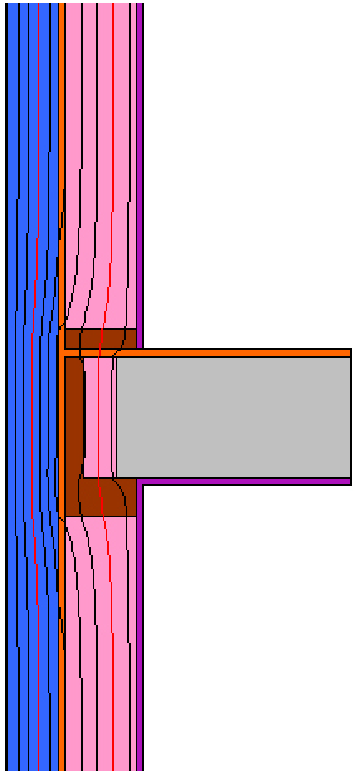
Section 2 – Common Linear Thermal Bridges



rim joist, 2x4 wall w 4” exterior XPS:
Ψ = 0.011 W/mK
(0.006 Btu/hr ft F)
Heat flux = 11.4 W/m



rim joist, 2x6 wall w 4” exterior XPS:
Ψ = 0.020 W/mK
(0.012 Btu/hr ft F)
Heat flux = 9.9 W/m

Overall, heat flow goes down with detail on right, despite higher Psi value.

Section 2 – Common Linear Thermal Bridges

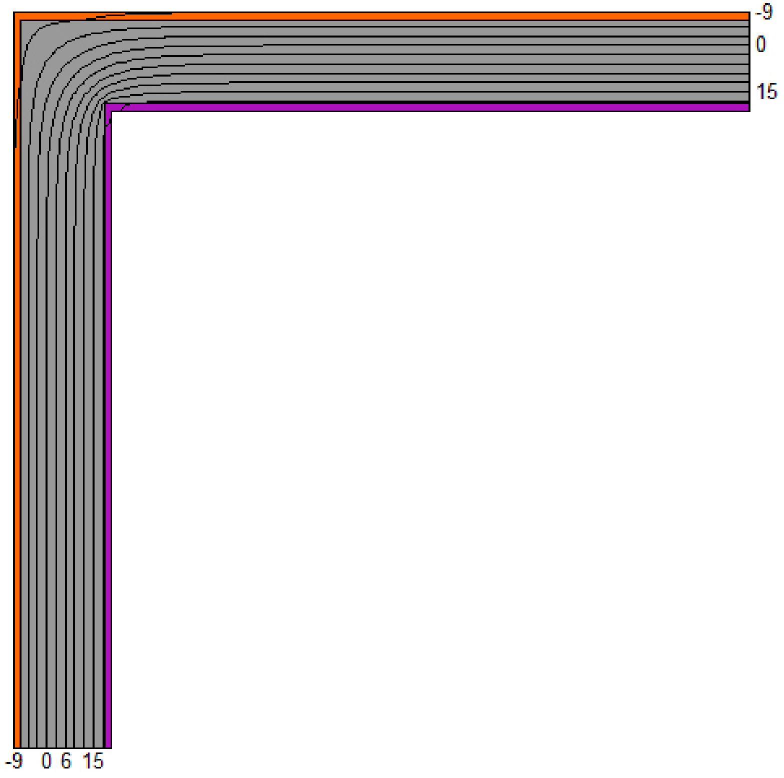
Is the psi value really an indicator of a detail's thermal quality?

Section 2 – Common Linear Thermal Bridges

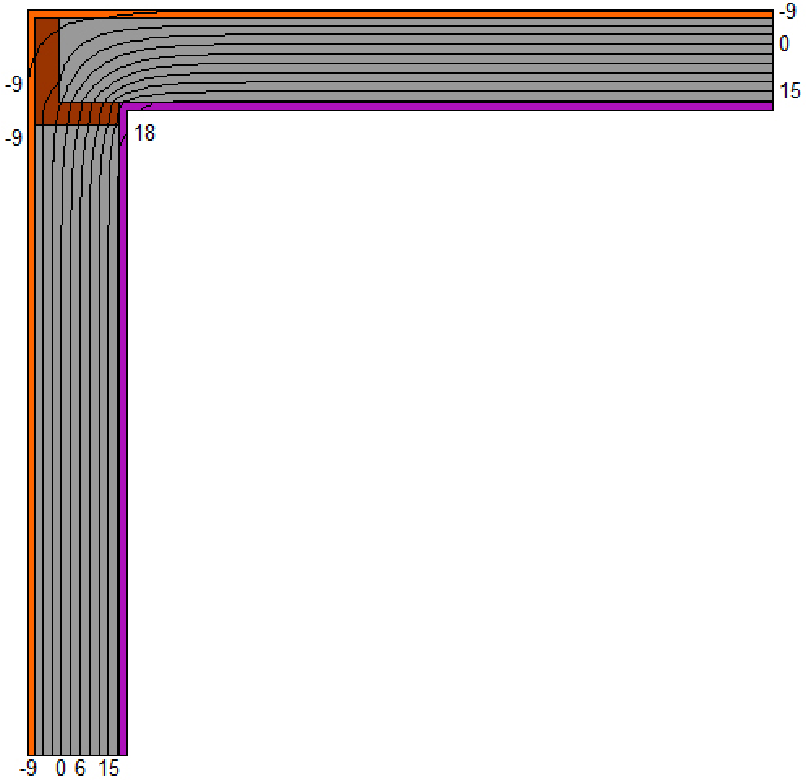
Is the psi value really an indicator of a detail's thermal quality?
Not really.

At structural thermal bridges, a psi value is a *comparison* between the U-value of the assembly(ies) and the U-value of the junction. A junction detail that "passes" (0.01 W/mK) for one assembly may not pass with another.

Section 2 – Common Linear Thermal Bridges



2x6 wall, no studs: Ψ = - 0.058 W/mK
(-0.034 Btu/hr ft F)



2x6 wall, 2-stud: Ψ = - 0.040 W/mK
(-0.023 Btu/hr ft F)

When is a performance comparison valid?

