Determining the Thermal Performance of Your Building Enclosure : Assessing Thermal Bridges

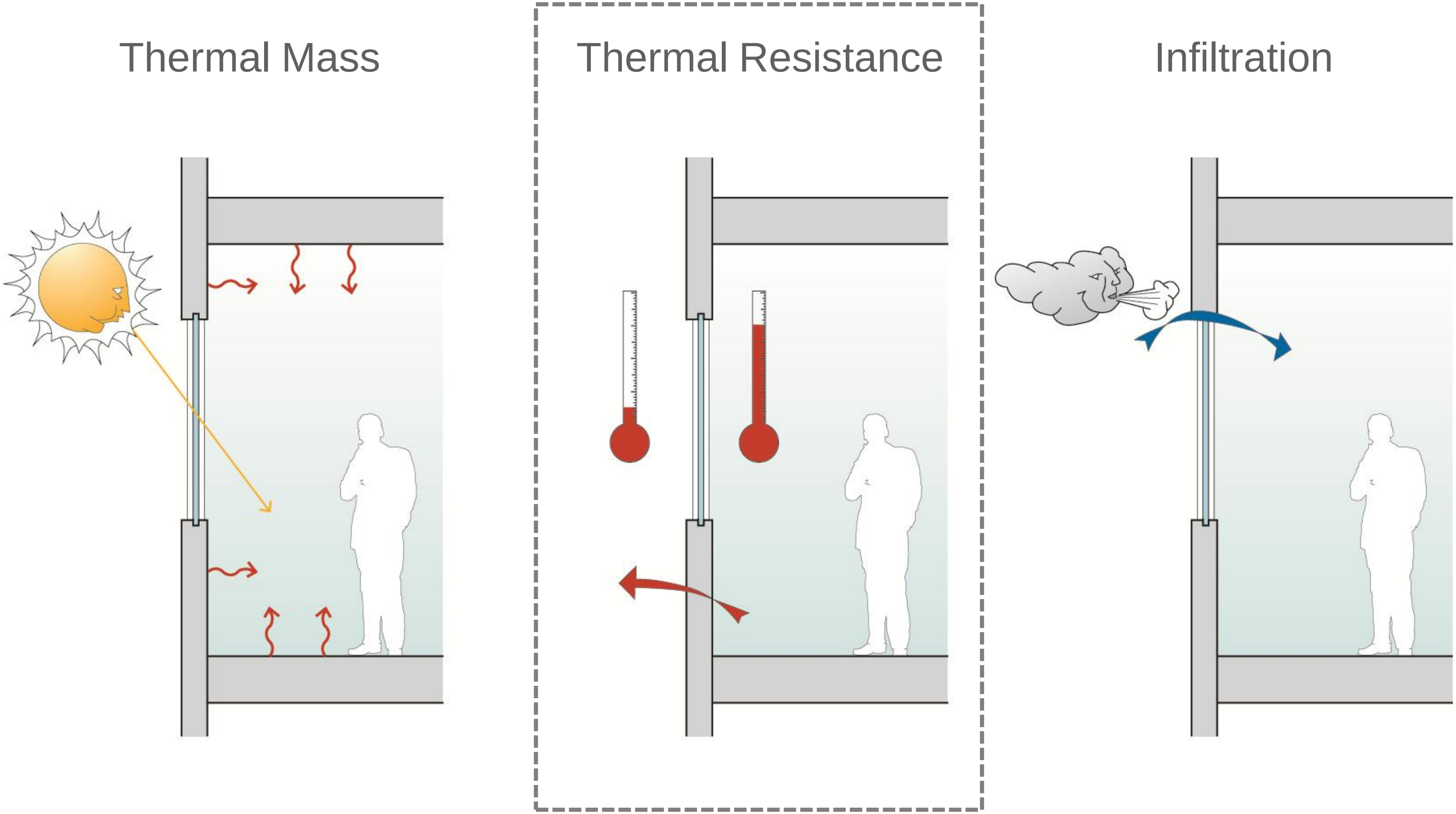
January 11, 2012

PAYETTE

AGENDA

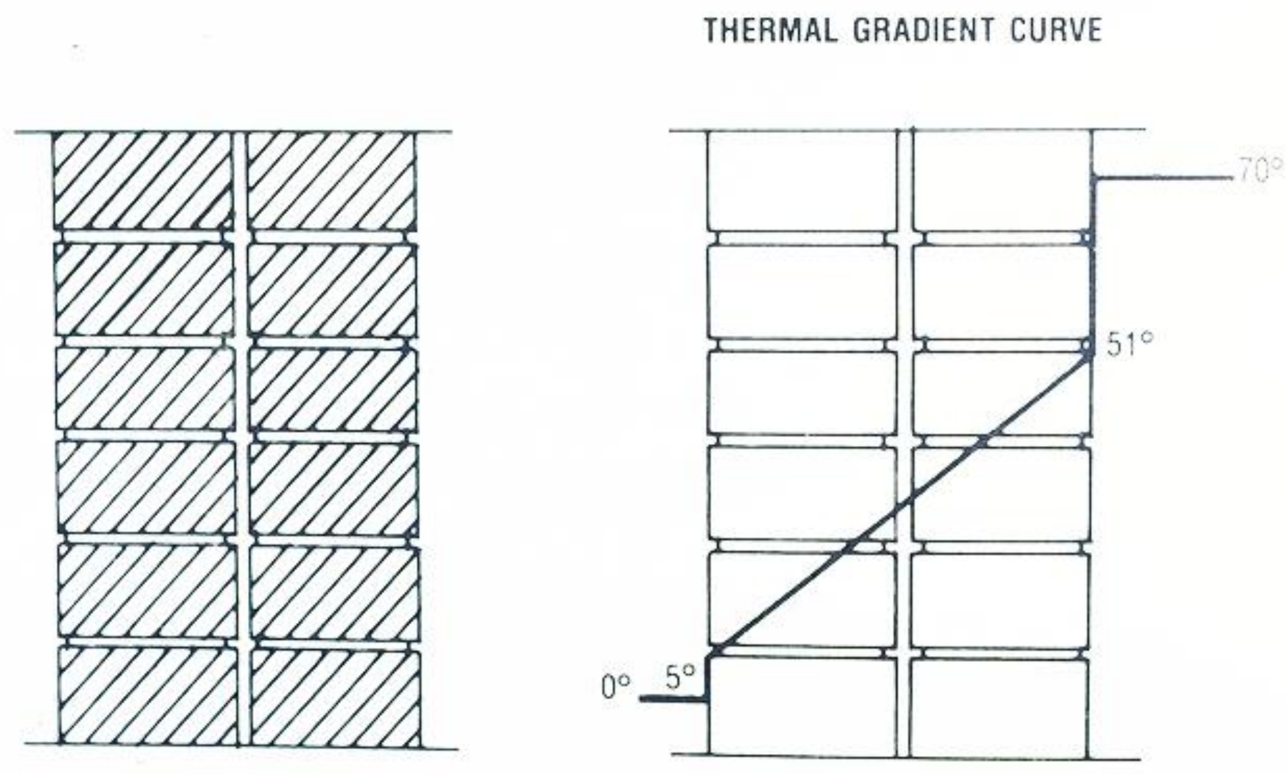
Introduction
Program Overview
Project Examples

THERMAL BRIDGING | INTRODUCTION



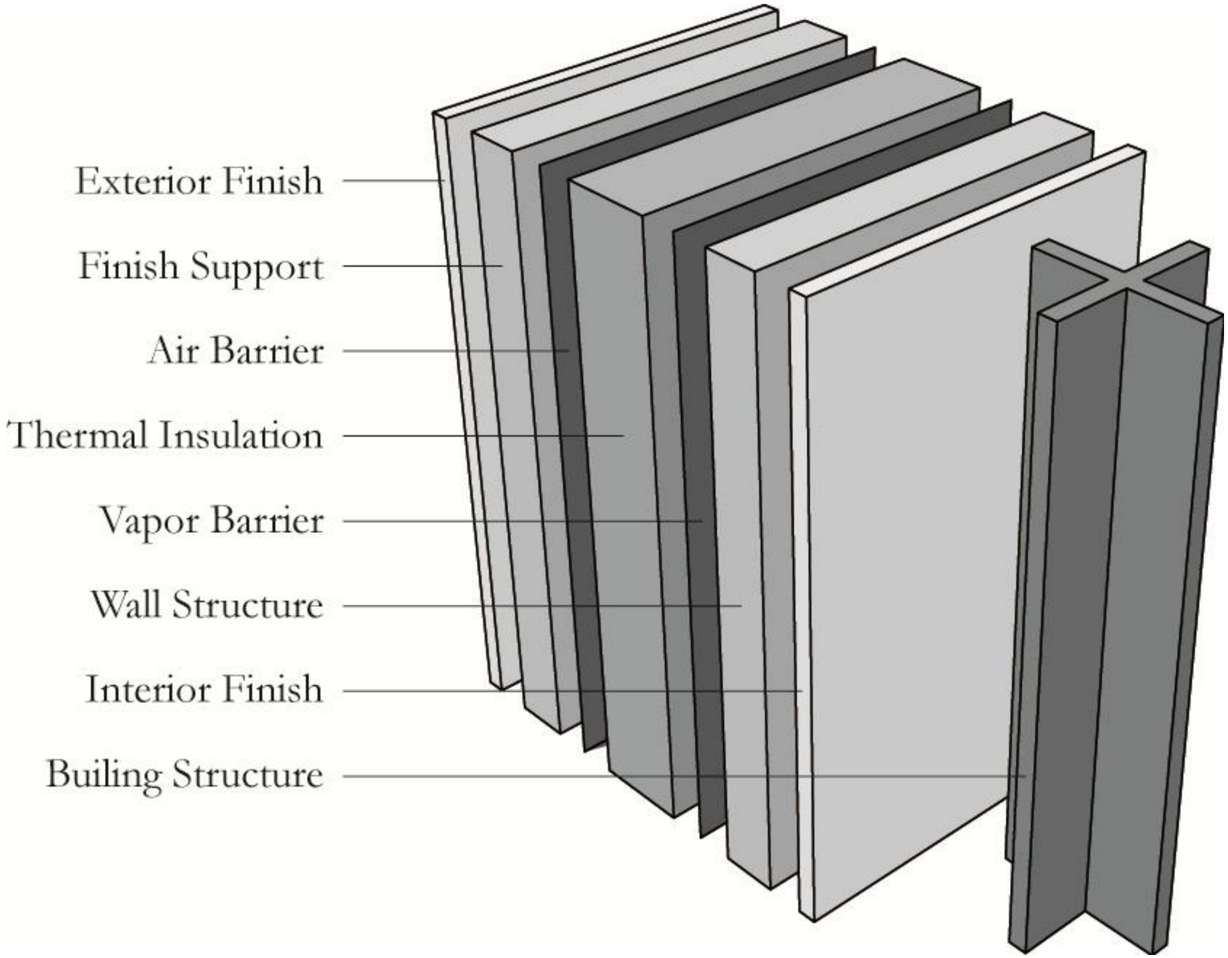
Solid portions of the building envelope can affect the building's energy usage in 3 ways, but this presentation focuses on the thermal resistance (R-value) of the assemblies.

THERMAL BRIDGING | INTRODUCTION



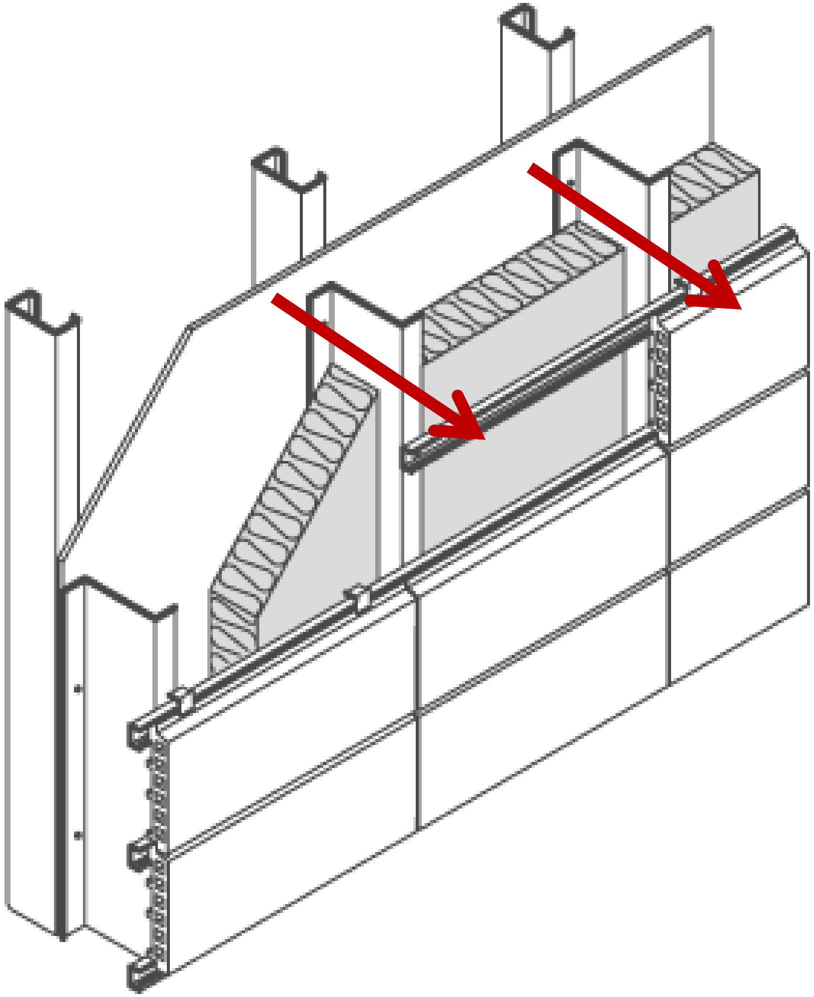
Historically, solid monolithic walls served all the functions (structural, thermal, acoustical, etc.) required of the building envelope.

THERMAL BRIDGING | INTRODUCTION



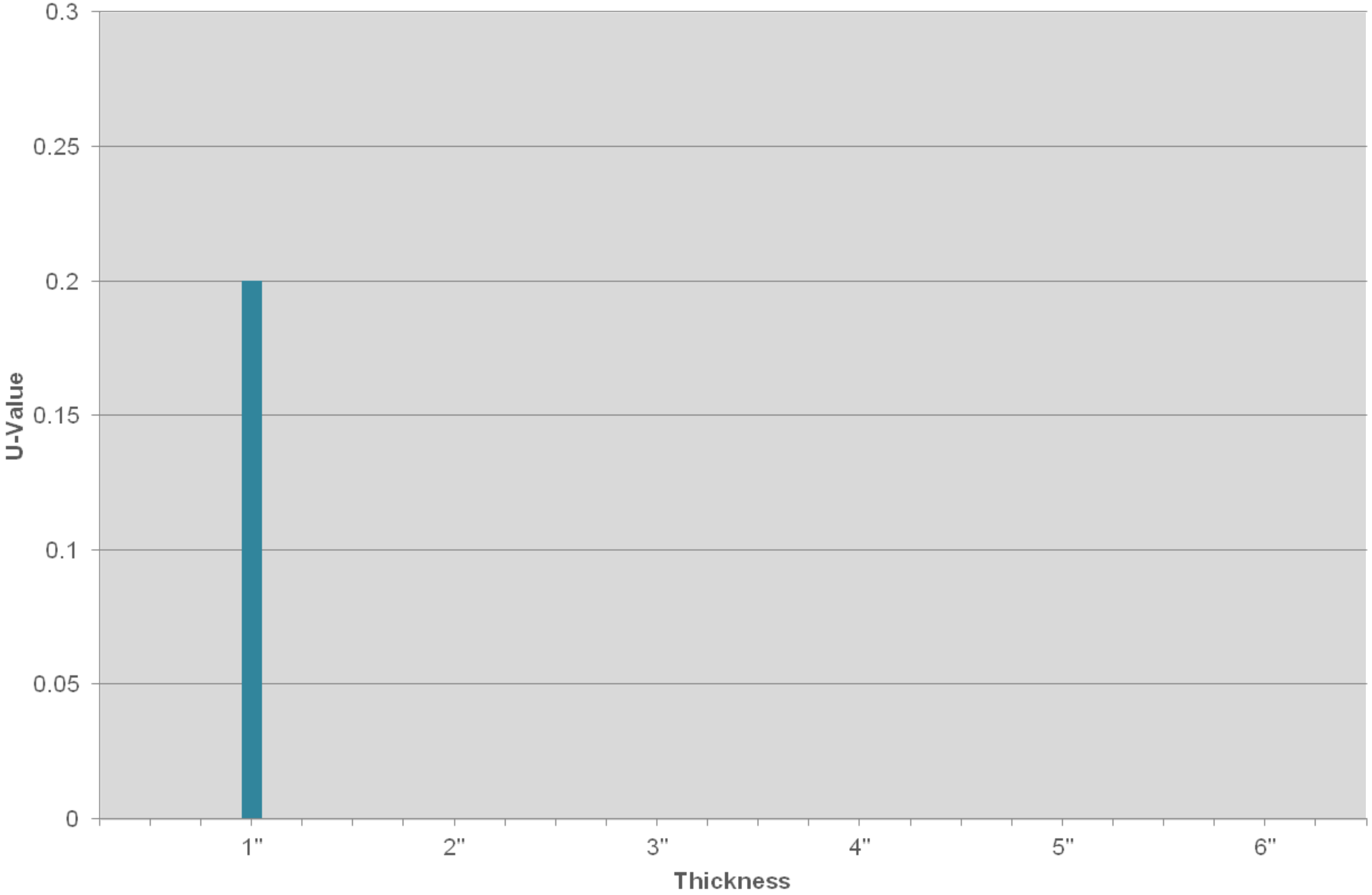
Current walls are now comprised of individual layers that have been optimized for the function that they serve.

