



Thermal Bridging Solutions: Minimizing Structural Steel's Impact on Building Envelope Energy Transfer

This document is the product of the joint Structural Engineering Institute (SEI)/American Institute of Steel Construction (AISC) Thermal Steel Bridging Task Committee, in conjunction with the SEI's Sustainability Committee's Thermal Bridging Working Group. More information on the work of the committee and on the topic in general can be found at www.seisustainability.org and www.aisc.org/sustainability respectively.

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Thermal Bridging

Reducing energy usage in buildings has become one of the most widespread goals in the construction industry. Efforts to reduce building energy use are typically focused on the mechanical, electrical and glazing systems and not the structural system.

However, one area where structural designers can reduce energy consumption is thermal bridging. For the prototype 3-story, 9,000 sq ft steel-framed, masonry clad structure evaluated in this study as much as 4% in annual energy savings can theoretically be realized if thermal bridging were to be accounted for in the design.

Thermal bridging refers to the loss of building energy through thermal conductivity of elements that “bridge” across the insulation of a wall or roof enclosure of a conditioned (i.e., heated or cooled) space when the outside temperature is warmer or colder than the interior space. While all structural framing materials contribute to thermal bridging, this document will only focus on strategies, solutions and improved details to address thermal bridging specific to steel members.

Historically Speaking

While the amount of energy loss due to thermal bridging may be significant, not many U.S. structural engineers are currently considering in their building designs. The lack of thermal bridging considerations appears to be due to fundamental misconceptions about the level of impact that a structural engineer’s everyday design decisions can have on the thermal efficiency of a structure. There are several reasons for this.

First, there is the unspoken premise held by many structural engineers that their sole purpose is to design an economical system to provide for the building’s structural integrity. Energy efficiency is seen as the responsibility of others—architects, mechanical engineers, envelope consultants, energy modelers, and others who understand thermal issues. The thinking is that structural integrity, serviceability, and durability are the areas of focus for the structural engineer.

Second, there does not seem to be a compelling argument to do things differently. Do structural details really make a significant difference in the overall energy performance of a building? How could a thin steel plate that extends through the insulation plane of an exterior wall cause very much heat loss? Shouldn't there be hard numbers about how much money will be saved in the occupants’ utility bills, so that a real-world comparison can be done between the savings and the cost of modified details using new materials and products to address the issue of thermal bridging?

Finally, if structural engineers are to move from the tried-and-true structural details—half-inch steel plates and angle legs extending out to support masonry, continuous steel canopy and balcony beams cantilevering out from the interior structure through

the building wall (see Figure 1), and steel-to-steel connections anchoring rooftop grillages down through the roof insulation—what are the alternative details that can be used with a similar level of confidence? Can the profession be comfortable with a detail that introduces plastic materials into the compressive stress zone of a connection, a facade support that uses intermittently spaced support elements rather than continuous ones, or a design detail that interrupts the steel structure at the point of maximum stress by inserting complicated, proprietary manufactured component?

Reducing heat flow within the building envelope has benefits that extend beyond reducing energy use, such as minimizing the potential for condensation on surfaces. Also, colder interior surfaces can make people feel colder than the ambient air temperature, causing them to raise the temperature of the room or plug in an electric heater to feel comfortable. These are considerations that the Committee will be addressing in the future.



Figure 1: Infrared scan of structural steel balcony beam cantilevering out from a structure.

Moving Forward

The goal of this document is to begin to address these questions with the understanding that a comprehensive perspective on the issues surrounding thermal bridging will take time to evolve. This is a new perspective on the evaluation of structural systems which will be guided by developments in other countries, a better understanding of building envelope performance, and the ever-increasing importance of managing our energy resources. This document discusses approaches to address thermal bridging issues in steel-framed structures that can currently be evaluated and implemented.

Heat Transfer through Building Envelopes: How It Works

Structural steel elements are integral to the building envelope or building enclosure. Accordingly, designers need to have a basic knowledge of how envelopes work, especially the thermal impact of steel elements penetrating the envelope.

Conduction, Convection, Radiation

Heat transfer can occur through a building envelope in three ways: conduction, convection, and radiation. Convection is the transport of heat energy in air that flows through the envelope. This can be a significant source of building energy loss if the envelope does not have an effective air barrier system in the envelope.