When the two models being compared have the same assemblies (or at least the same U-values) and the same geometry (that is, the relative position of the assemblies). The only difference is at the junction. Example above.

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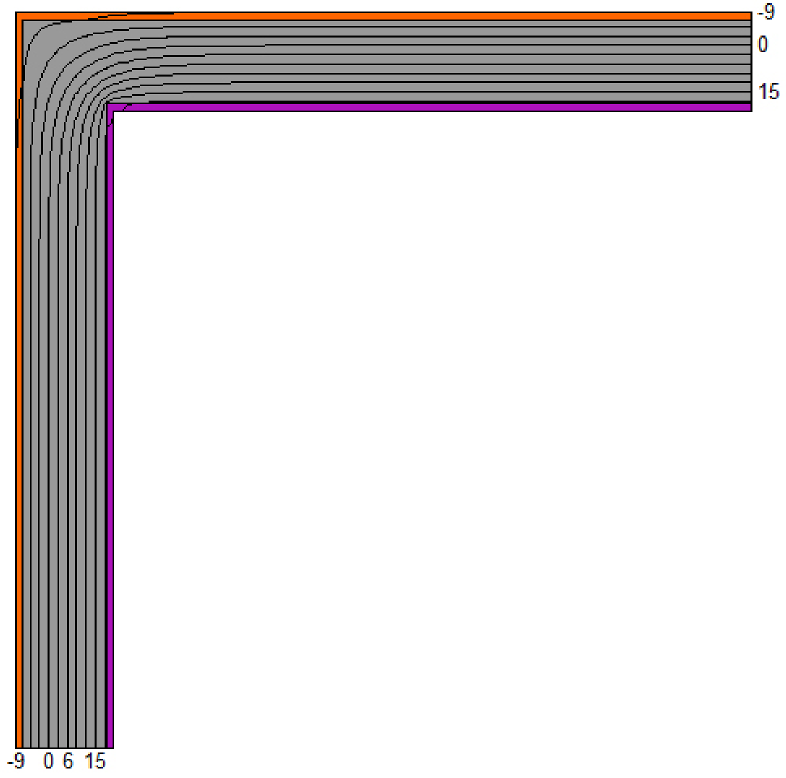
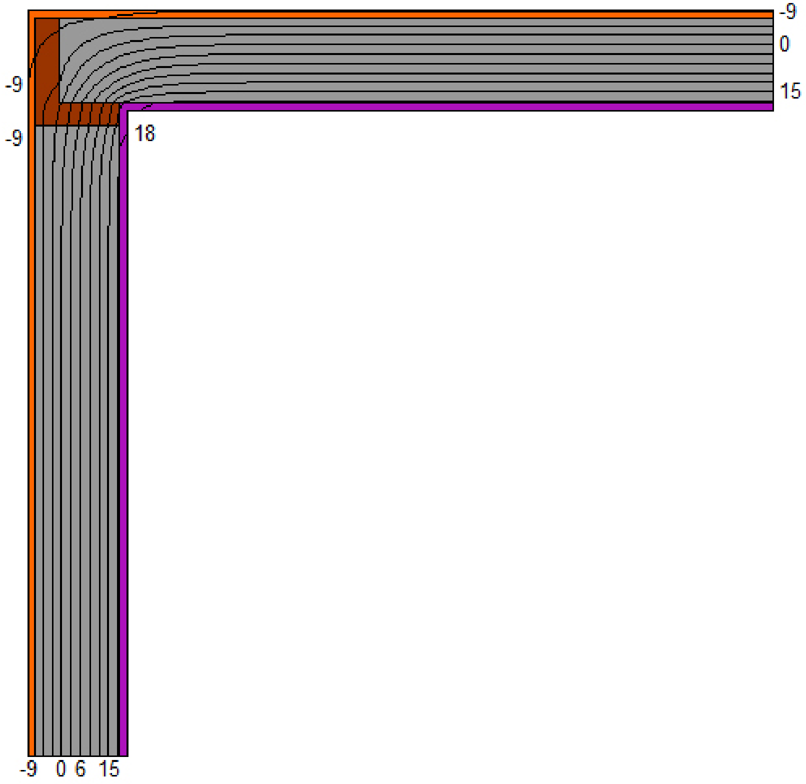
Section 2 – Common Linear Thermal Bridges





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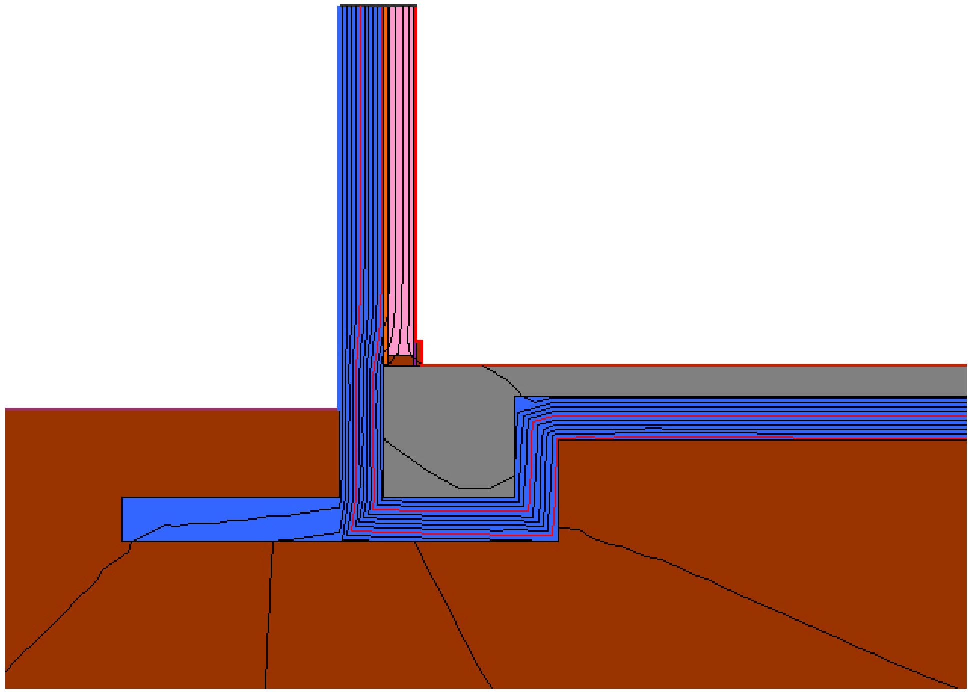
(-0.034 Btu/hr ft F)

2x6 wall, 2-stud: Ψ = - 0.040 W/mK
(-0.023 Btu/hr ft F)

When is a performance comparison valid?