THERMAL BRIDGING | INTRODUCTION



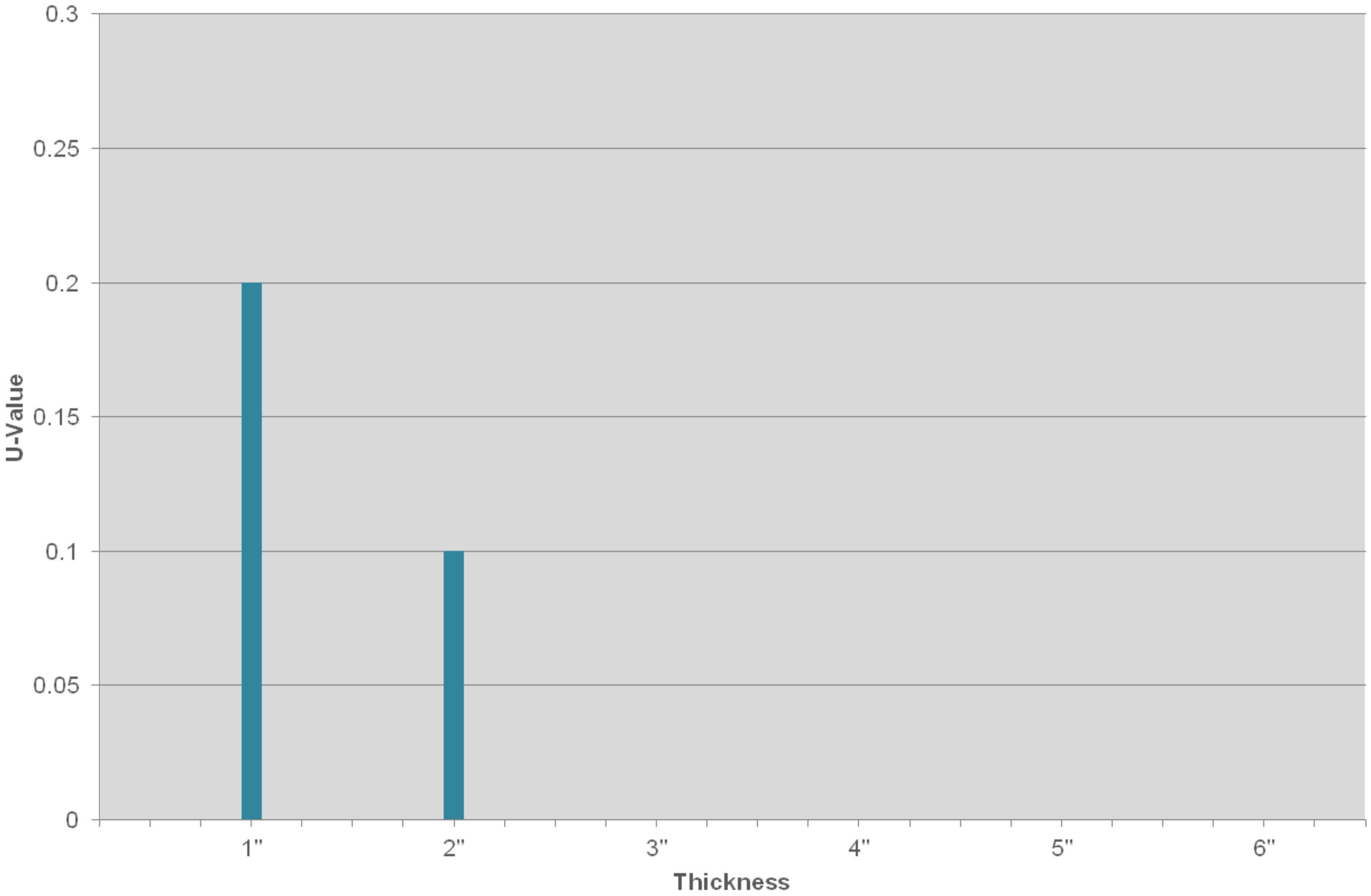
However, these layers are all held together with highly conductive materials, most commonly metal.

THERMAL BRIDGING | INTRODUCTION



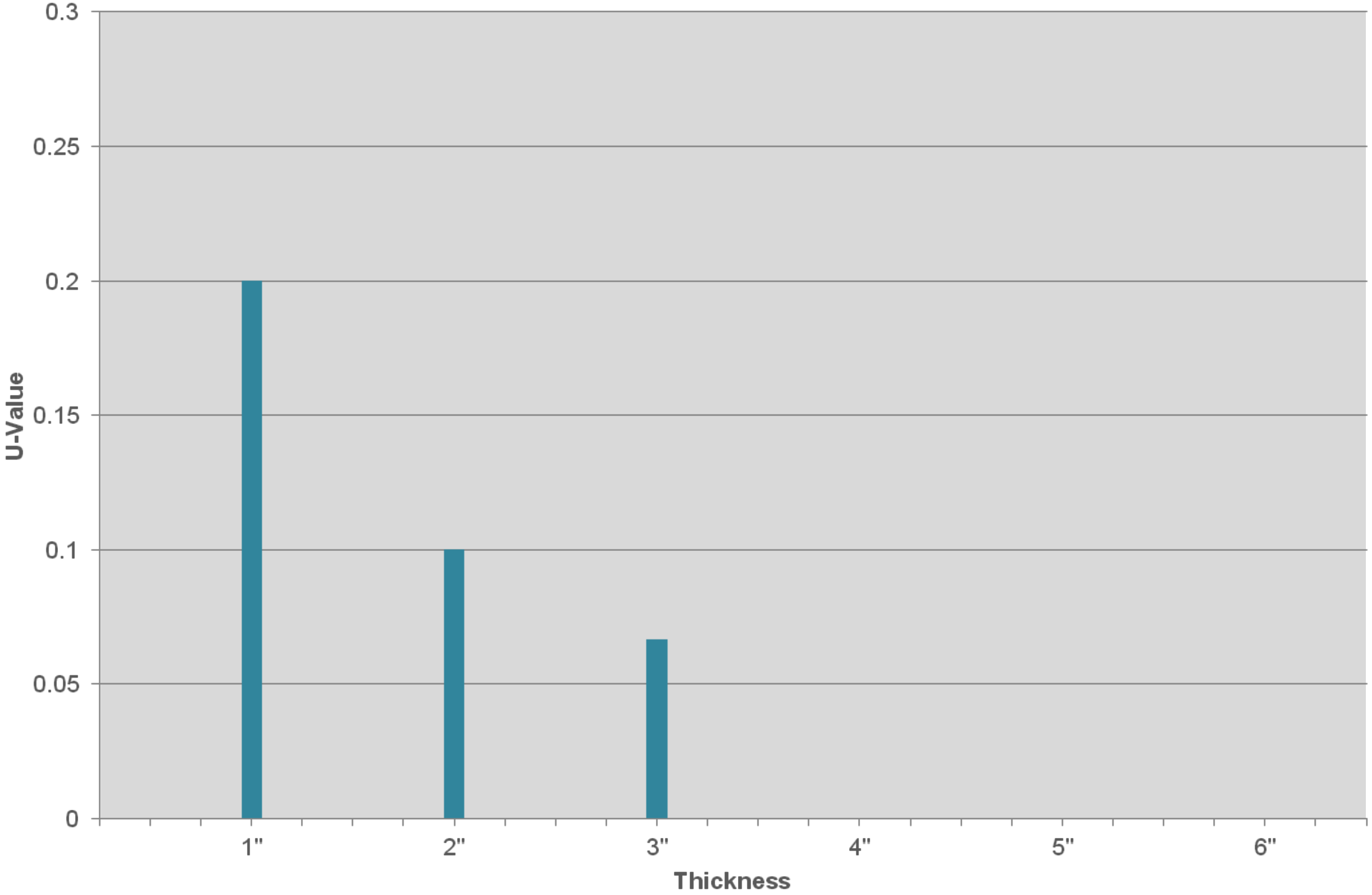
If you have 1” of XPS insulation you have a U-value of 0.2.

THERMAL BRIDGING | INTRODUCTION



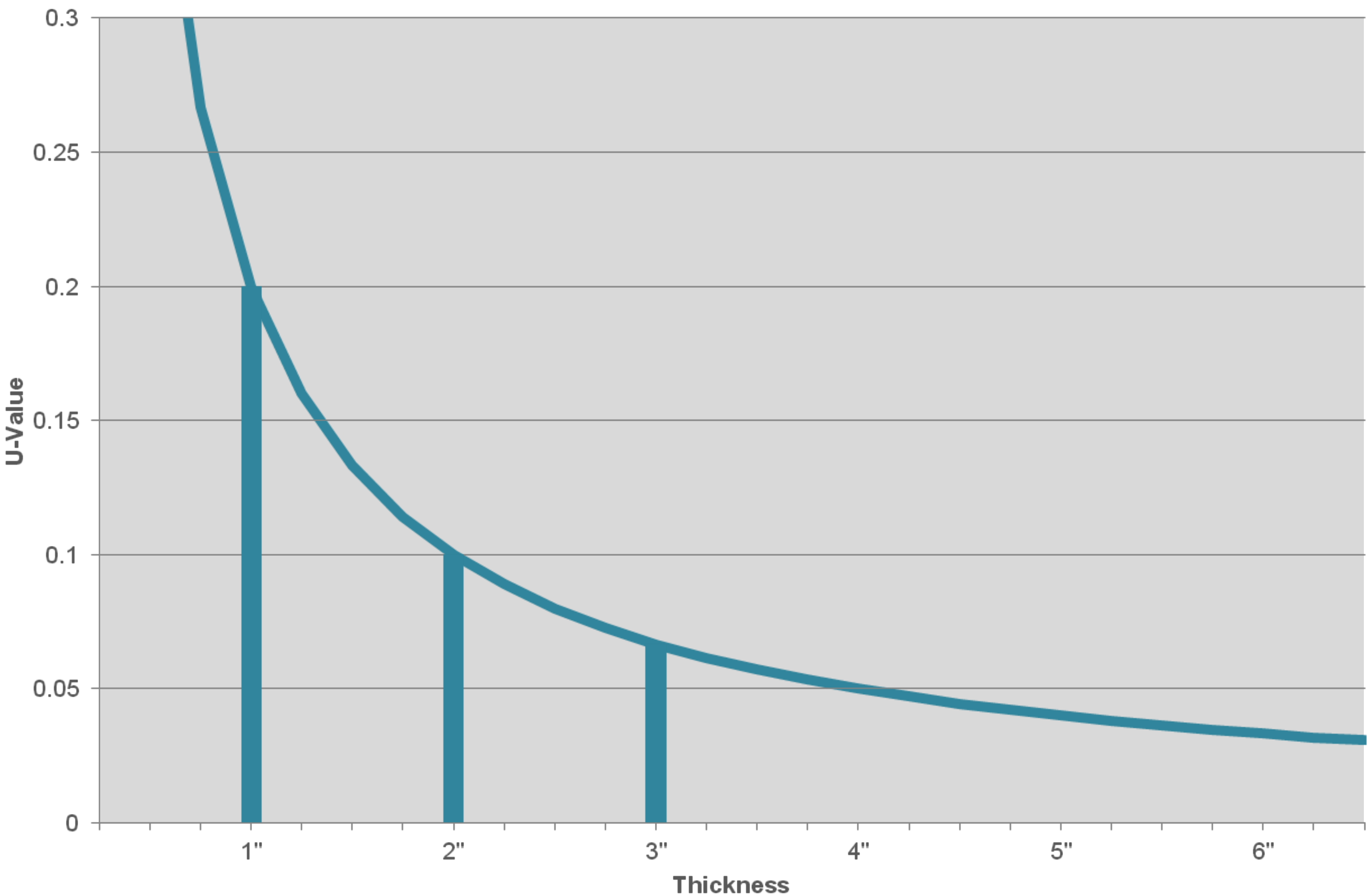
If you add another inch, doubling the amount to 2”, your heat flow through the wall is cut in half.

THERMAL BRIDGING | INTRODUCTION



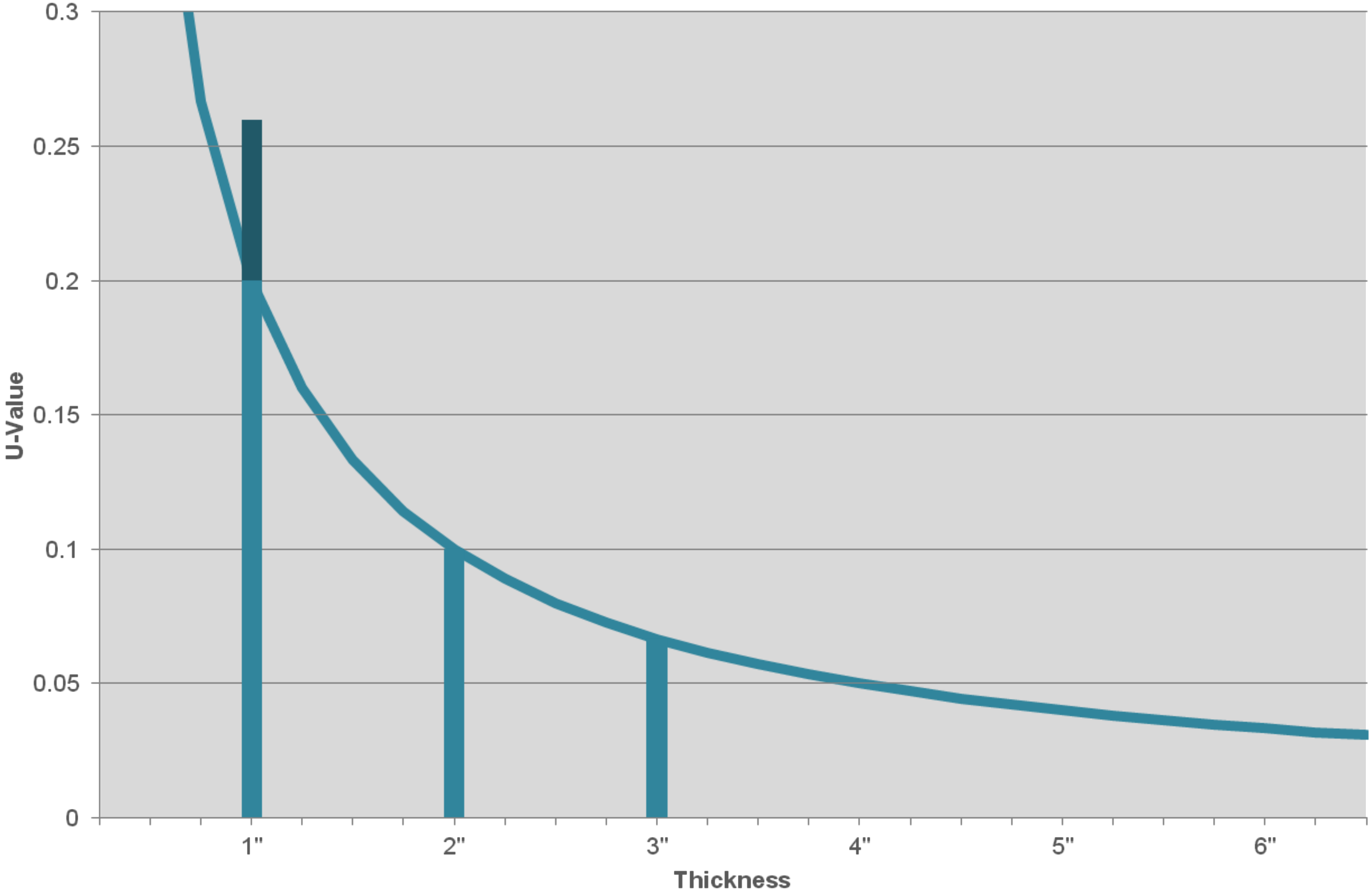
If you add yet another inch of insulation, the heat flow through that wall only decreases by about a third.