Radiation is responsible for very little heat transfer across the envelope, but radiation on the exterior surface of a building in the form of solar gain, or heat loss on a cold, clear night can be very significant. Also, on the inside, warm bodies (such as humans) radiate heat to colder surfaces—such as exterior walls cooled by heat loss through conductive materials.

Conduction—the flow of heat through materials—is responsible for the majority of the heat flow through almost all functional building envelopes, and is the primary concern in terms of thermal bridging. Resisting conductive heat flow is usually accomplished by the use of insulation materials.

R-Values and U-Factors

There are two units for measuring an assembly's heat flow properties: R-value and U-factor. An assembly's R-value is a measure of its resistance to heat flow. The normal convention in the U.S. is to express the R value per inch of material, with the units $\text{hr}\cdot\text{ft}^2\cdot^\circ\text{F}/\text{Btu}$. It was originally developed to compare different types of thermal insulation, but it has become the generally accepted measure of all materials, not just insulation, as well as a metric for complete envelope assemblies. The inverse of the R-value is the U-factor ($U = 1/R$), which is a measure of the ability of an assembly to transfer heat, expressed in the conventional U.S. units $\text{Btu}/\text{hr}\cdot\text{ft}^2\cdot^\circ\text{F}$. The R-value and U-factor for an assembly depend on the materials contained in the assembly and their geometry. Each material has an intrinsic thermal conductivity, k ($\text{Btu}/\text{hr}\cdot\text{ft}\cdot^\circ\text{F}$). For some materials, this k value may vary significantly with temperature, but for most common building materials the properties are relatively constant for the range of temperatures normally experienced by buildings.

The use of the R value to “rate” assemblies is more complicated and requires consideration of the three-dimensional paths that heat can take through the assembly. The commonly used “effective R-value” is an imprecise term that is used differently for different purposes. For example, a material with higher thermal mass or capacity (that is, the ability to store thermal energy), such as brick, may have a low R-value (as measured in a steady state condition) but transfers heat at a lower rate when temperatures fluctuate, such as between warm days and cold nights.

Serial vs. Parallel Conductive Heat Paths

Conductive heat flow through a building envelope assembly, such as a wall, can occur either in series or parallel, similar to the flow of electricity.

In a series heat path, heat moves progressively through one material, then the next, and so on. Series heat flows occur when the building materials are layers in adjacent planes like a sandwich: for example, a wythe of brick, then a layer of rigid insulation, then another wythe of block in a wall assembly. For such systems, the total R-value of the assembly can be determined by simply adding the R-values of the individual layers, times their thickness.

A parallel heat path occurs when a plane of material is interrupted, or “bridged,” by another material that has different thermal properties. For example, a steel plate passing through a layer of rigid insulation forms a parallel heat path. Parallel heat paths are more complicated to evaluate than a series path. In a steady state system, if the bridging material is well connected thermally on both sides, the effective R-value of the total area can be calculated by tallying the algebraic sums of the materials' areas times their U-factors, divided by the total area, and inverting the result. This is the formula:

$$R_{\text{eff}} = A_{\text{total}} / [(A_1 \cdot U_1) + (A_2 \cdot U_2)]$$

For example, for a 10 foot square area of one inch of expanded polystyrene insulation (say R-4 per inch) bridged (penetrated from one side to the other) by a ¼-in. steel plate, 10 ft wide, (R-0.0031 per inch), the effective R-value of the total wall area would be:

$$(14,400) / [(30) / (0.0031) + (14,370) / (4)] = 1.1$$

So, within the range of assumptions and limitations of this formula, the effective R-value for the plane of insulation in the wall would drop from R-4 to R-1.1 with the addition of the steel plate.

Quantification of Energy Loss

Although quantitative and easy to use, the formula for calculating an effective R-value, based on parallel heat paths across an insulation plane, has significant limitations that make it a poor model for the actual energy lost in buildings. The main limitation is the assumption of fully effective thermal transfer of the materials outside of the insulation thickness—both interior and exterior. A highly conductive material can only transfer heat to its full potential if the heat energy can be brought to it on

one side, and can have it all drawn away on the other side. For this reason, the formula should be interpreted as the “maximum reduction of R-value” only.