In this example, the heat flow through the corner on the right really is 0.018 W/mK greater than the heat flow through the corner on the left.

Section 2 – Common Linear Thermal Bridges

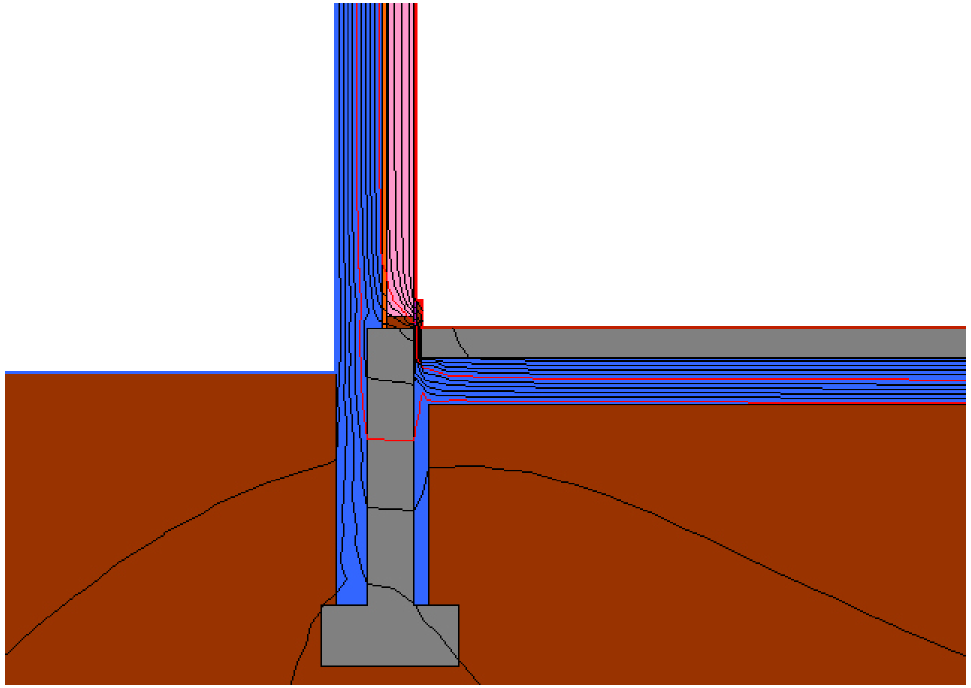


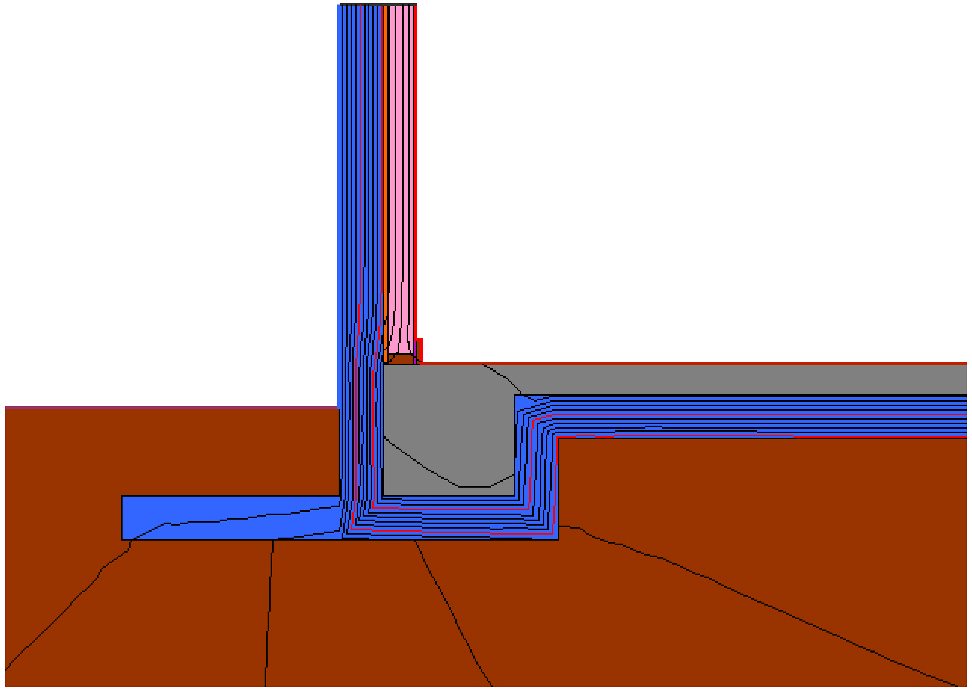
FPSF (well insulated): Ψ = 0.013 W/mK
(0.008 Btu/hr ft F)

Thick layers of continuous insulation can improve the performance of the detail, but even a very well insulated FPSF is still close to the 0.01 W/mK limit.

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

Section 2 – Common Linear Thermal Bridges





Thermally broken stem wall: Ψ = 0.018 W/mK (0.010 Btu/hr ft F)

Heat flux = 23.4 W/mK

FPSF (well insulated): Ψ = 0.013 W/mK (0.008 Btu/hr ft F)

Heat flux = 23.2 W/mK

Cutting the radiation fin off is sometimes more effective than insulating it.