THERMAL BRIDGING | INTRODUCTION



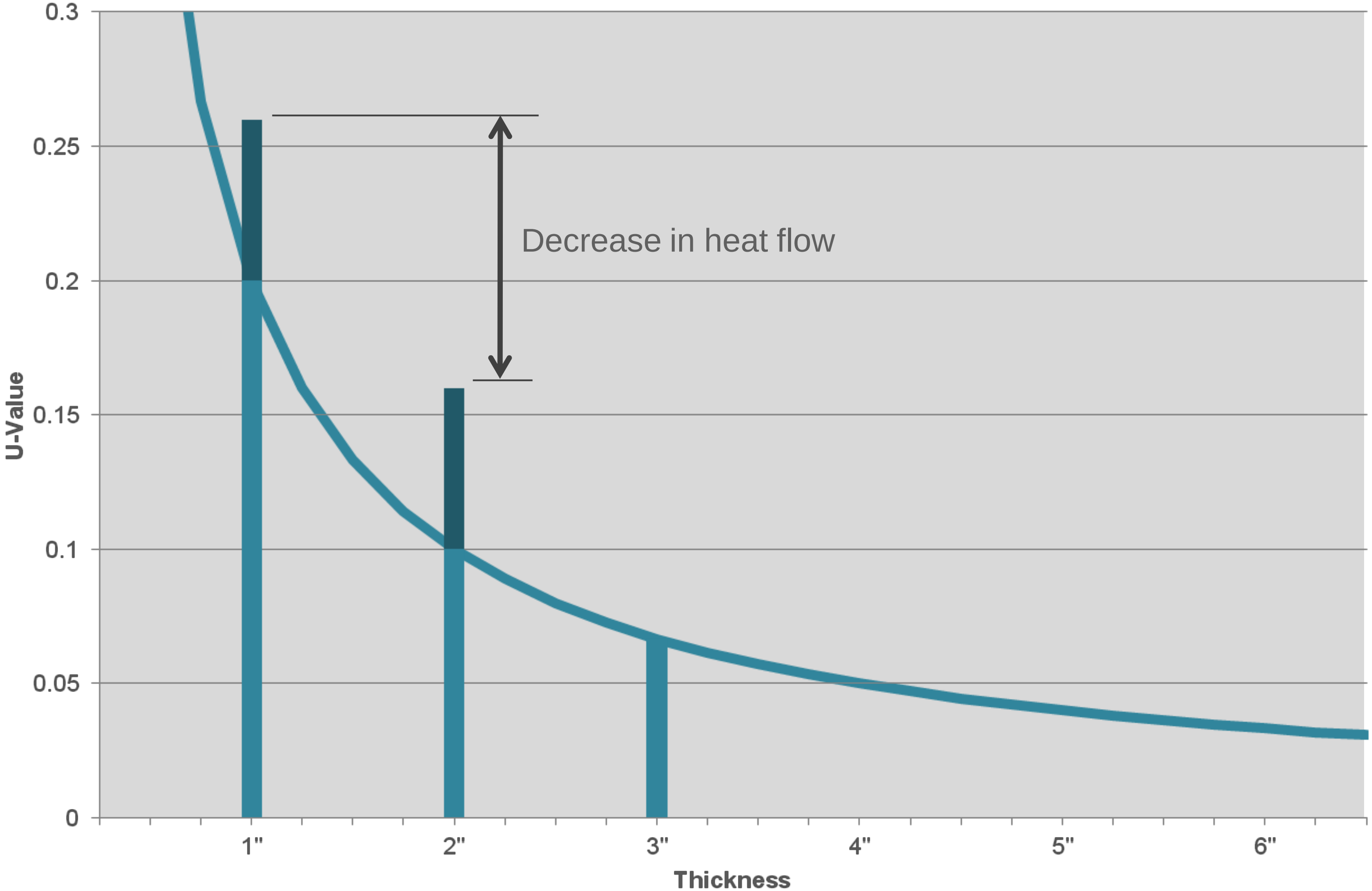
And so on . . . as you increase the amount of insulation there are diminishing returns.

THERMAL BRIDGING | INTRODUCTION



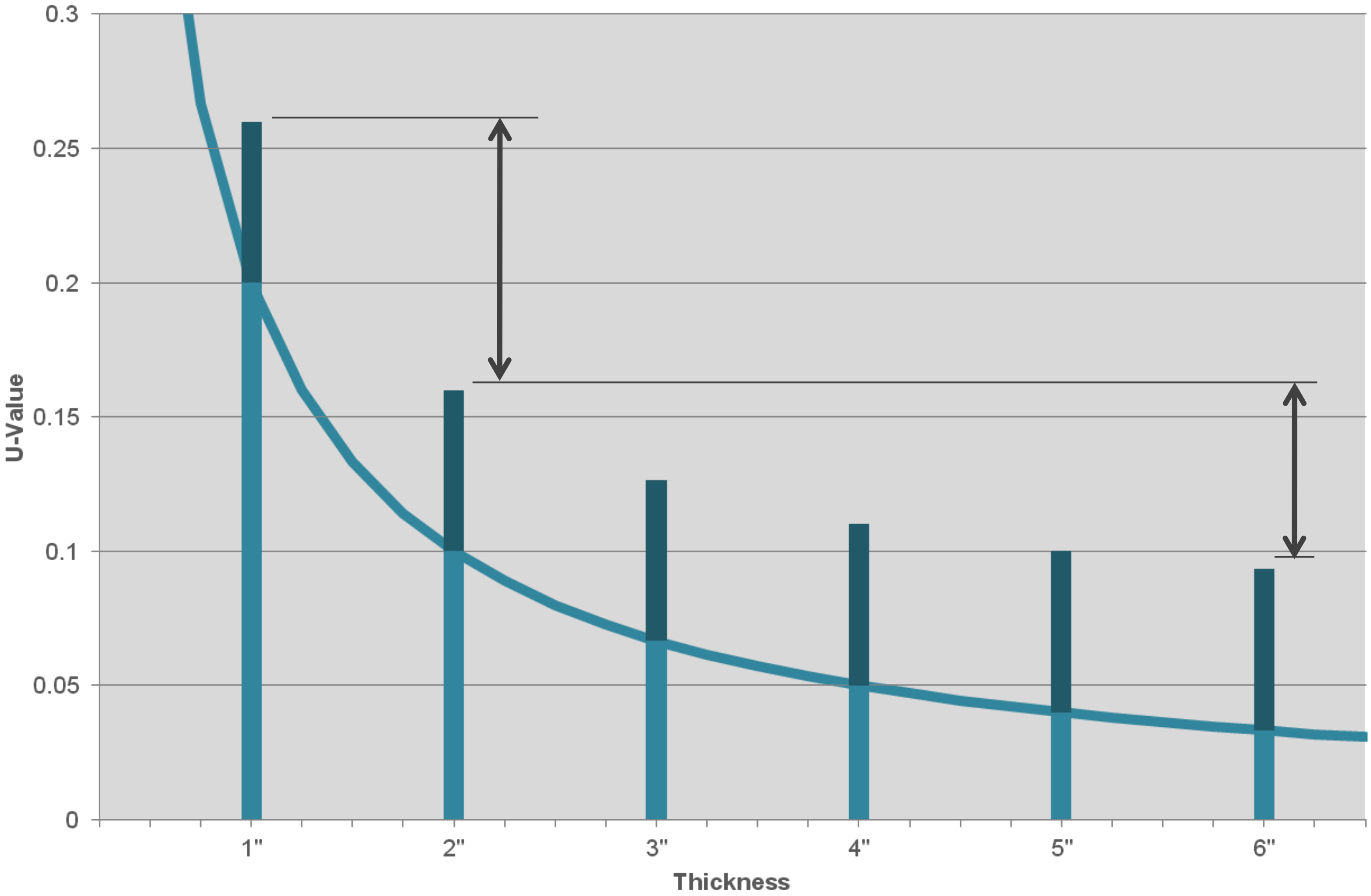
If thermal bridges occur through the insulation this increases the heat flow and the U-value of the assembly.

THERMAL BRIDGING | INTRODUCTION



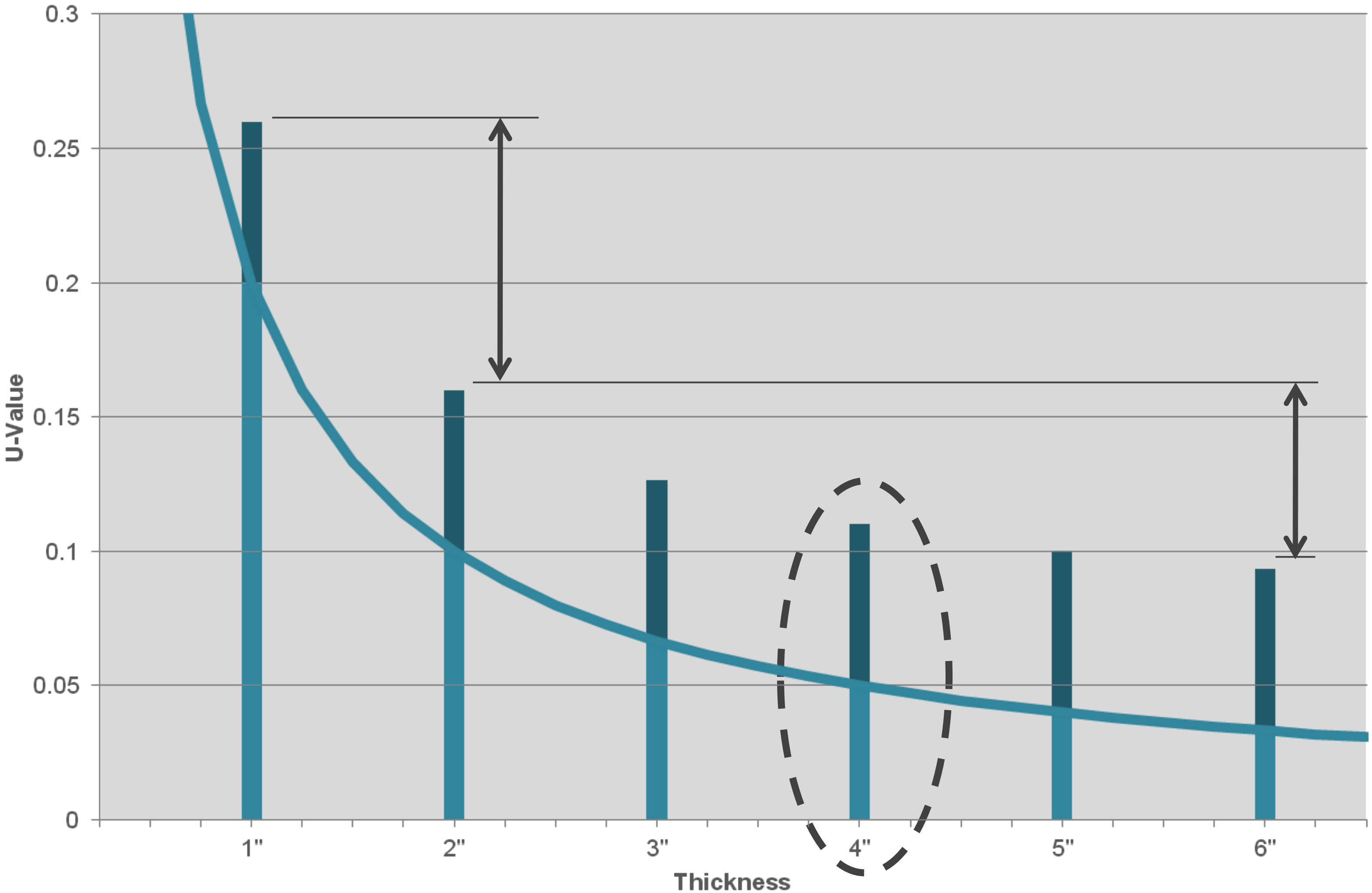
However when there is little insulation, increasing the amount of insulation still significantly decreases the heat flow, so the thermal bridge is not as much of a concern.

THERMAL BRIDGING | INTRODUCTION



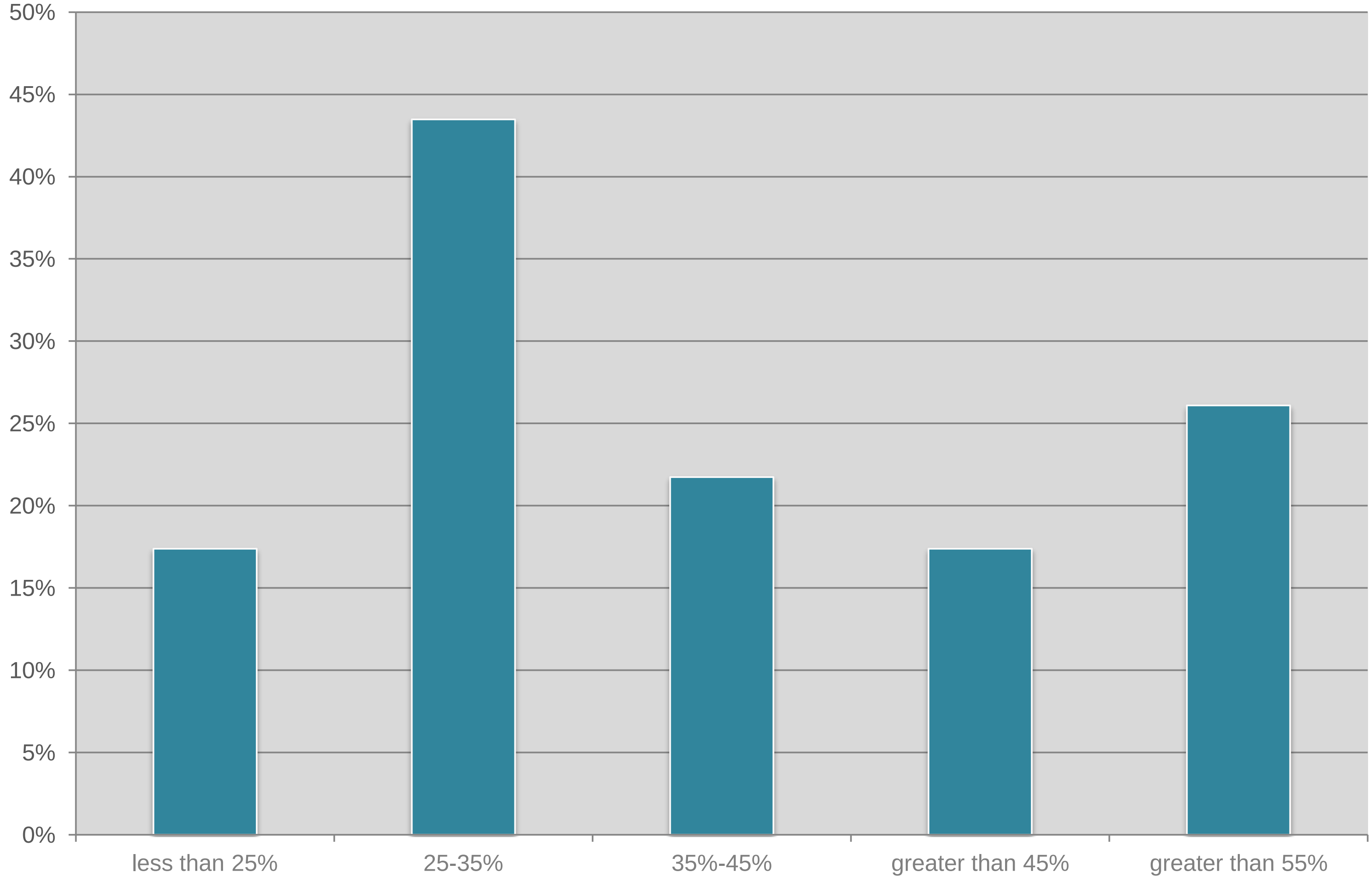
As you continue to increase the amount of insulation, it has less and less impact, and the thermal bridges become the dominant source of heat loss.

THERMAL BRIDGING | INTRODUCTION



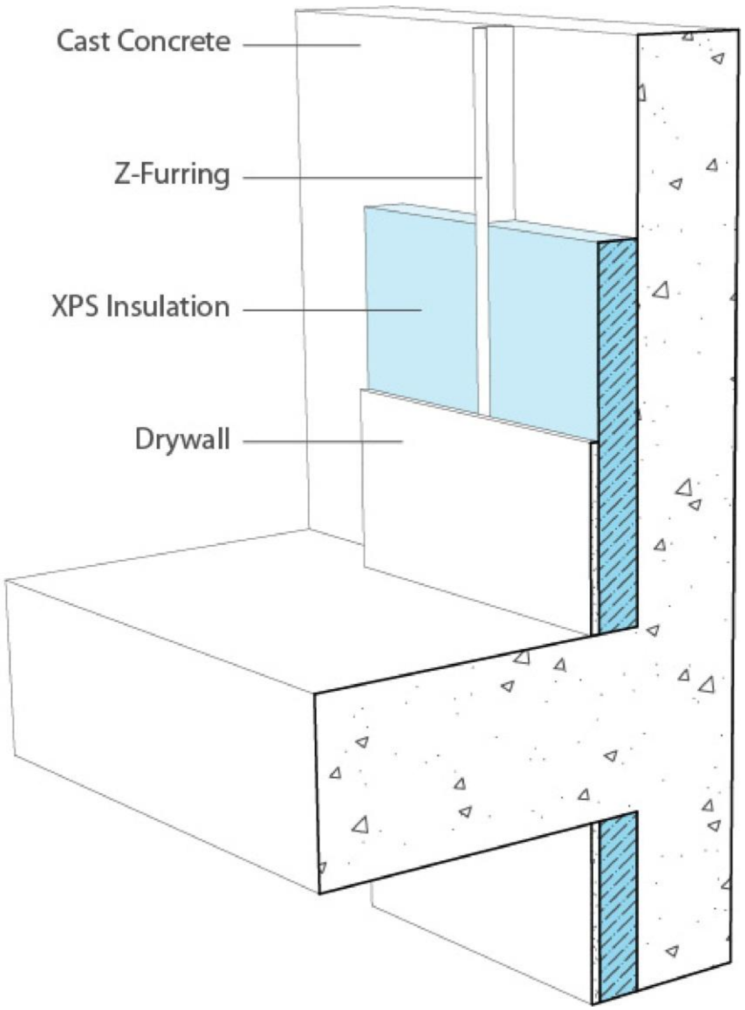
Current code requirements are for approximately 4” of insulation, and research on thermal bridges indicate the heat flow through the bridges to be about equal or more. To further improve the performance of our facades going forward, we need to address the thermal bridges in our design.