Knowing the amount of energy that a building loses through a thermal steel bridge is important. However, it is difficult to manage what cannot be observed and measured. Fortunately, methods exist to help qualify and quantify the issue.

Infrared Imaging

Infrared (IR) cameras images can provide a quick visual assessment of the heating or cooling energy lost through a building envelope. The cameras detect and display the infrared radiation signatures from surfaces, called thermographs. For materials with an *Emissivity Factor* (also known as E-Factor, which is the ratio of absorbed vs. reflected/transmitted energy) of 1.0, this is directly proportional to the surface temperature of the object. For materials with a factor significantly less than 1.0 (such as unpainted metals and glass), the signatures include a portion of IR waves reflected off the surface.

Accurate IR building thermography requires certain conditions, such as a significant temperature differential between the inside and outside of a building. Surfaces should not be recently exposed to sunlight, as this will skew the results due to solar radiation heating. The E-Factor of the building materials should be known so compensations can be made. Since surface temperatures can be affected by both heat conduction and convection through the building envelope, the difference in interior versus exterior air pressure should be taken into account.

An IR scan of a completed and occupied building can be useful feedback on a building's performance, mainly to identify problems that should be avoided next time. However building *envelope* commissioning can include IR scanning as part of the verification process to ensure that the envelope was constructed in accordance with the design. (See Figure 2)

Energy Modeling

A precise and accurate energy model of a building takes into account the actual three-dimensional details of the building, including all the materials' thermal transfer properties and thermal mass, and the type and effectiveness of the air barrier system. It also requires a precise set of predictions of operational usage, building occupancy, and weather conditions that the building will experience. With such a model, different structural building envelope details can be modeled and iterated to optimize their performance characteristics. Although precise models are clearly useful, they require enormous cost and effort.

Most building energy modeling assessments performed today consider greatly simplified building systems. They use broad-brush assumptions about mechanical systems, occupant usage, climate data, as well as the overall insulation and air leakage performance of typical wall, roof, and fenestration assemblies. This approach makes it feasible to perform the modeling within the constraints of the design and construction

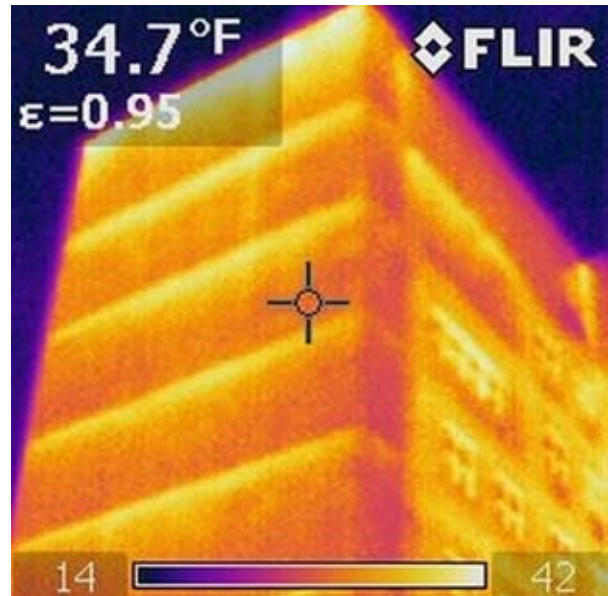


Figure 2: Brick in contact with warm steel shelf angles, which stand out in infrared images.

project, but it does not directly consider the effect of “hot spots” or discrete conditions—such as steel bridging details—that are more prone to heat transfer. In addition, much of the modeling performed today is done when the building design is nearly complete or completed, precluding the model from providing feedback on the structural design. ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) Technical Committee 4.4's new document 1365-RP, “Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings” provides thermal performance data on 40 common steel and concrete building envelope details for mid- and high-rise construction.