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

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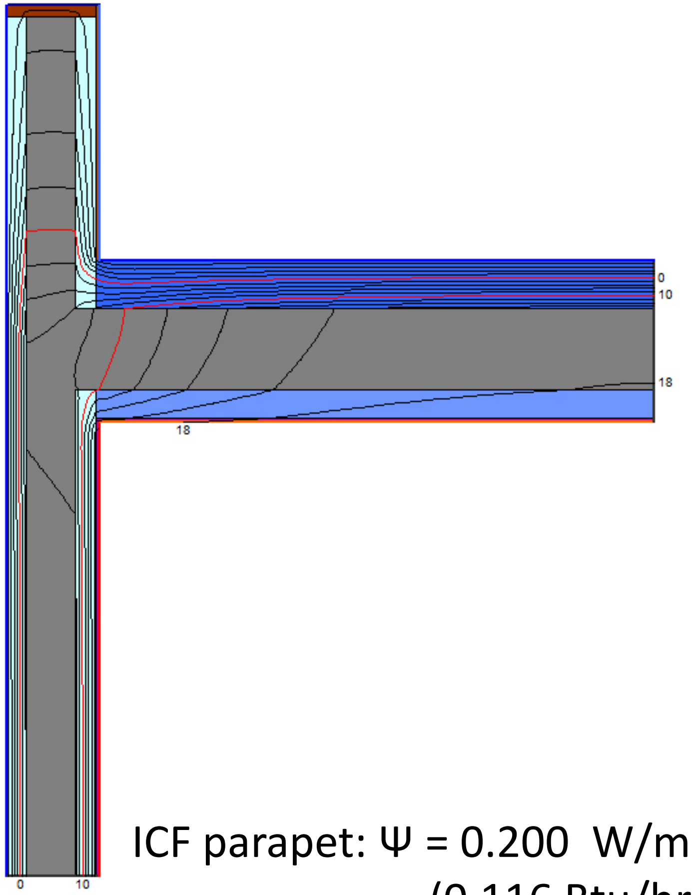
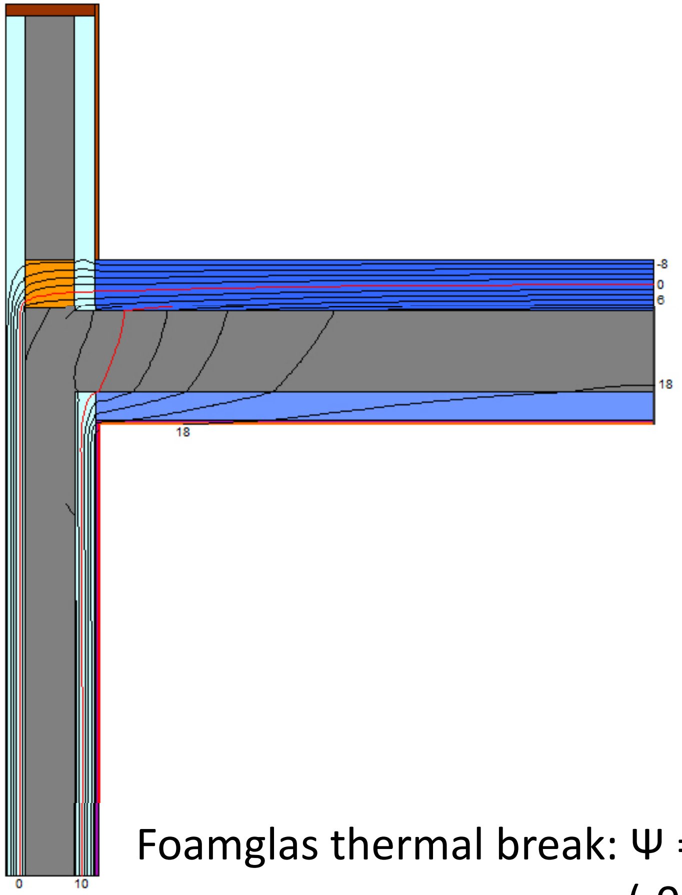
Section 2 – Common Linear Thermal Bridges



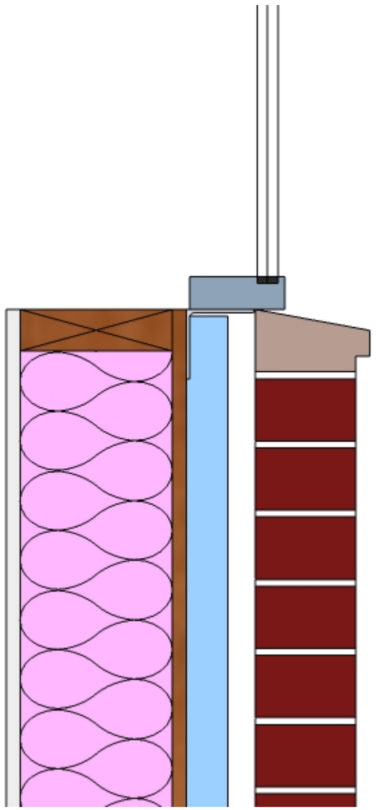
ICF parapet: Ψ = 0.200 W/mK
(0.116 Btu/hr ft F)



Foamglas thermal break: Ψ = -0.071 W/mK
(-0.041 Btu/hr ft F)

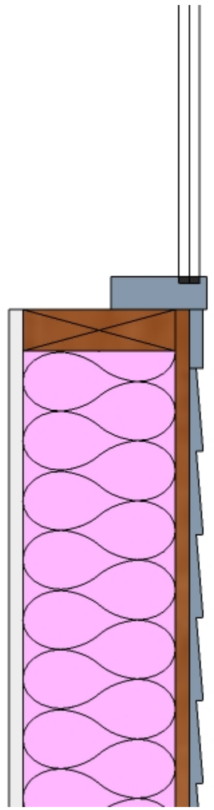
Another good location to cut off the radiation fin.