THERMAL BRIDGING | SURVEY RESULTS

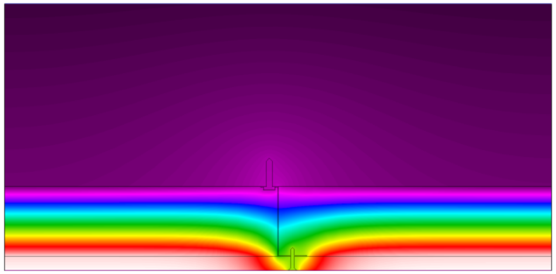


In professional practice there is little knowledge and understand of the impact that thermal bridges have in our design, as can be seen in the varied results of the survey.

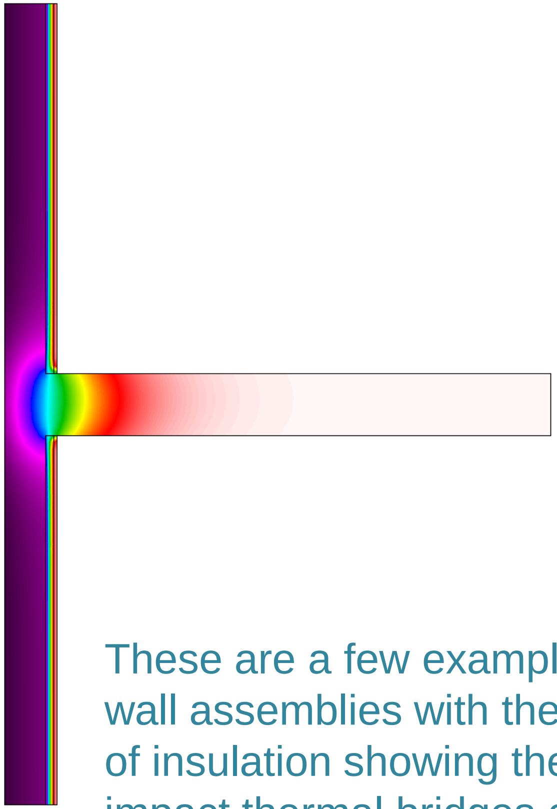
THERMAL BRIDGING | SURVEY RESULTS



TOTAL R-Value = **-66%**



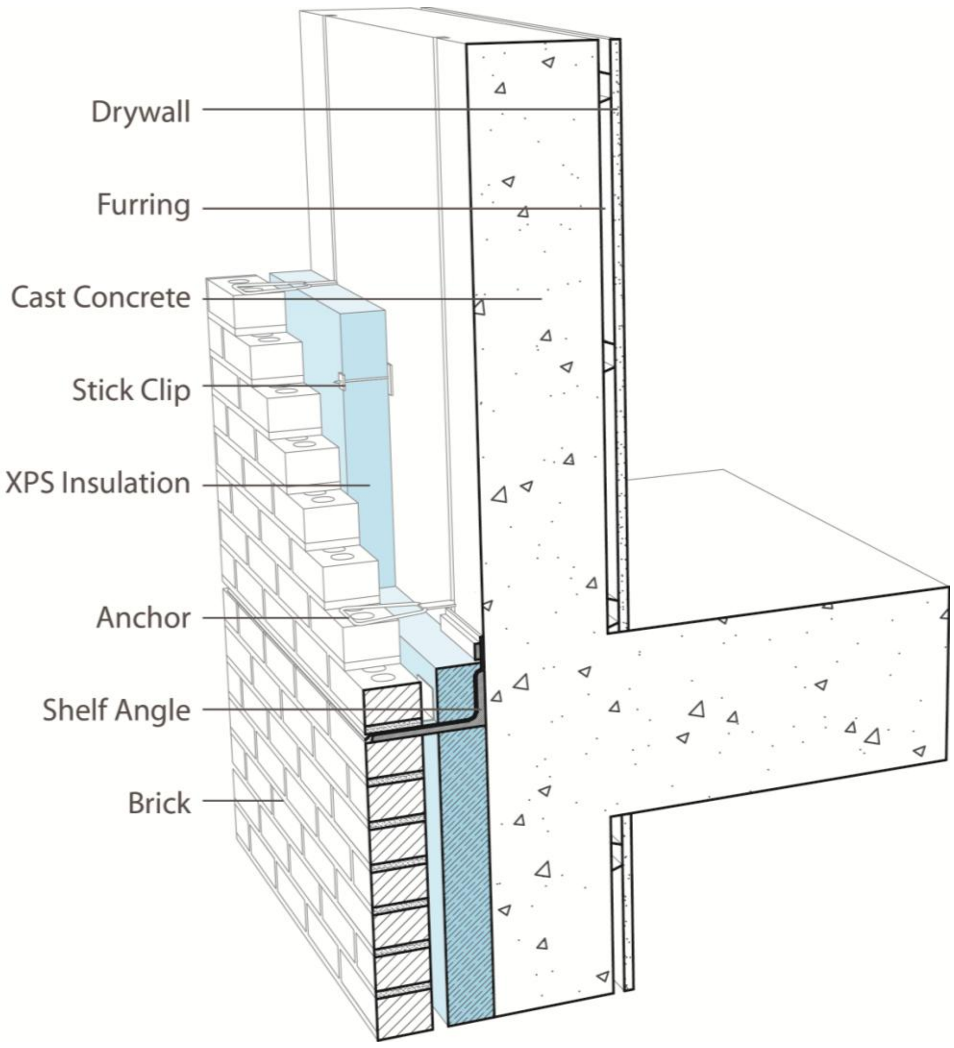
Z-Furring
-41%



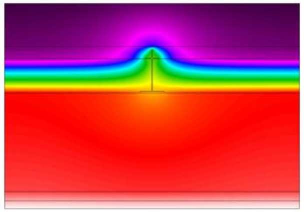
Slab
-42%

These are a few examples of varying wall assemblies with the same amount of insulation showing the range of impact thermal bridges can have.

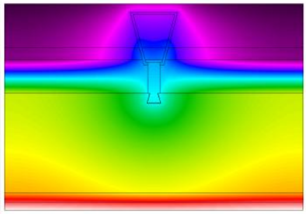
THERMAL BRIDGING | SURVEY RESULTS



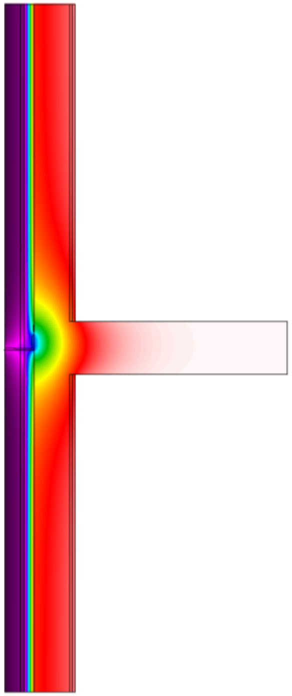
TOTAL R-Value = **-45%**



Stick Clip
-2%

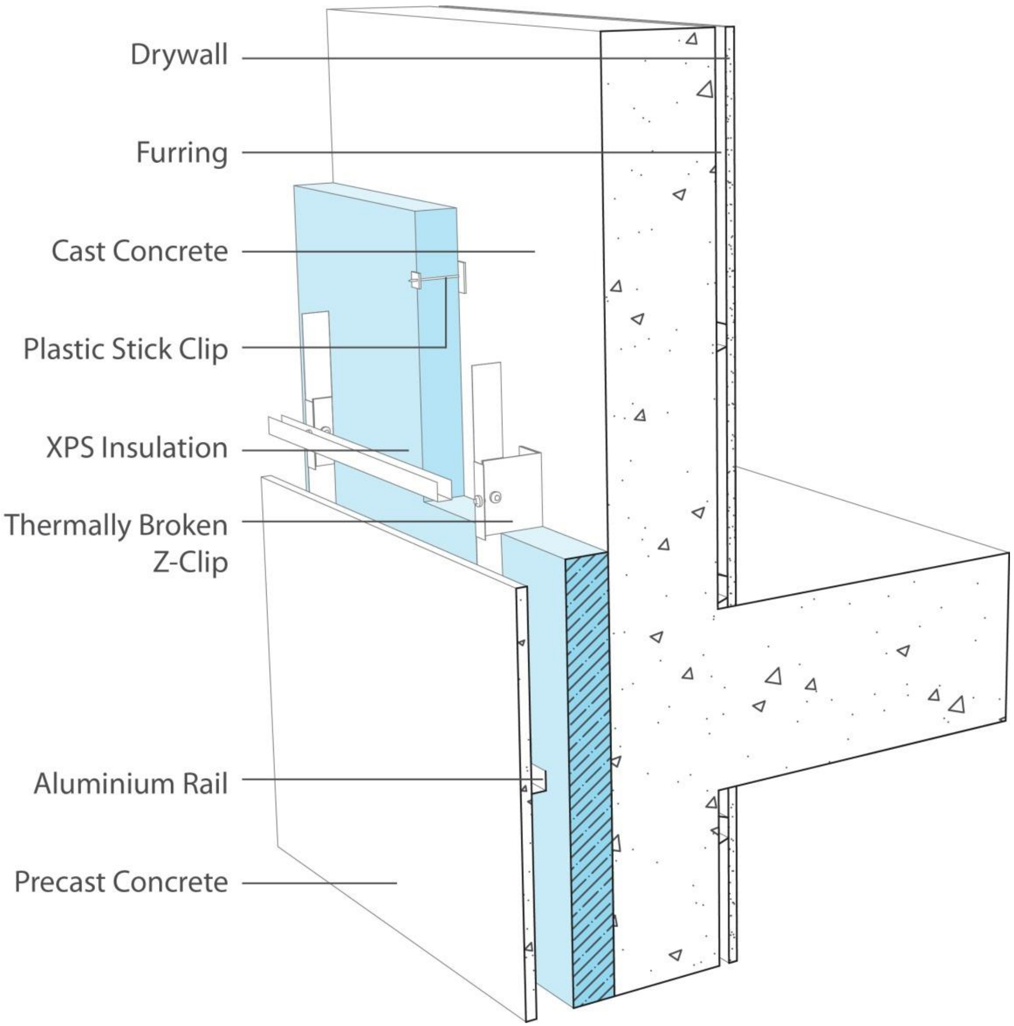


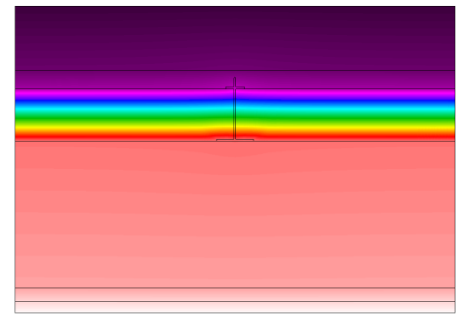
Dovetail Anchor
-17%



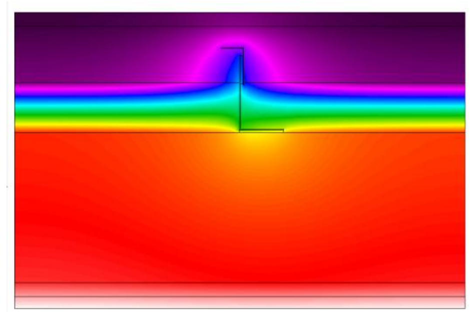
Shelf Angle
-34%

THERMAL BRIDGING | SURVEY RESULTS





Stick Clip
0%

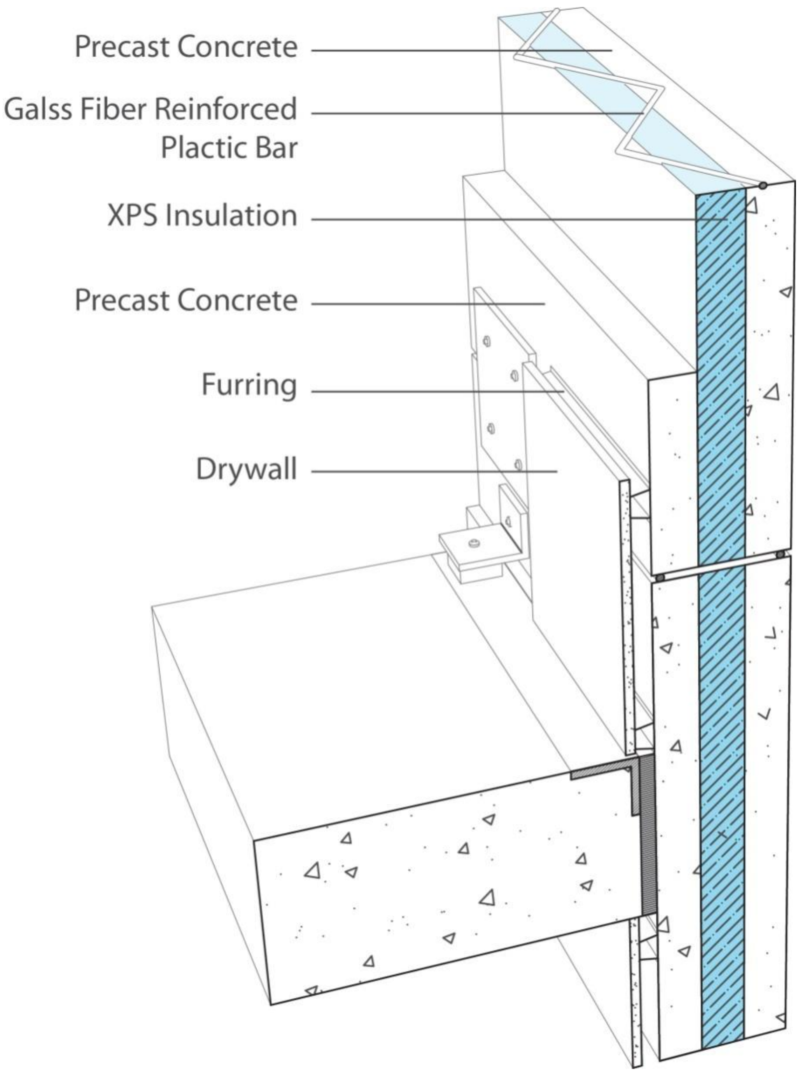


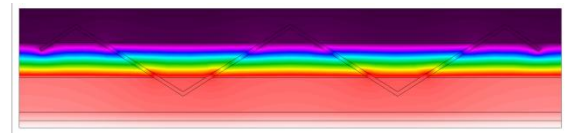
Z-Clip
-25%

TOTAL R-Value = **-25%**

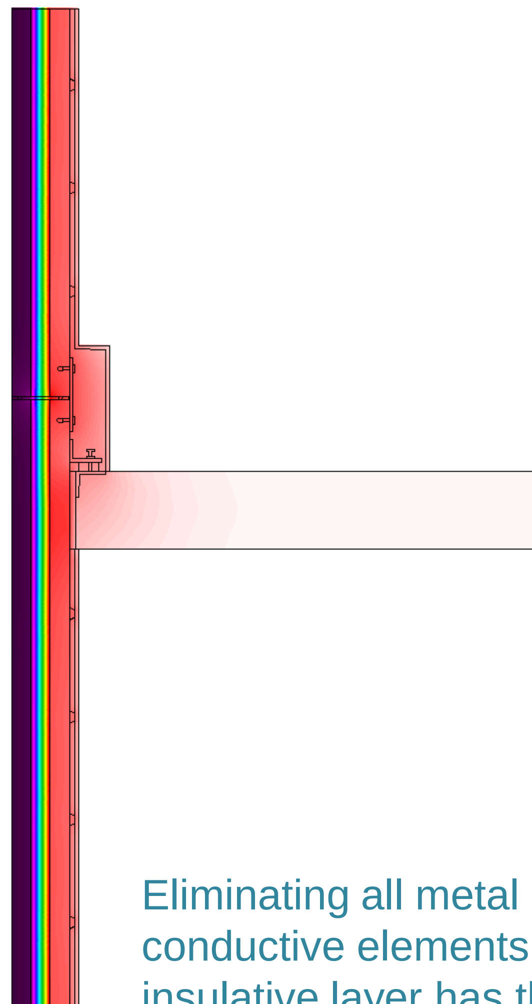
Even this thermally broken rainscreen system is impacted by thermal bridges.

THERMAL BRIDGING | SURVEY RESULTS





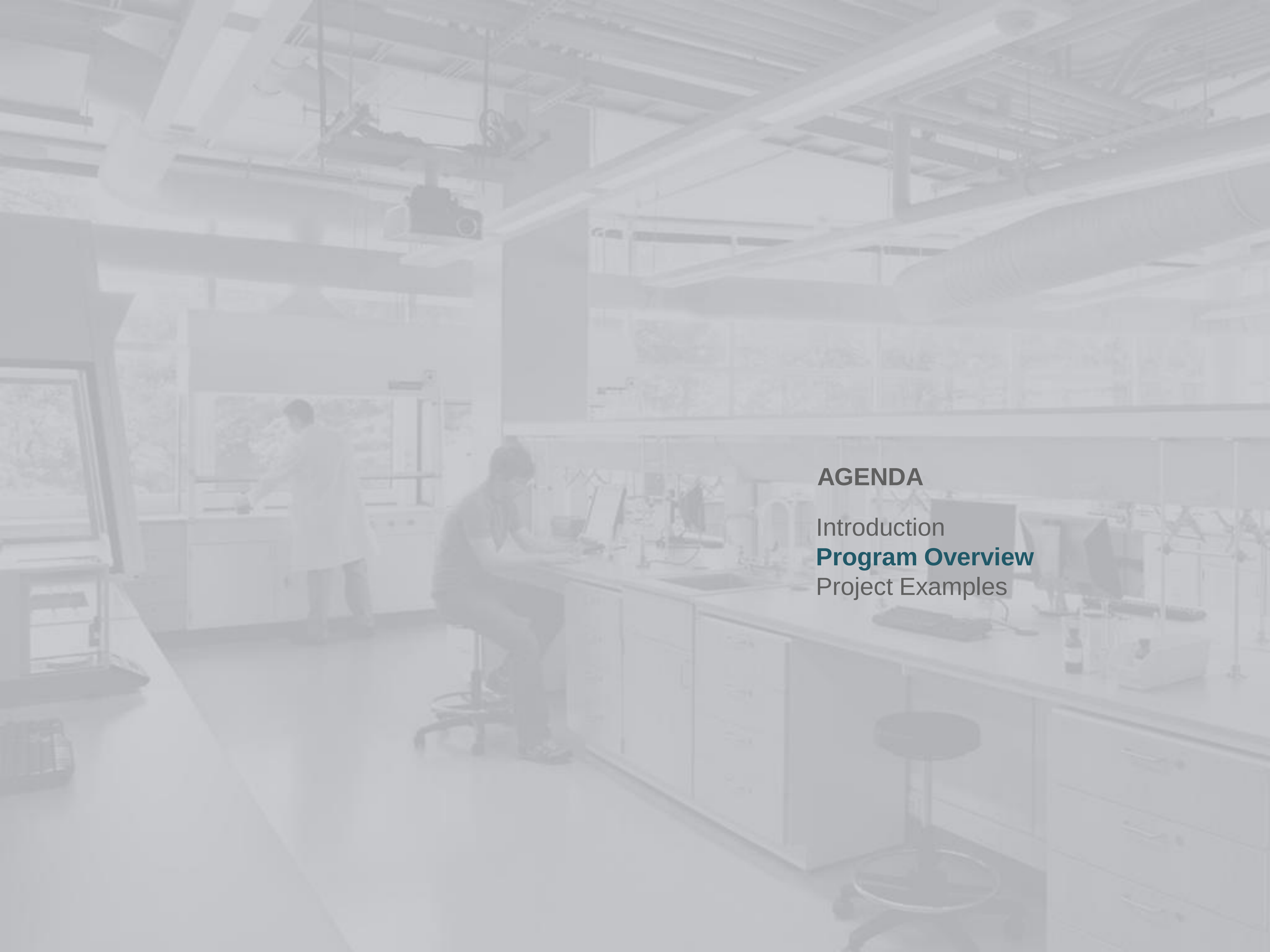
GFRP Bar
-1%



Panel
Connection
-7%

TOTAL R-Value = **-7%**

Eliminating all metal and highly conductive elements from penetrating the insulative layer has the best performance.



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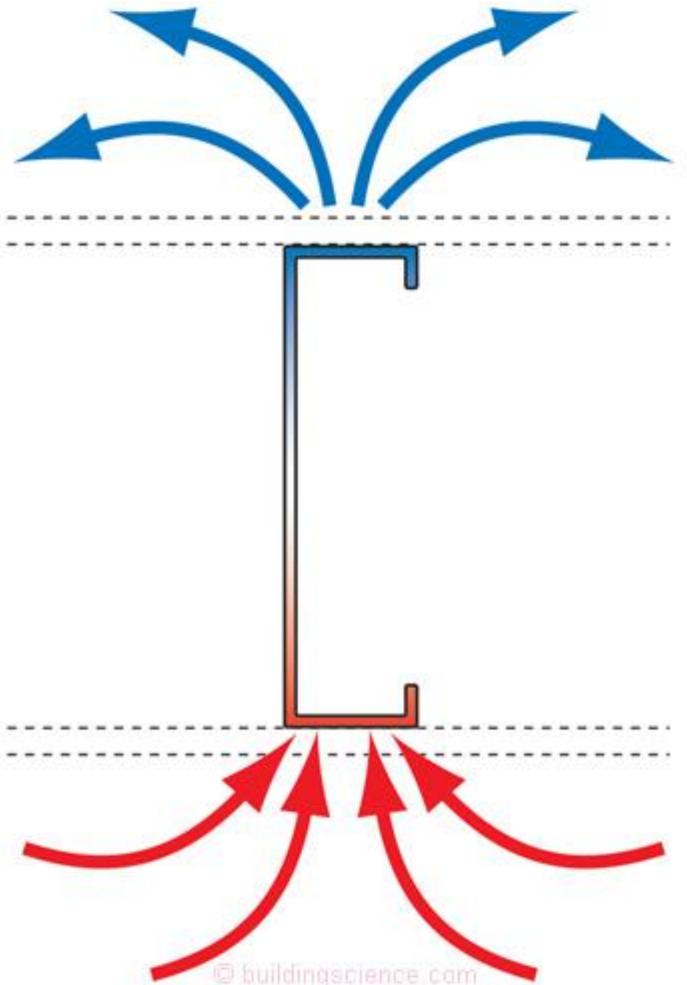
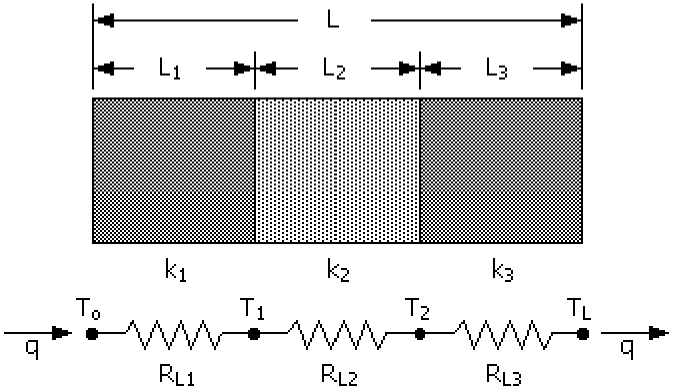
THERMAL BRIDGING | HEAT TRANSFER FUNDAMENTALS

3D Heat Flow in a 1D Simulation Engine



The challenge with understanding thermal bridges is that they are a 3D heat flow problem, but energy modeling software only can account for 1D heat flow.

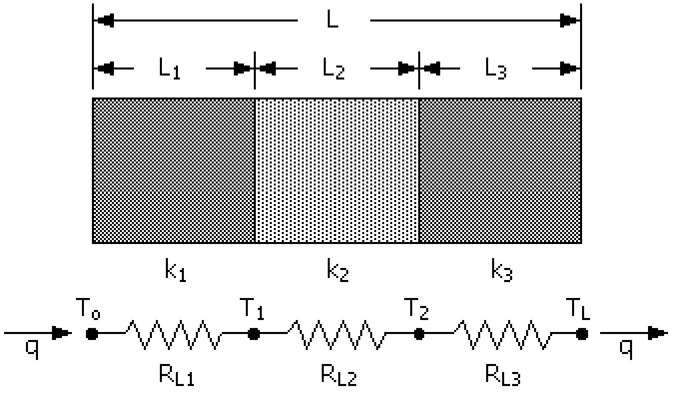
1D Heat Flow

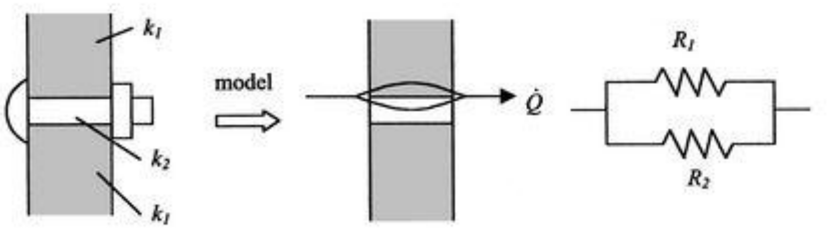


Heat flow through the envelope is analogous to current flow in an electrical circuit, where each layer of the assemblies provides thermal resistance in series. This is how energy models account for heat lost and gained through the building envelope.

THERMAL BRIDGING | HEAT TRANSFER FUNDAMENTALS

2D Heat Flow





When there is an element bridging the insulation, a parallel path of heat flow develops, and because it provides little resistance heat flows dramatically faster through that element.

THERMAL BRIDGING | HEAT TRANSFER FUNDAMENTALS

Parallel Path Method doesn't work for highly conductive elements

TABLE A9.2B Effective Insulation/Framing Layer R-Values for Wall Insulation Installed Between Steel Framing

Nominal Depth of Cavity, in.	Actual Depth of Cavity, in.	Rated R-Value of Airspace or Insulation	Effective Framing/Cavity R-Value at 16 in. on Center	Effective Framing/Cavity R-Value at 24 in. on Center
Empty Cavity, No Insulation				
4	3.5	R-0.91	0.79	0.91
Insulated Cavity				
4	3.5	R-11	5.5	6.6
4	3.5	R-13	6.0	7.2
4	3.5	R-15	6.4	7.8
6	6.0	R-19	7.1	8.6
6	6.0	R-21	7.4	9.0
8	8.0	R-25	7.8	9.6

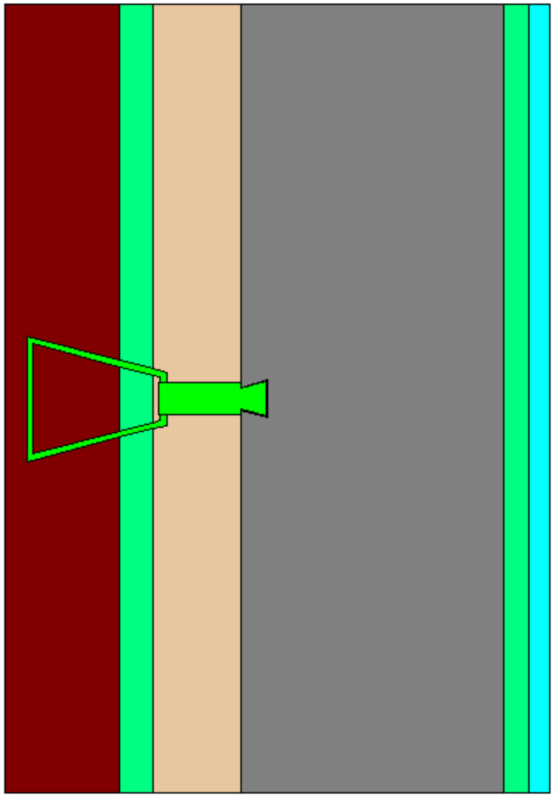
Represents 0.4% of the wall area but decreases R-value by 50-70%

Because of this, it accounts for a far greater amount of the heat flow than is represented by area, so it cannot be calculated by hand with the parallel path method (weighted average R-value by area).

THERMAL BRIDGING | THERM OVERVIEW

2D Heat Transfer Program:

- Define section geometry & material properties such as thermal conductance

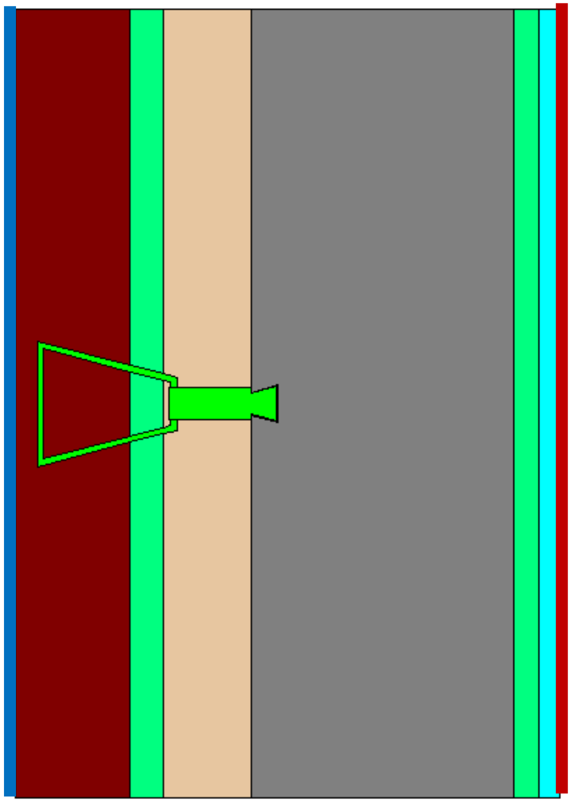


THERM is a 2D heat transfer program developed by Lawrence Berkeley National Laboratory that can be used to simulate the heat flow through an assembly.

THERMAL BRIDGING | THERM OVERVIEW

2D Heat Transfer Program:

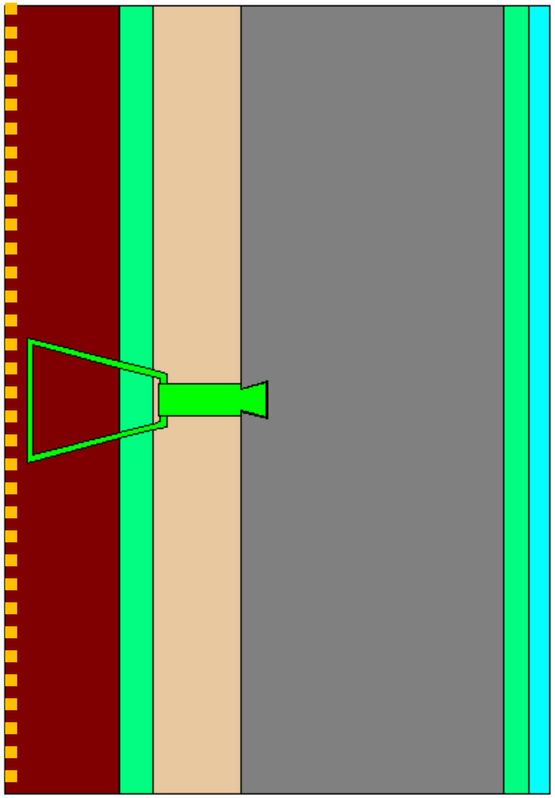
- Define section geometry & material properties
- Define surface temperatures & coefficients



THERMAL BRIDGING | THERM OVERVIEW

2D Heat Transfer Program:

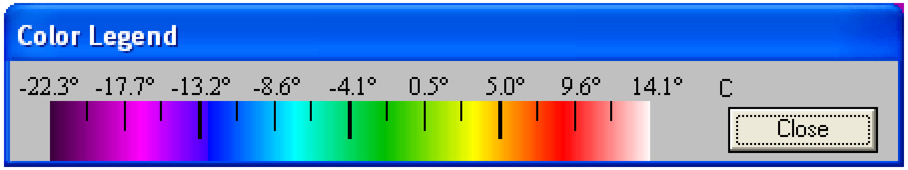
- Define section geometry & material properties
- Define surface temperatures & coefficients
- Define surface(s) to calculate U-value

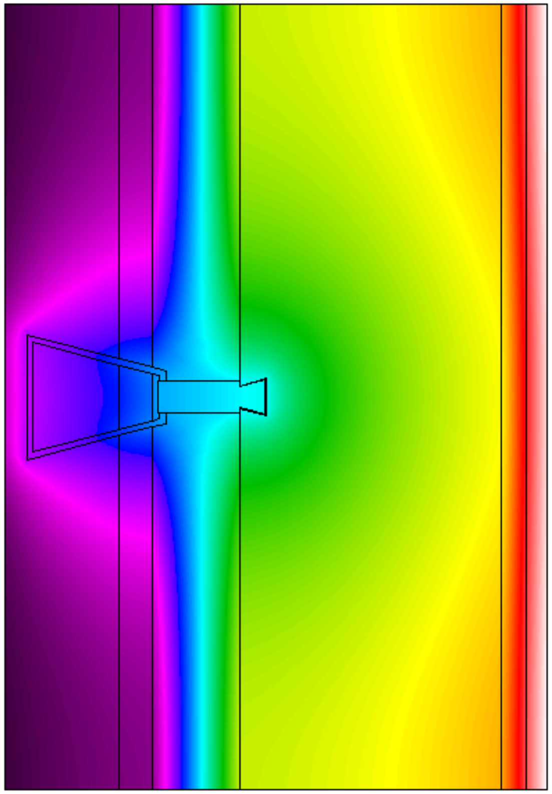


THERMAL BRIDGING | THERM OVERVIEW

2D Heat Transfer Program:

- Results provided are U-value(s), temperature gradients & heat flow

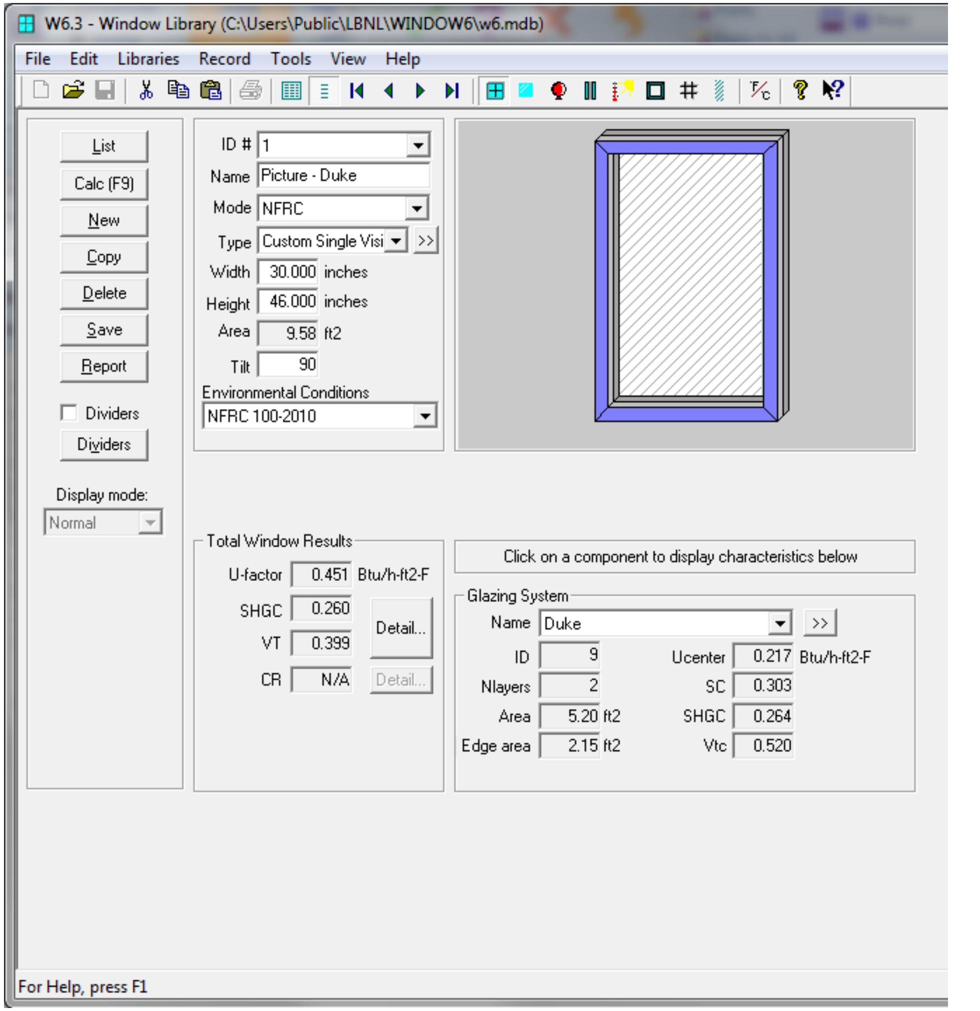




THERMAL BRIDGING | WINDOWS 6.3

Windows:

- Extensive glazing library
- Build assemblies
- Define frames and shading elements
- Calculates assembly U-value
- Imports assembly into THERM



Windows is a program that works with THERM for glazing systems. It's glazing library has almost all glasses commercially available, and you can build assemblies to determine glazing properties like the SHGC, visual transmittance, center of glass U-value (glass only), and assembly u-value (glass & frame). It also exports the assembly and it's properties into THERM for more detailed analysis.