Section 2 – Common Linear Thermal Bridges



Window positioned outside of thermal envelope, Ψ = 0.10 W/mK (0.058 Btu/hr ft F)

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 (0.023 Btu/hr ft F)

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

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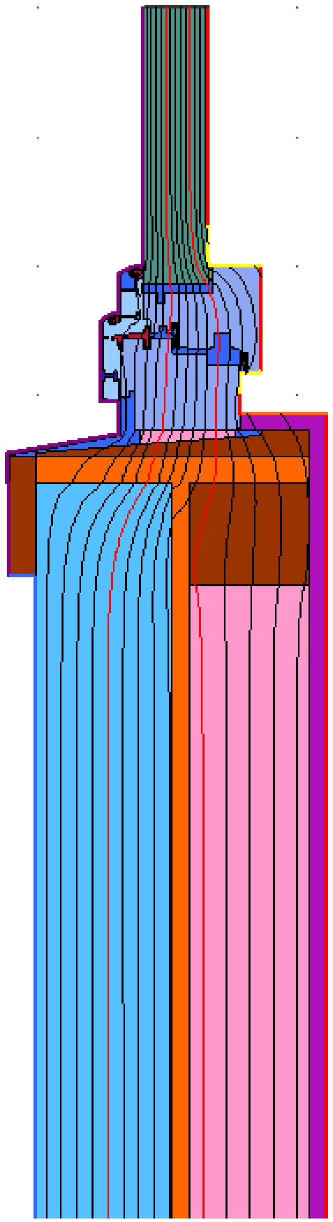
Section 2 – Common Linear Thermal Bridges



Window centered in plane of insulation, Ψ = 0.02 to 0.03 W/mK (0.012 to 0.017 Btu/hr ft F)

R-value of window is almost preserved

Section 3 – Using psi values in PHPP/WUFI Passive

How do I know which thermal bridges need to be entered in PHPP/WUFI Passive?

Section 3 – Using psi values in PHPP/WUFI Passive

How do I know which thermal bridges need to be entered in PHPP/WUFI Passive?

PHI requires 1 of 2 paths:

1) Enter psi-values for all thermal bridges, both + and -
2) Enter only thermal bridges with psi values over 0.01 W/mK

Path 2 begs the question – how do I know which TBs will be over 0.01 W/mK, before I've modeled them?

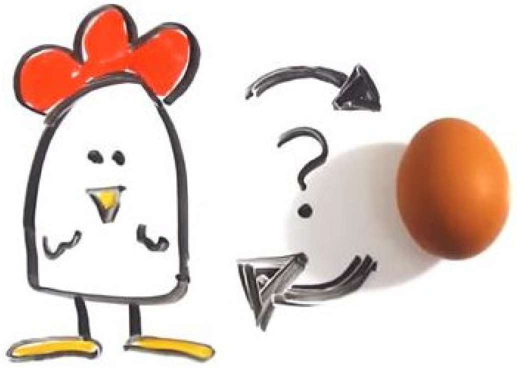


Image source: http://www.theblaze.com/blog/2013/01/24/finally-the-answer-sort-of-for-what-came-first-the-chicken-or-the-egg/

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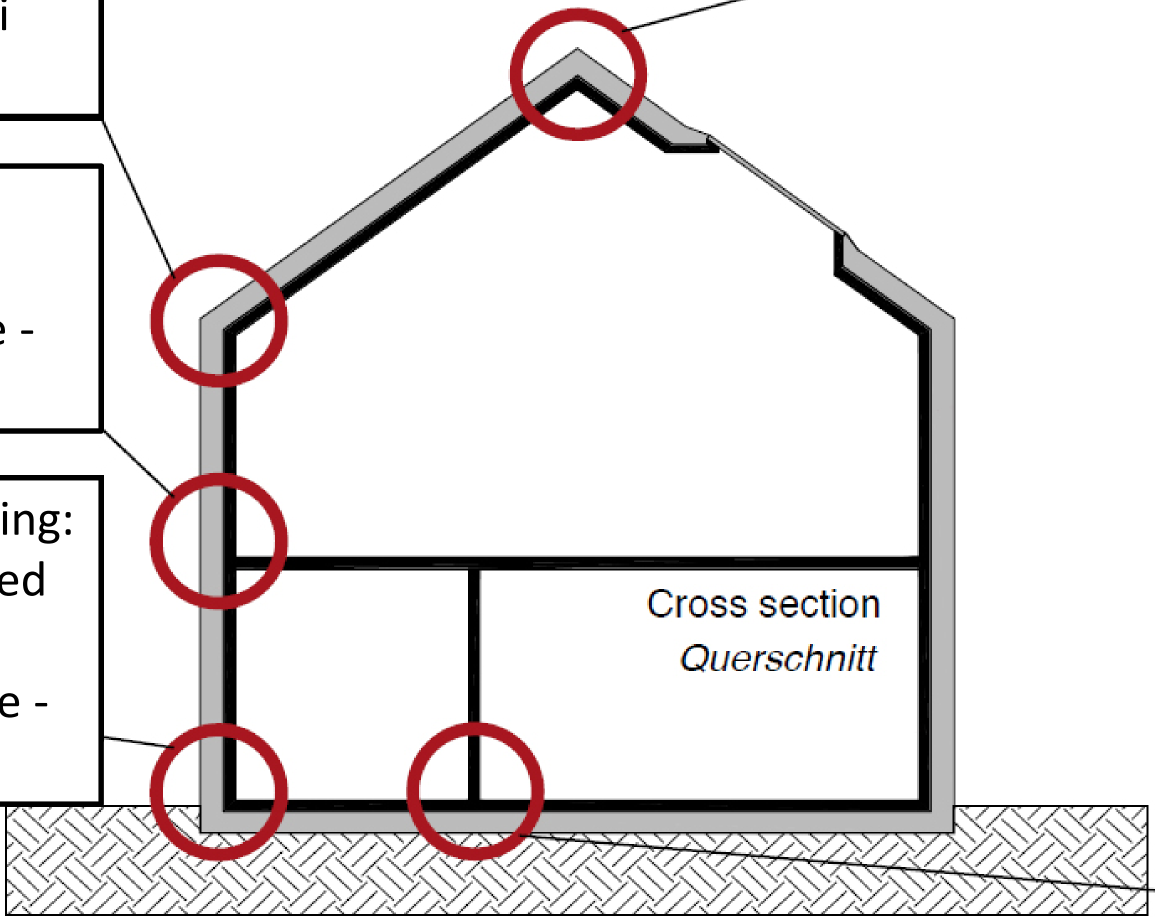
Section 3 – Using psi values in PHPP/WUFI Passive