THERMAL BRIDGING | DISCONTIUOUS ELEMENTS

How to make a 2D program simulate a 3D world:

Table 22: Average Surface Temperature Results Comparision (Griffith 1997)

	Measured	Parallel Path		Isothermal Planes		Averaged	
	°C	°C	% Different	°C	% Different	°C	% Different
Nylon, 229mm	12.4	11.5	*-7.3%*	11.5	*-7.3%*	11.5	*-7.3%*
Stainless,457mm	11.0	11.3	*+2.7%*	10.5	*-4.5%*	10.9	*-0.9%*
Stainless,305mm	10.8	11.2	*+3.7%*	10.1	*-6.5%*	10.7	*-0.9%*
Stainless,229mm	10.7	11.1	*+3.7%*	9.8	*-8.4%*	10.5	*-1.9%*
Stainless,152mm	10.5	10.9	*+3.8%*	9.2	*-12.4%*	10.1	*-3.8%*
Stainless, 76mm	9.4	10.3	*+9.6%*	7.9	*-16.0%*	9.1	*-3.2%*
Steel, 229mm	8.8	11.1	*+26.1%*	7.7	*-12.5%*	9.4	*+6.8%*
Average			*±8.1%*		*-9.7%*		*± 3.5%*

THERM is a 2D simulation engine, but heat flow is 3D. Therefore, THERM can not accurately account for discontinuous bridging elements (like bolts), but is accurate for continuous elements (like studs). Work around methods have been developed to allow it to reasonably simulated discontinuous elements. One method, the parallel path method, underestimates the heat flow, while the other, the isothermal planes method, overestimates it. If you average the results of the 2 methods, they are much closer to the real world results.

THERMAL BRIDGING | DISCONTIUOUS ELEMENTS

Parallel Path Method

- Weighted average of 2 simulations

$$U_P = F_B * U_B + F_N * U_N$$

Whereas, U_P = U-value parallel path

F_B = Fraction of bridging element

U_B = U-value from THERM with bridging element

F_N = Fraction of clear wall

U_N = U-value from THERM of clear wall

The parallel path method requires 2 simulations. One with the discontinues bridging element, and one without it. A weighted average by area of the 2 calculated U-values is then taken to combine them.

THERMAL BRIDGING | DISCONTIUOUS ELEMENTS

Parallel Path Method

- 1 simulation with a weighted average of the conductivities

$$k_{eff} = F_B * k_B + F_N * k_N$$

Whereas, U_I = U-value from THERM using isothermal planes method

k_B = effective conductivity

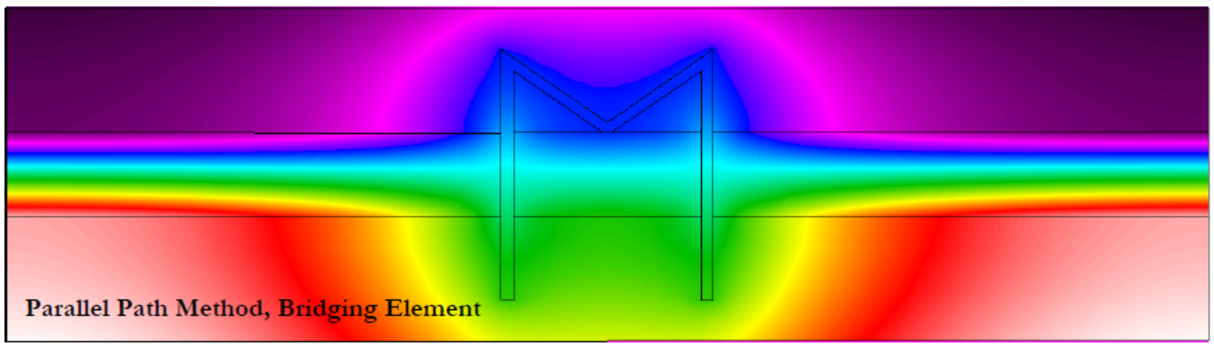
k_B = conductivity of bridging element

k_N = conductivity of non-bridging element

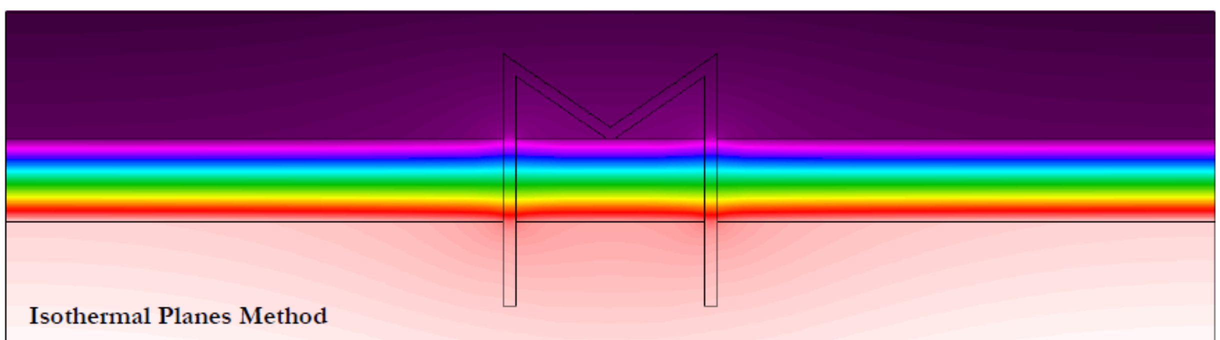
The isothermal planes method requires 1 simulation. A weighted average by area of the thermal conductivity of the bridging element and the insulation is taken to determine an effective conductance. The simulation is run with this value for the discontinuous element.

THERMAL BRIDGING | DISCONTIUOUS ELEMENTS

R-11.1



R-2.3



R-8.9

Example R-value results for a metal M-tie from the 3 runs for the two methods described.

THERMAL BRIDGING | DISCONTIUOUS ELEMENTS

	Wall Fraction	U-Value (W/m²°K)	Difference from Calculated
Calculated	1	0.56	-
Parallel Path, Clear Wall	0.99	0.51	-
Parallel Path, M-Tie	0.01	2.43	-
Parallel Path, Combined	1	0.53	-7.0%
Isothermal Planes	1	0.64	+12.5%
Averaged U-Value	**1**	**0.58**	**+2.8%**

For an example that can be calculated with the revised zone method (Lee & Pessiki, 2008) for validation, the averaged results from the 2 THERM simulation methods differed by less than 3%.

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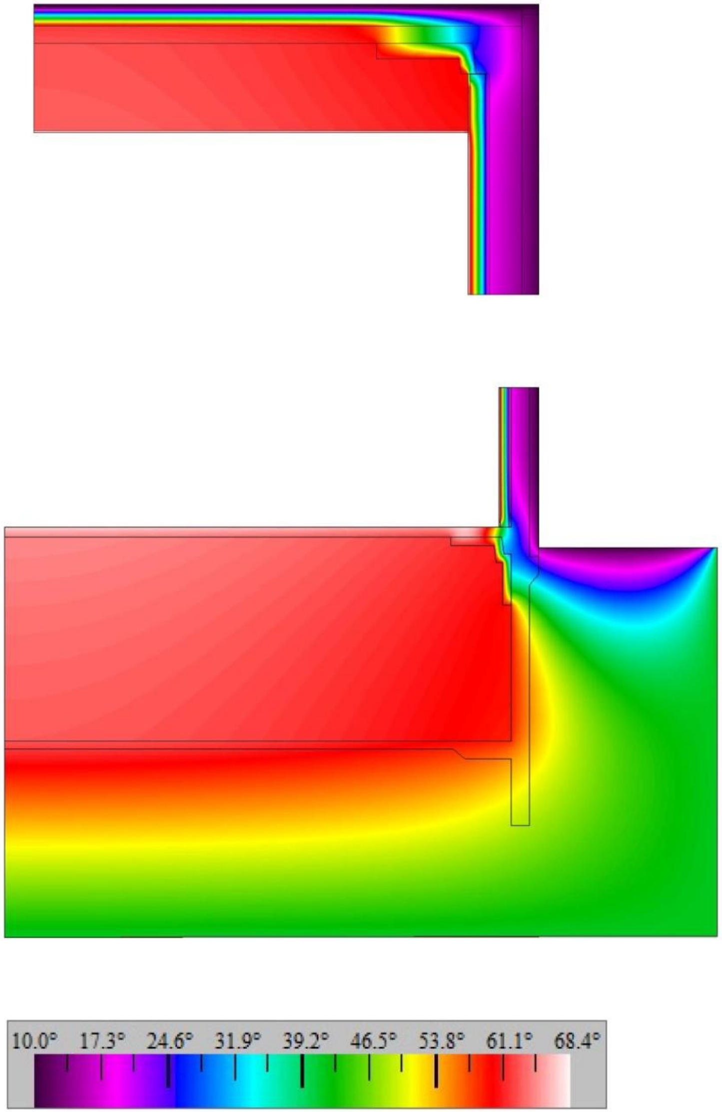
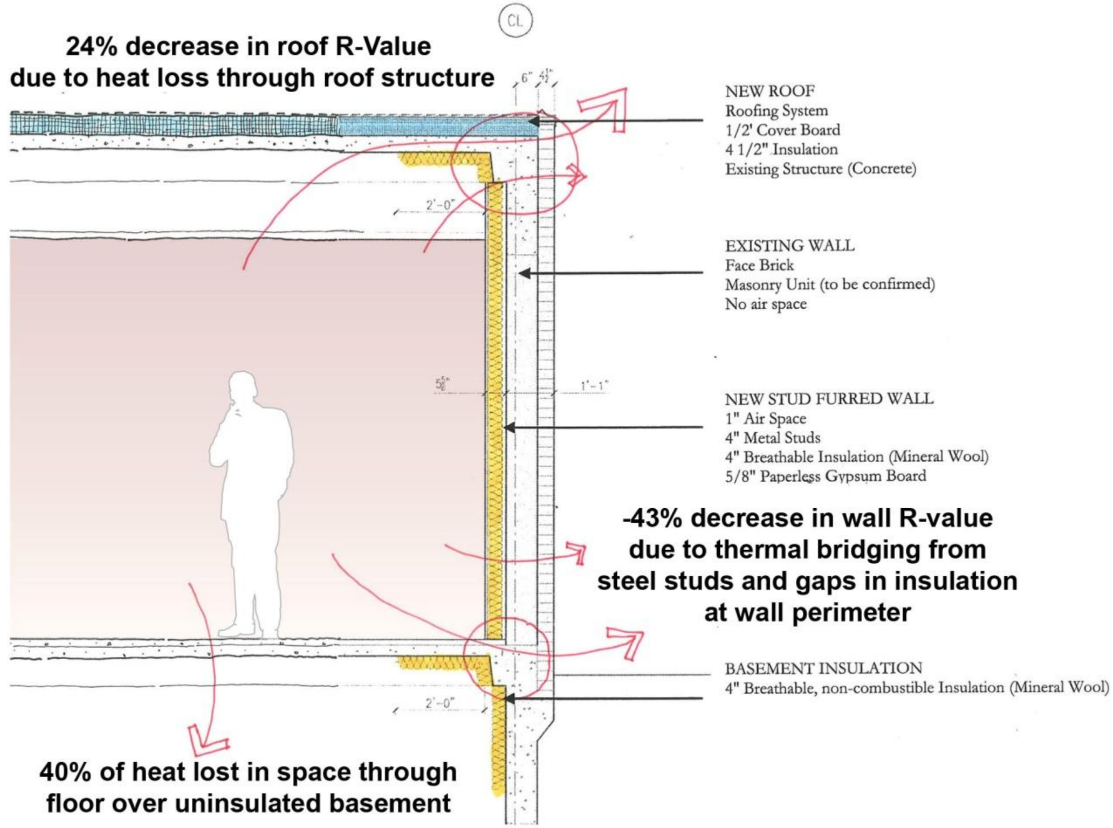
THERMAL BRIDGING | VA BROCKTON MENTAL HEALTH

Original Design



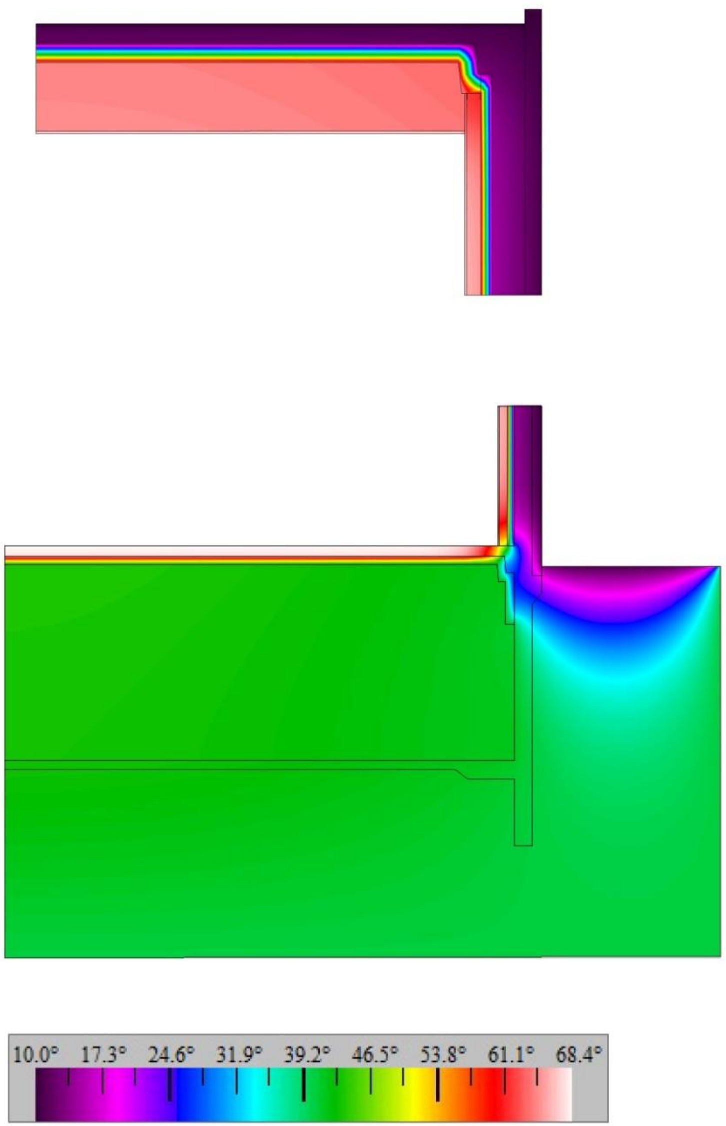


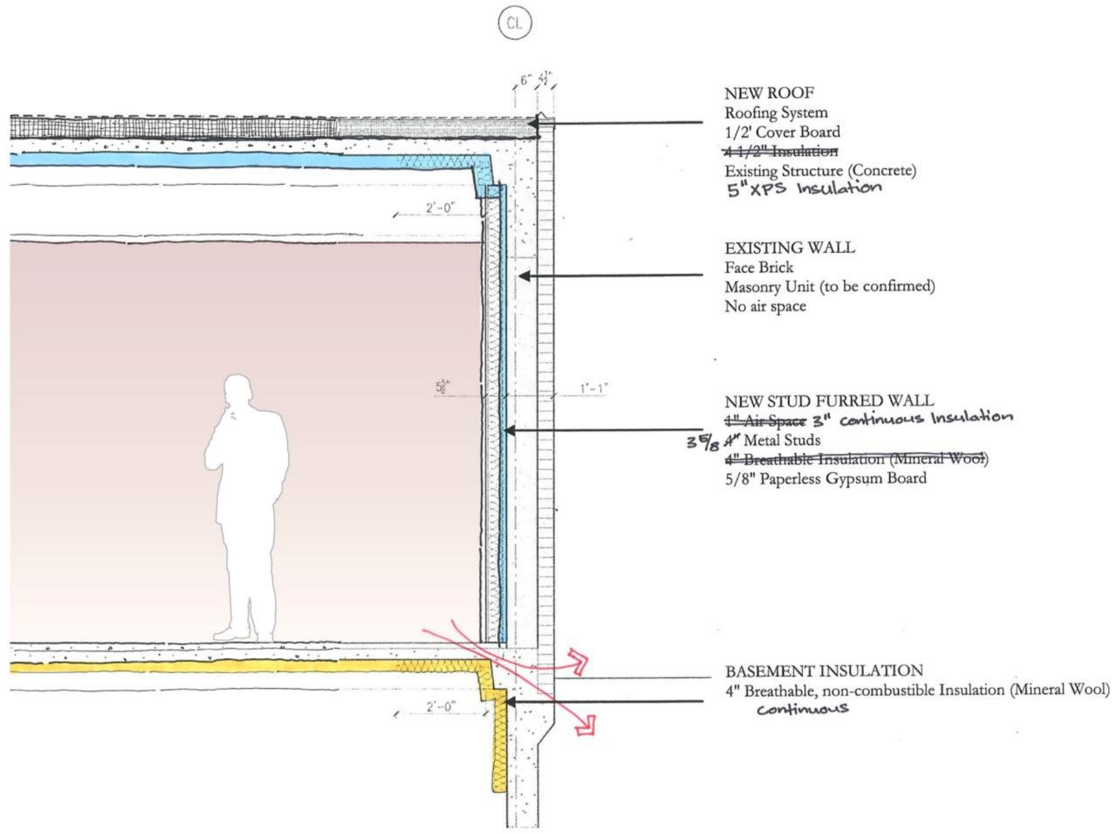
Typical wall section

THERM was used to analyze the heat flow through the renovation of an existing façade. The simulation highlighted that having no insulation over the heated basement, and thermal bridges in the design significantly decreased the thermal performance from the design intent.

THERMAL BRIDGING | VA BROCKTON MENTAL HEALTH

Alternative Design Option 2





Typical wall section

A number of alternate designs were investigated to improve the thermal performance of the design, and create a more continuous thermal barrier. In existing conditions, it is often impossible to eliminate all thermal bridges.

THERMAL BRIDGING | VA BROCKTON MENTAL HEALTH

	Original Design			Proposed Alternative Design #2		
	Calculated R-Value	Simulated R-Value	Difference	Calculated R-Value	Simulated R-Value	Difference from Original Design
Roof	29.1	22.1	- 24%	31.6	27.9	+ 26%
Walls	15.9	9.1	- 43%	18.5	13.5	+ 48%
Floor	3.5 + ground	8.2	NA	15.9+ ground	24.5	+ 199%

Even still, with a few changes, a dramatic improvement in the R-value of the assemblies can be seen.

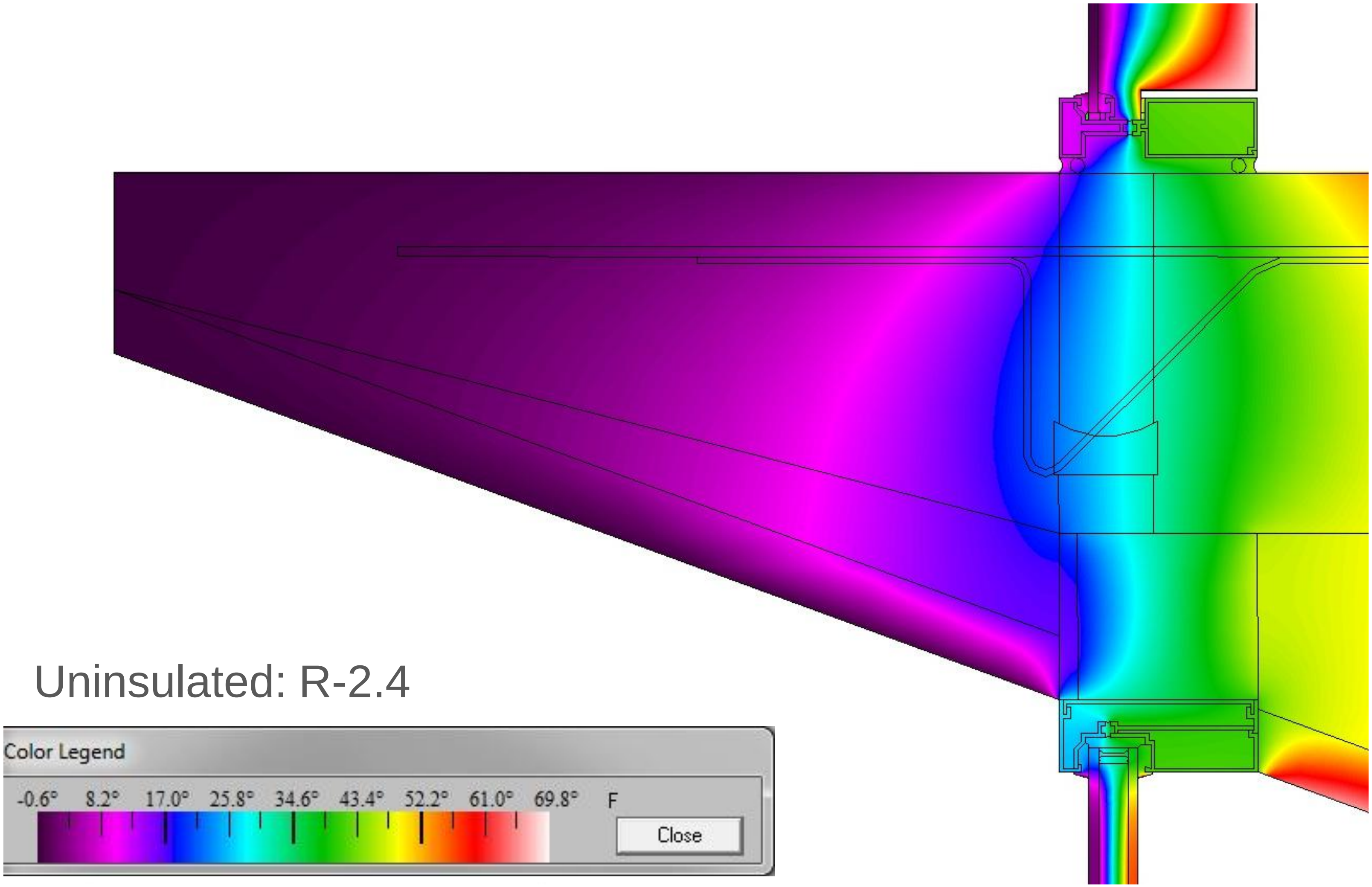
THERMAL BRIDGING | VA BROCKTON MENTAL HEALTH

	Original Design	Proposed Alternative Design #2	Difference
Heat Loss @ Winter Design Conditions	370.2 Btu/h·ft	213.7 Btu/h·ft	- 42%
Breakdown of Heat Loss			
Roof	29%	40%	
Wall	32%	38%	
Floor	39%	22%	

Reminder: R-value is $h \cdot ft^2 \cdot {}^\circ F/Btu$

This resulted in a significant decrease in the heat lost in the building.

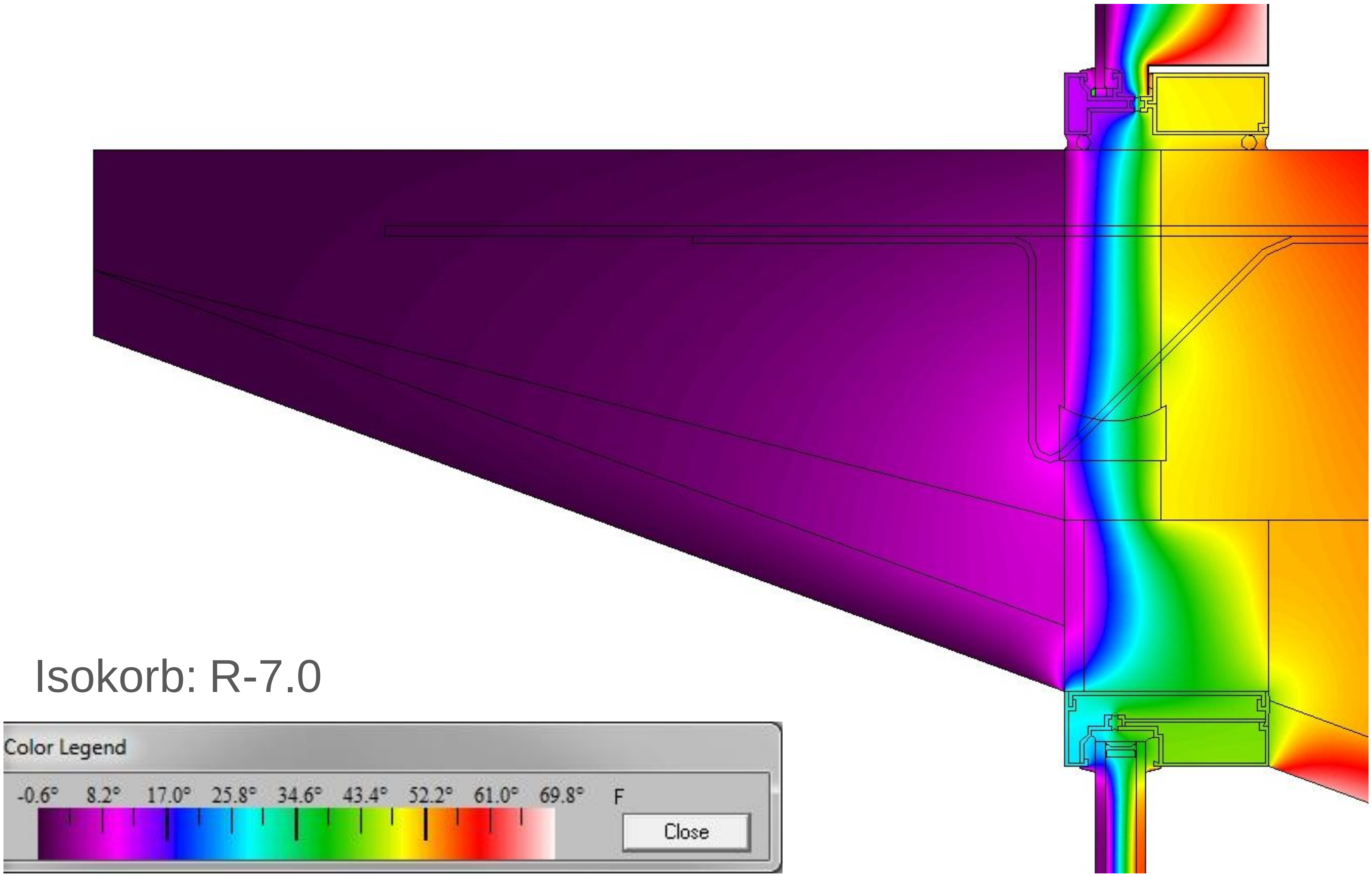
THERMAL BRIDGING | DUKE



This analysis investigated a concrete slab that created an overhang for exterior shading. Alternative options to insulate the slab were investigated.

THERMAL BRIDGING | DUKE

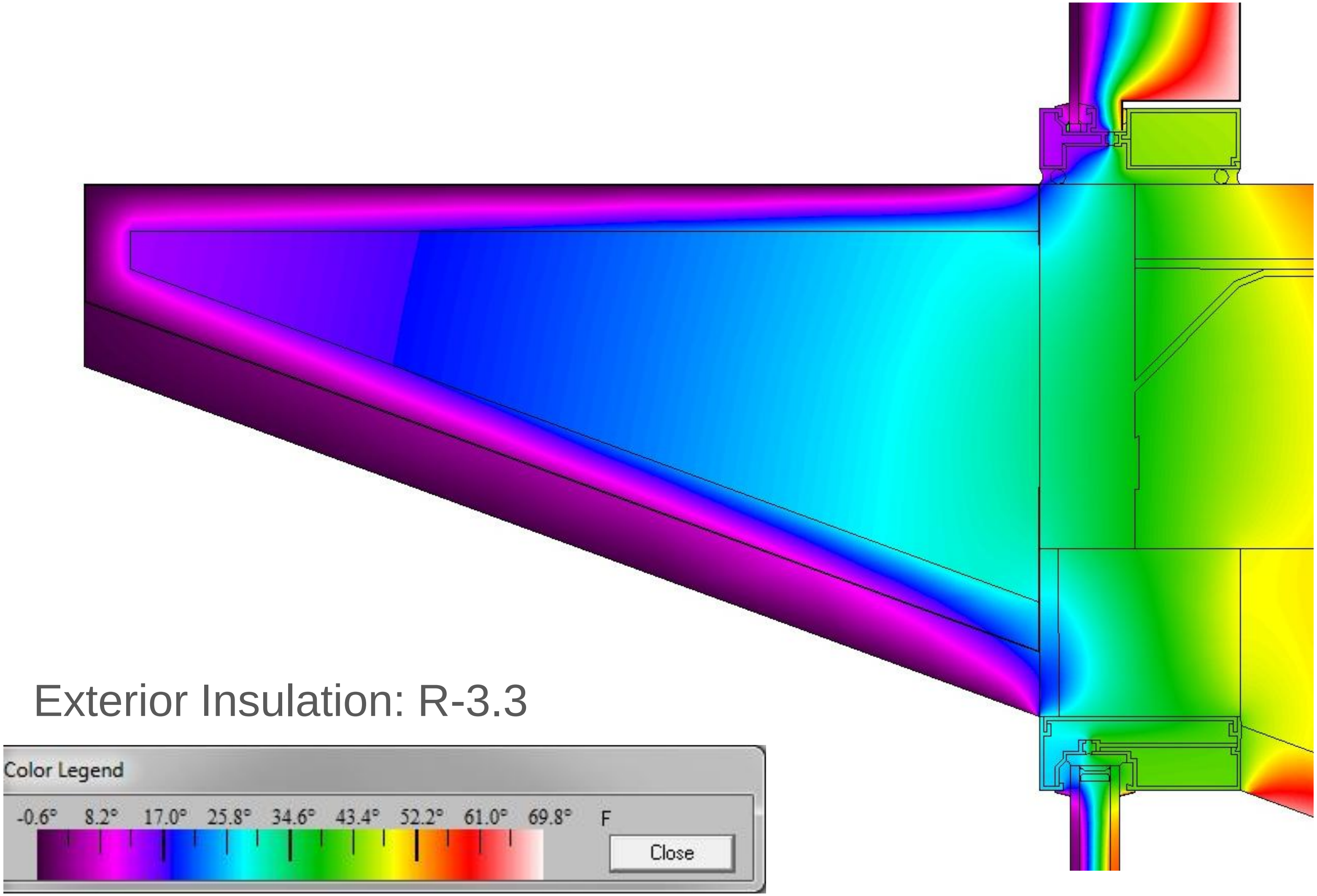
Isokorb: R-7.0



The best performing option was to have a thermally broken system like this one.