Eaves:
Most details will have negative psi value

Rim joist:
Almost always positive psi value - MODEL

Wall to slab/footing:
Only well-designed details will have negative psi value - MODEL



Roof ridge:
Most details will have negative psi value

Footing below bearing wall or post:
Only well-designed details will have psi value < 0.01 W/mK- MODEL

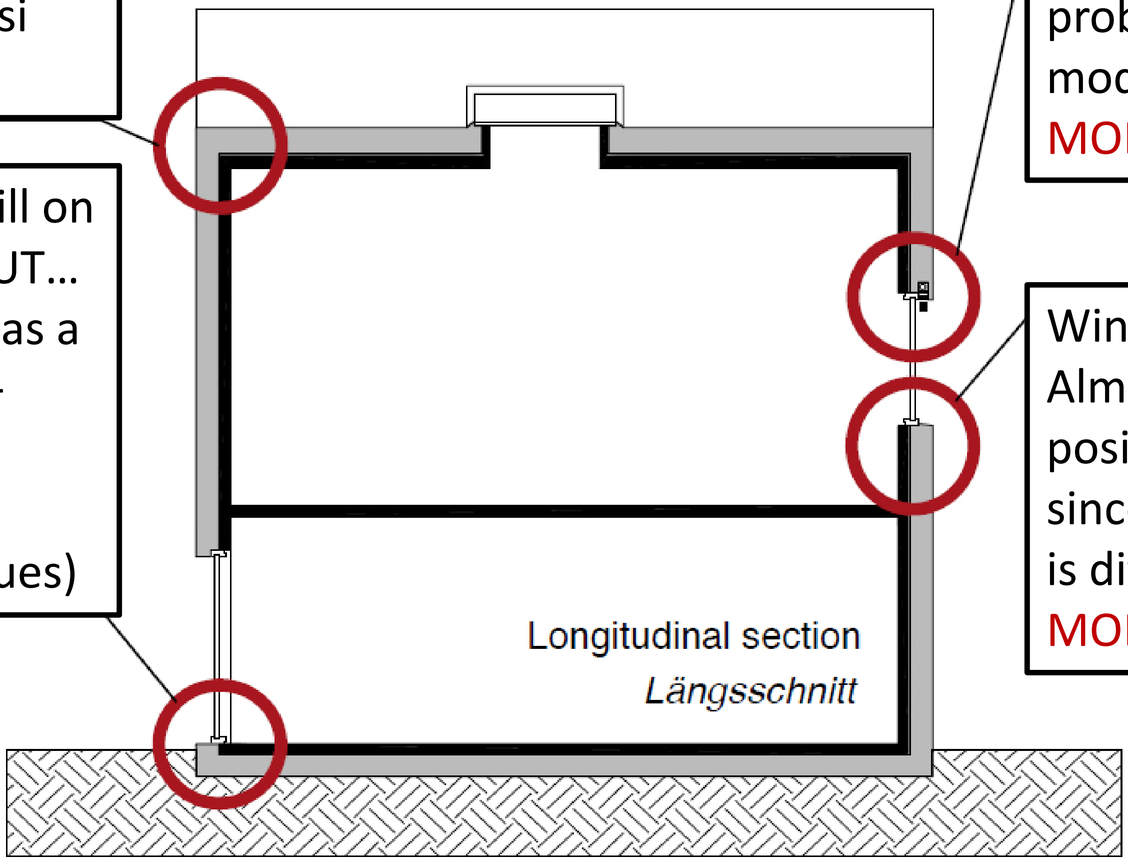
Section 3 – Using psi values in PHPP/WUFI Passive

Rake:
Most details will have negative psi value

Window/door sill on slab: MODEL, BUT… Can be entered as a window sill TB + wall-to-slab TB (requires two separate psi values)

Window head:
If overinsulated, probably no need to model. If not – MODEL

Window sill:
Almost always positive psi value since overinsulation is difficult – MODEL