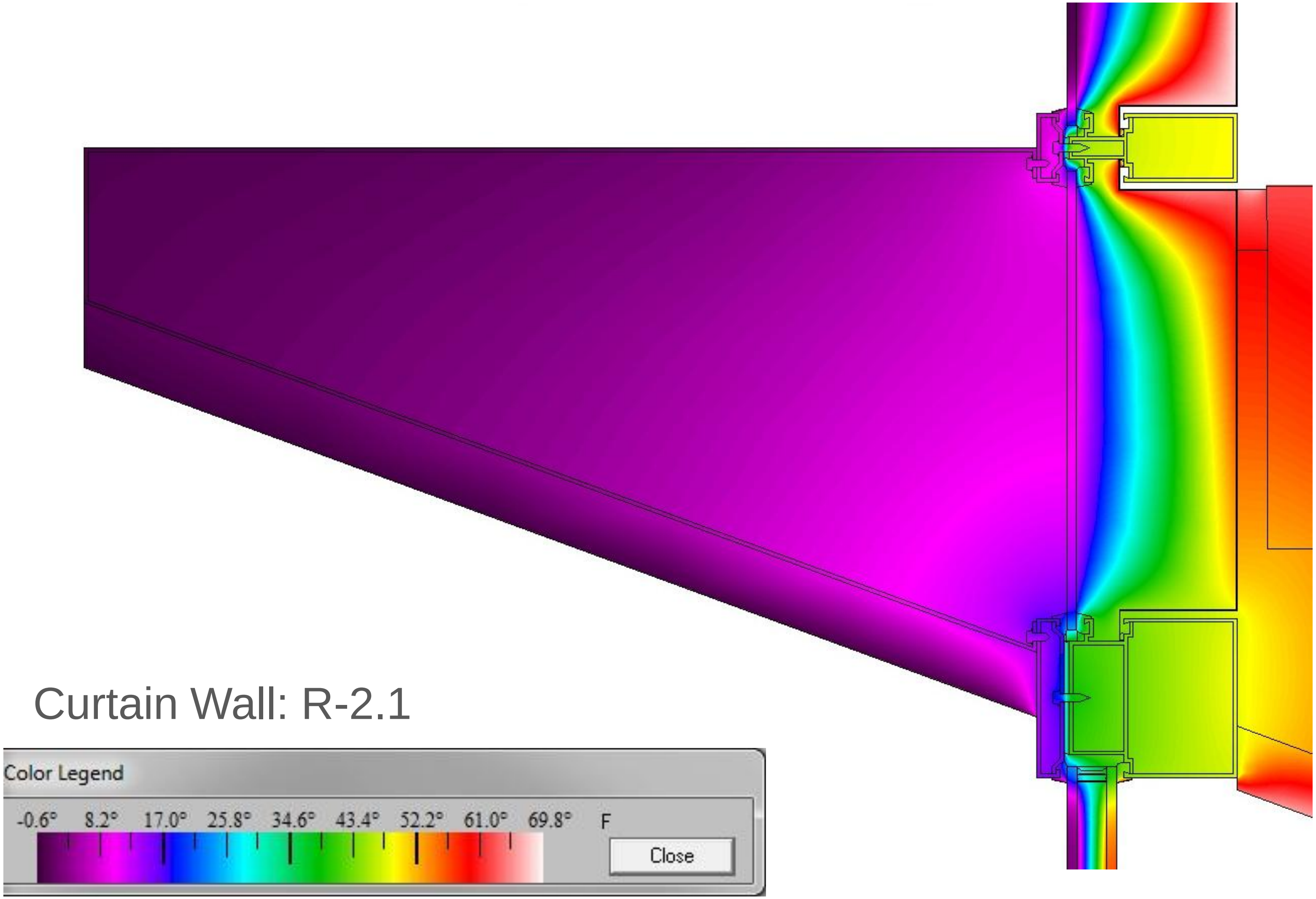
THERMAL BRIDGING | DUKE

Exterior Insulation: R-3.3



Terminating the slab at the façade and having a folded metal panel with insulation was investigated, but thermal bridges occurring at the joins and at the storefront mullions dramatically decreased performance.

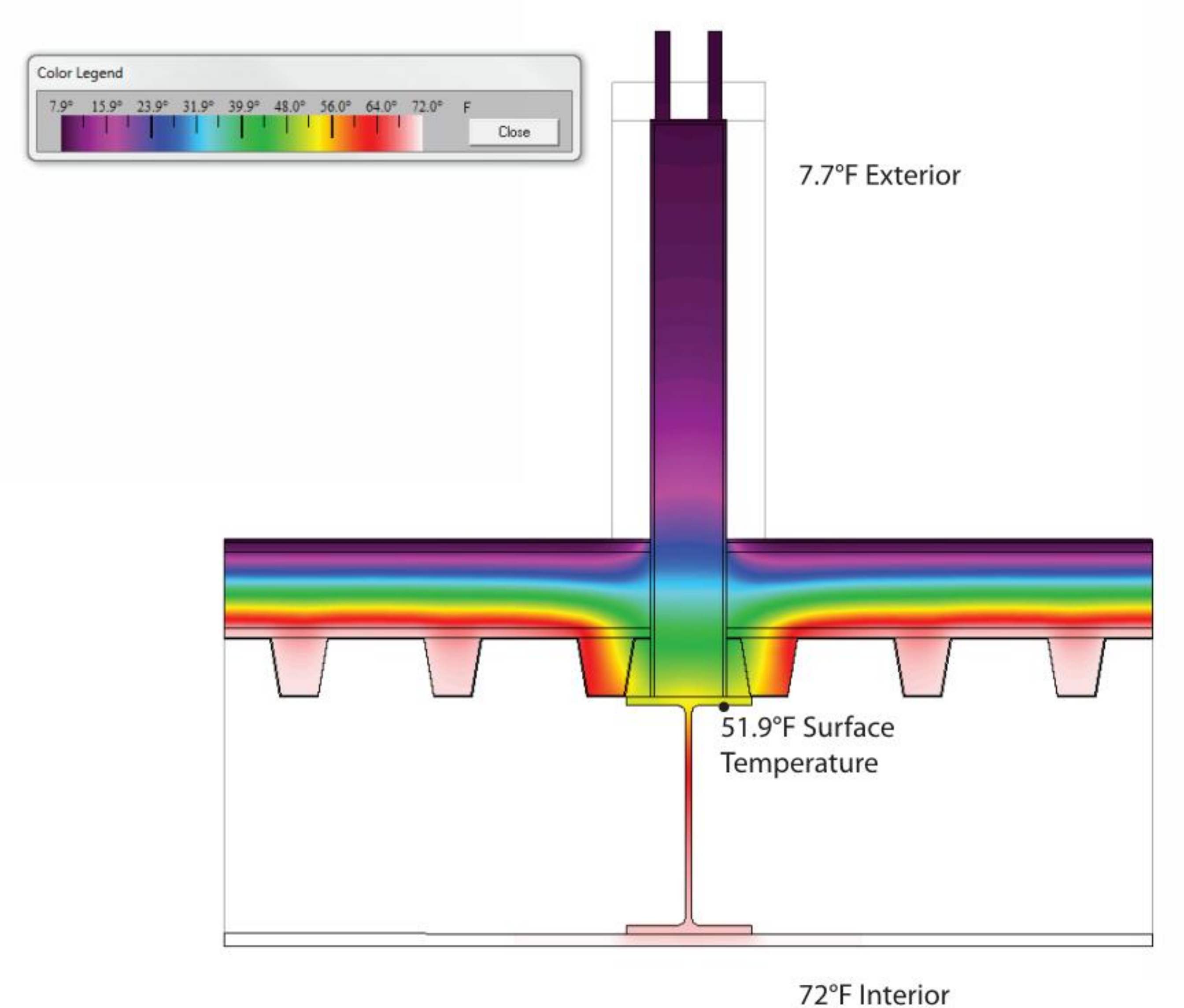
THERMAL BRIDGING | DUKE



Curtain Wall: R-2.1

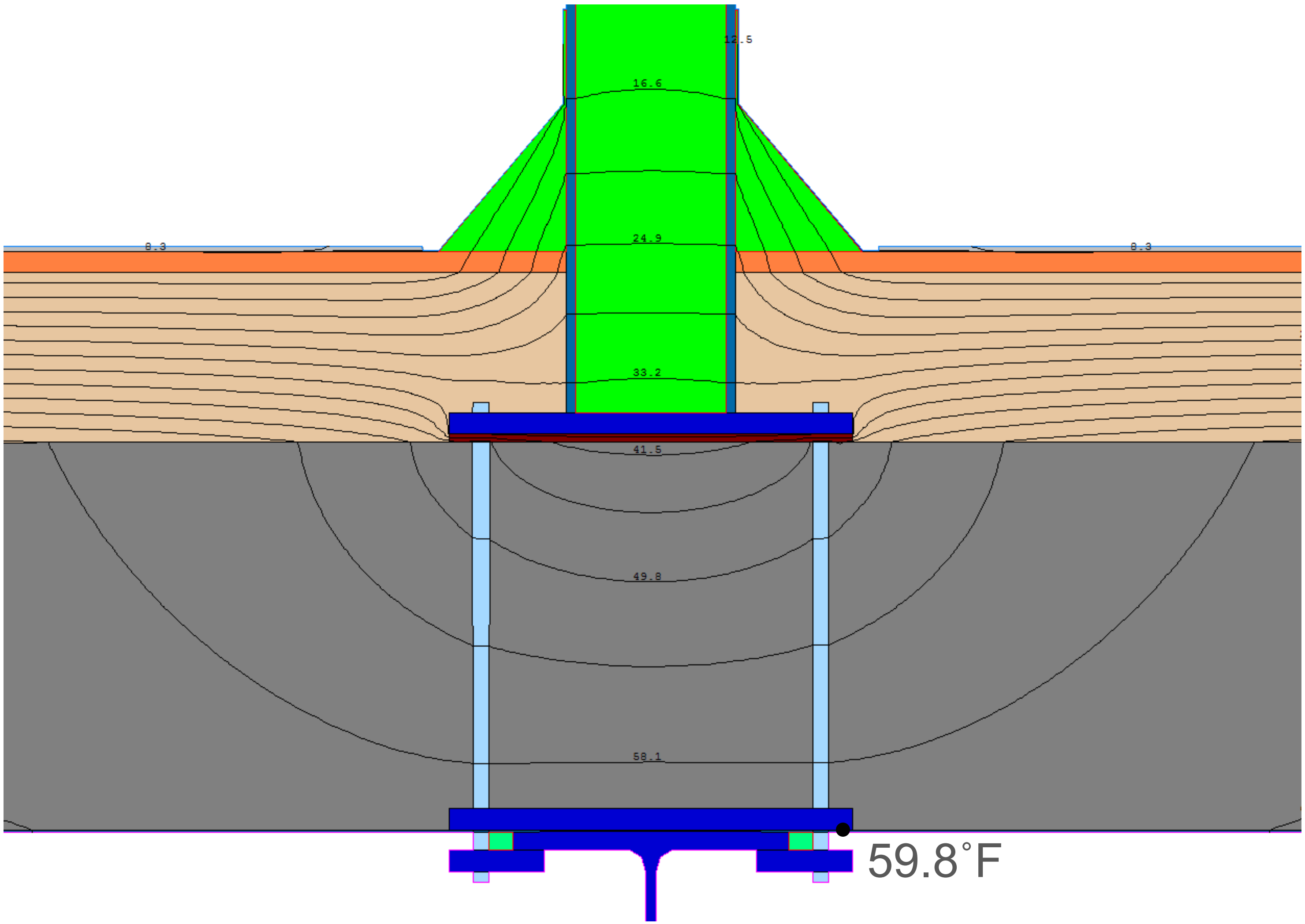
This spandrel panel option does nor perform well, because there is a large amount of heat lost through the mullions.

THERMAL BRIDGING | MUSEUM PROJECT



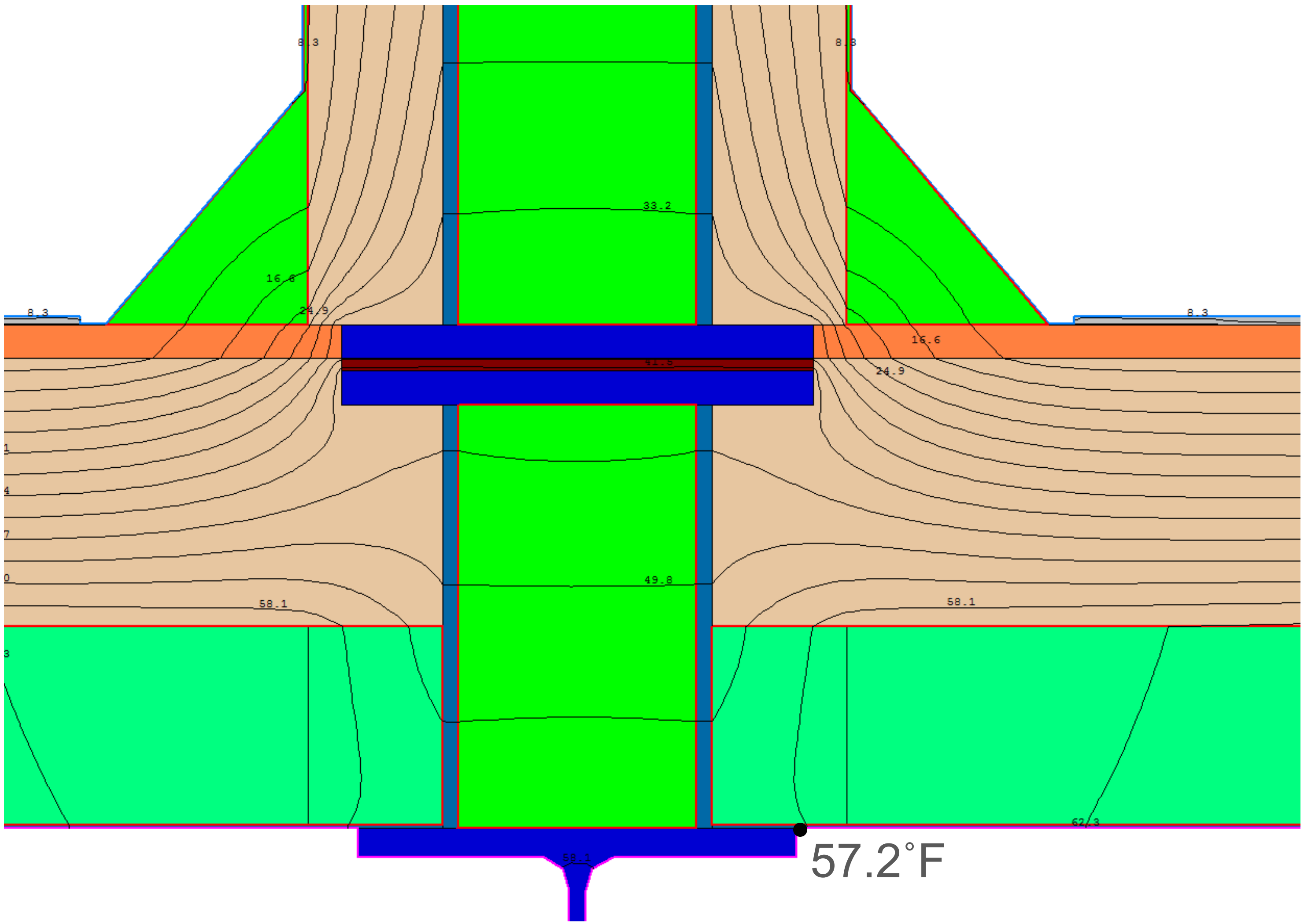
In addition to determining the U-value, THERM can also be used to determine potential condensation conditions. Given the tight temperature and humidity ranges in this museum, condensation would occur at 55˚F.

THERMAL BRIDGING | MUSEUM PROJECT



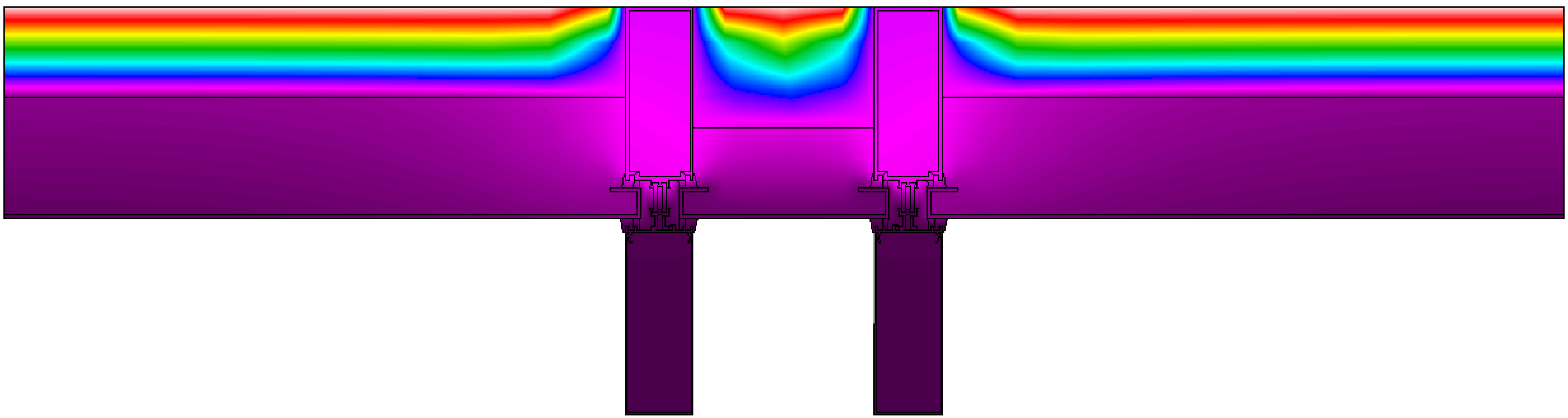
Alternative options to thermally break the davit from the interior structure were investigated.

THERMAL BRIDGING | MUSEUM PROJECT

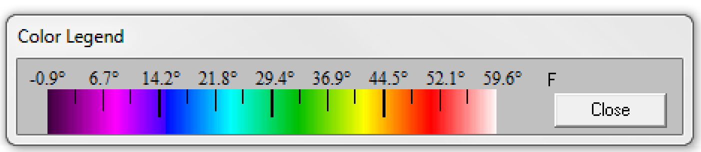


Some conditions also require exterior insulation.

THERMAL BRIDGING | VERTEX



Curtain Wall: R-7.1 simulated, R-19 specified



Heat flow simulations can also be a quick way to understand discrepancies between the design intent and proposed design details, such as with this metal panel curtain wall.

THERMAL BRIDGING | RESOURCES

Program

- THERM: http://windows.lbl.gov/software/therm/therm.html
- WINDOWS: http://windows.lbl.gov/software/window/6/index.html
- Documentation & Tutorials: http://windows.lbl.gov/software/window/6/w6_docs.htm
- Steel Studs: http://www.ornl.gov/sci/roofs+walls/calculators/modzone/index.html

THERMAL BRIDGING | RESOURCES

Material Conductivity

- http://www.coloradoenergy.org/procorner/stuff/r-values.htm
- ASHRAE Handbook of Fundamentals

Air Film Coefficients

- ASHRAE Handbook of Fundamentals

Climate Conditions

- EPW Weather Files: http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm


THANK YOU.
2.6 °C
-7.3