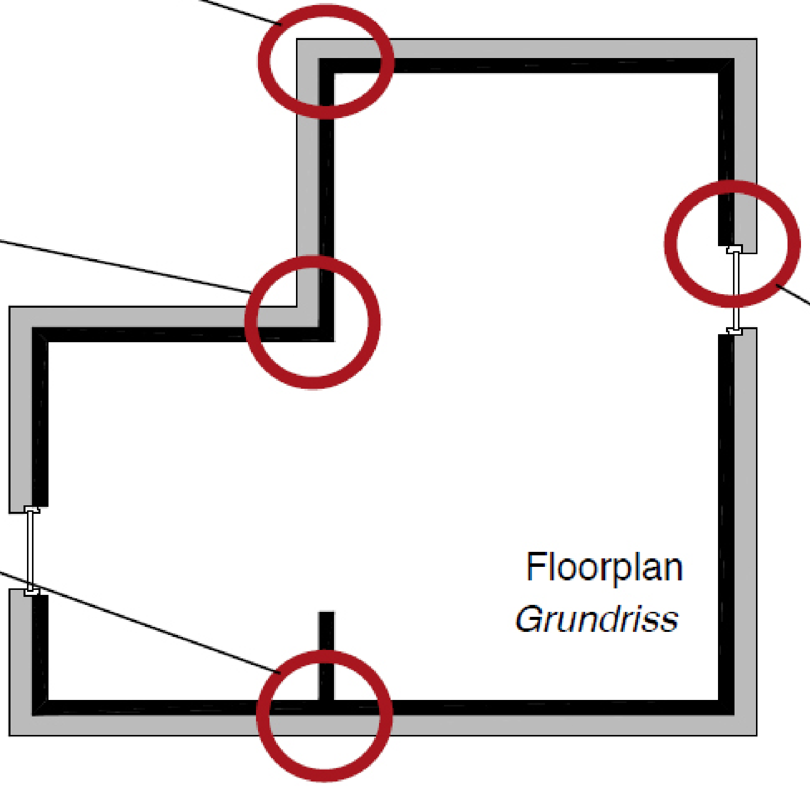


Section 3 – Using psi values in PHPP/WUFI Passive

Exterior corner:
Most details will have negative psi value

Interior corner:
Almost always positive psi value – MODEL

Wall junction:
If insulation layers are interrupted - MODEL



Window jamb:
If overinsulated, probably no need to model. If not – MODEL (Many times, PHI allows the head detail to be used for the jamb too.)

Section 3 – Using psi values in PHPP/WUFI Passive

Other places to keep in mind for possible thermal bridges

- Plumbing stacks
- Rain pipes (interior)
- ERV vent penetrations (to the exterior)
- Sump pumps
- Radon remediation pipes (if interior to the building)

These need to be properly detailed and insulated. They need to be taken into account in the PHPP, but not usually modeled in THERM or FLIXO.

Section 3 – Using psi values in PHPP/WUFI Passive

Found on the bottom of the Areas sheet in PHPP

Auxiliary calculation r		
Nominal width:	75	mm
Insul. thickness:	38	mm
Thermal conductivity	0.038	W/(mK)
Interior pipe diameter:	0.075	m
Exterior pipe diameter:	0.151	m
α-Surface	6.80	W/(m²K)
Ψ–value	0.254	
Reduction factor	0.70	
Ψ–value	**0.178**	**W/(mK)**
To enter as group 15 thermal bridge		

Section 3 – Using psi values in PHPP/WUFI Passive

		Heat recovery efficiency Unit η_{HR}	Humidity recovery efficiency	Specific efficiency [W/cfm]	Application [cfm]	Frost power input
	Go to ventilation units list 1-Sorting: LIKE LIST					
Ventilation unit selection	01ud-Comfoair 550 w/ enthalpy	0.84	0.65	0.57	29 - 324	x

Implementation of frost protection	2-Elec.	Room temperature (°F)	68
Limit temperature [°F]	28	Avg. ambient temp. heat. period (°F)	41
Useful energy [kBTU/yr]	663	Avg. ground temp (°F)	54

Conductivity outdoor air duct	Ψ	BTU/hr.ft.°F	0.201
Length of outdoor air duct		ft	16.00
Conductivity exhaust air duct	Ψ	BTU/hr.ft.°F	0.201
Length of exhaust air duct		ft	21.00
Temperature of mechanical services room		°F	68
(Enter only if the central unit is outside of the thermal envelope)			

Effective heat recovery efficiency $\eta_{HR,eff}$ **79.7%**

Effective heat recovery efficiency subsoil heat exchanger

SHX efficiency	η^*_{SHX}	
Heat recovery efficiency SHX	η_{SHX}	0%

Secondary calculation
Ψ-value supply or outdoor air duct

Nominal width:	6.00	in
Insulation thick	2.00	in
Reflective coating?	x	Yes
		No
Thermal resistance	4.00	R per inch
Nominal air flow rate	128	cfm
Δϑ	27	°F
Exterior duct diameter	6.00	in
Exterior diameter	10.00	in
R–Interior	0.39	hr.ft^2.°F/BTU
R-Surface	2.13	hr.ft^2.°F/BTU
Ψ–value	**0.201**	**BTU/hr.ft.°F**
Surface temperature difference	4.43	°F

Secondary calculation
Ψ-value extract or exhaust air duct

Nominal width:	6.00	in
Insulation thickness	2.00	in
Reflective coating?	x	yes
		no
Thermal resistance	4.00	R per inch
Nominal air flow rate	128	cfm
Δϑ	27	°F
Exterior duct diameter	6.00	in
Exterior diameter	10.00	in
R–Interior	0.39	hr.ft^2.°F/BTU
R-Surface	2.13	hr.ft^2.°F/BTU
Ψ–value	**0.201**	**BTU/hr.ft.°F**
Surface temperature difference	4.43	°F

Section 3 – Using psi values in PHPP/WUFI Passive

When do I need to **model** a thermal bridge?

1. If a thermal bridges is unavoidable, then the thermal bridge coefficient must be “verified” by the Certifier.

2. Catalogue values for comparable constructions is acceptable “verification”.

3. The thermal bridge coefficient may be estimated, but only if 1) the Certifier allows this and 2) the Certifier verifies the coefficient is appropriately and conservatively estimated based on either a catalog value or a calculation.

4. Otherwise, a thermal bridge calculation is necessary.

Section 3 – Using psi values in PHPP/WUFI Passive

When do I need to **consider** thermal bridges?

EARLY and OFTEN:

1) Thermal bridge modeling is part of the design process

2) Save time and money by reducing the number of positive thermal bridges

3) Design buildings well below the 15 kWh/(m^2a) [4.75 kBTU/ft^2/yr] so negative thermal bridges do not need to be modeled and catalog/conservative values for positive thermal bridges can be used (11 -13 kWh/(m^2a)) [3.49 – 4.12 kBTU/ ft^2 /yr]

4) Make sure to design your building with allowances for typical thermal bridges

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Section 3 – Using psi values in PHPP/WUFI Passive

Thermal bridge inputs

No.	Thermal bridge - denomination	Group No.	Assigned to group	Quantity	x (	Length [m]	-	Subtraction length [m]	)=	Length l [m]	User determined Ψ-Wert [W/(mK)]	User determined $f_{Rsi=0.25}$ (optional)
1	TB rim joist	15	Thermal bridges Ambient	1	x (	52.38	-		) =	52.38	0.014	
2	Plumbing vent stack	15	Thermal bridges Ambient	1	x (	1.00	-		) =	1.00	0.120	
3					x (		-		) =			
4					x (		-		) =			
5					x (		-		) =			
6					x (		-		) =			
7					x (		-		) =			
8					x (		-		) =			
9					x (		-		) =			
10					x (		-		) =			
11					x (		-		) =			
12					x (		-		) =			
13					x (		-		) =			
14					x (		-		) =			
15					x (		-		) =			
16					x (		-		) =			
17					x (		-		) =			
18					x (		-		) =			
19					x (		-		) =			
20					x (		-		) =			
21					x (		-		) =			
22					x (		-		) =			
23					x (		-		) =			
24					x (		-		) =			
25					x (		-		) =			

A	Thermal bridges Ambient	15	53.38	m
P	Perimeter thermal bridges	16	0.00	m
B	Thermal bridges FS/BC	17	0.00	m

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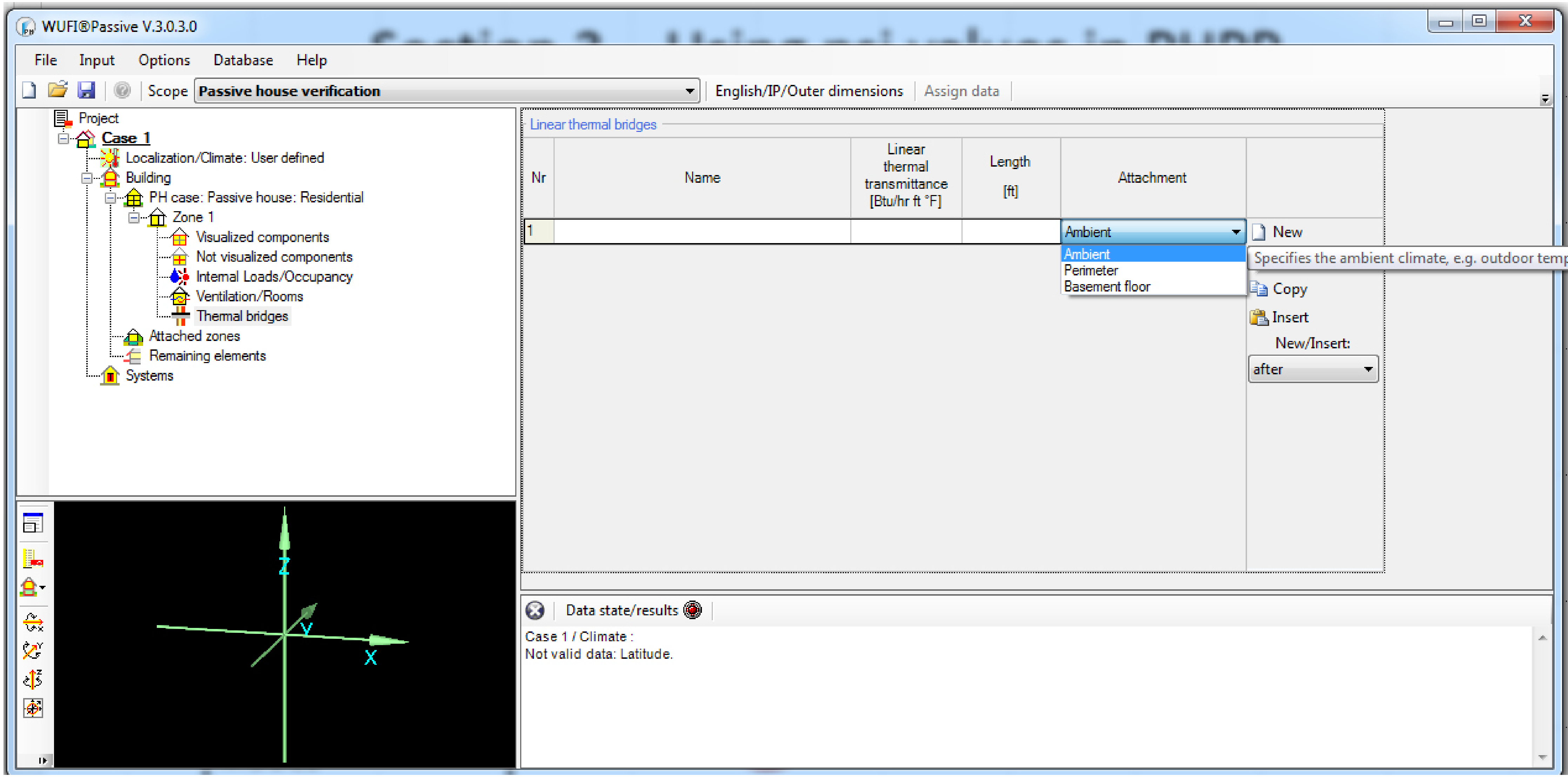
Section 3 – Using psi values in PHPP/WUFI Passive



THERM vs Flixo

Pros of Flixo

- Validated and regularly updated to match ISO standards and protocols
- Easy-to-use drawing tools greatly speed workflow
- Report pages with pre-formatted elements simplify viewing and sending results
- Specialized tools such as the air cavity tool simplify complex window analysis protocols
- Heat flux and psi value calculations performed in the software

Cons of Flixo

- Cost - $344 for 1 yr license to Flixo Energy Plus (with dxf import)
- Odd functionality split between various versions

Pros of THERM

- Free
- Large user group and familiarity

Cons of THERM

- Drawing tools difficult to use
- Complex drawings (ex - window frames) prone to crash during simulation
- Psi value calcs require calculations outside the program (in excel workbook, for example)
- No built-in reporting capability
- dxf imports can be problematic

Special thanks to…

- Zola European Windows
- InfoMind, makers of Flixo software

The Why of Psi

Workshop Presenters:

for CertiPHIers Cooperative…

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