Energy modeling can also be completed on individual sections of buildings, such as windows or other targeted areas, using software programs. These programs model the individual elements of the building section and calculate the heat transfer across the section based on their thermal properties in accordance with the laws of thermodynamics. They can provide a reasonable calculation of an effective R-value of a section of a building envelope, especially where a “hot spot” has an effect. This R-value can then be used in an overall building energy model. This is the approach taken in this document to clearly identify areas and alternative approaches to addressing bridging in structural steel details. Typically, the role of the energy modeler does not fall to the structural engineer. This responsibility usually falls on the architect or mechanical engineer/subcontractor.

Thermal Bridging and the Codes

Building envelope considerations for energy efficiency that take into account thermal bridging are now being evaluated for inclusion in codes and standards for both baseline and high-performance green buildings. Three

key publications, the International Green Construction Code (IGCC) and ASHRAE 189.1 and 90.1, offer some insight on how codes may potentially adopt thermal bridging provisions.

- International Green Construction Code (IGCC). The IGCC, a product of the International Code Council, is scheduled for final publication in March 2012. The IGCC states that the “building thermal envelope” shall exceed requirements in the International Energy Conservation Code (IECC) by 10%.
- ASHRAE Standards. ASHRAE 189.1, *Standard for the Design of High-Performance, Green Buildings Except Low-Rise Residential Buildings*, contains tables that list maximum U-values for various envelope assemblies and minimum R-values for insulation. ASHRAE 1365-RP, “Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings” may affect how the ASHRAE standards address the issue and potentially incorporate thresholds. Completed 2011, the project’s objective was to provide thermal performance data—both indexed surface temperatures and thermal transmittance—for 40 common building envelope details for mid- and high-rise construction, using three-dimensional

finite-element analysis heat-transfer software (thermal transmittance was calculated for clear field, linear and point anomalies). If and how the results of this study will result in thermal transmittance requirements being incorporated into future versions of ASHRAE 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*,—and presumably 189.1—is yet to be determined.

While none of these publications currently incorporate thermal transmittance requirements of steel elements that bridge the building envelope, the potential for future recommendations and guidance is certainly there, especially as opportunities to increase energy efficiency in buildings are pursued. In fact, at a recent meeting of the ASHRAE Standing Standards Project Committee 90.1 (SSPC 90.1), the Envelope Subcommittee identified several topics for further consideration and development; among them is thermal bridging. Proposals are expected to be developed in early 2012.

Alternative Materials and Various Restrictions

The incorporation of alternative steel or non-steel structural materials can provide benefits in areas where thermal steel bridging situations are encountered.

Stainless Steel

Stainless steel has a different metallurgical chemistry than carbon steel resulting in an R-value about three times that of carbon steel. Material costs for stainless steel are approximately four times that of A992 structural steel. However, with limited, strategic use of the material, additional costs can be minimized. The use of stainless steel members or stainless steel bolts in areas of thermal bridging concern can significantly reduce heat transfer. Material and construction costs for the general contractor by adding in stainless steel to the connection assembly can result in incremental upfront construction costs to the project. Welding processes need to be appropriately specified for material compatibility and to reduce potential for stress corrosion cracking.

Alternative Materials

The use of unconventional “alternative” materials such as fiber reinforced polymers (FRP), or recently introduced proprietary design-delegated elements, comes with issues common to new technologies. In many cases, a prescriptive

code-based acceptance procedure is not available for these technologies and alternative compliance must be demonstrated. In some cases the material may appear to be prohibited, such as the use of FRP for masonry support, requiring the use of an alternate analysis to justify use of a “non-combustible” material. A foam layer in a façade connection load path, for example, may be successfully employed on the building exterior, by treating the foam as insulation for code life safety requirements. However, because code reports, UL assembly, and loss prevention criteria are not yet able to address the building solutions needed for structural thermal breaks in many cases, special approvals will likely be necessary. Fire protection analyses and time-tested technology reporting from other countries are recommended approaches that have seen some stateside success. Note that the *AISC Specification for Structural Steel Buildings* (ANSI/AISC 360-10) does not currently address any non-steel assemblies as they relate to handling thermal bridging conditions.

The mechanical properties of the elements used are an important aspect of the structural engineering considerations. Obtaining these values for proprietary materials can sometimes be challenging, which can lead to structural engineers’ reluctance to consider such details.

Solution Concepts

As building envelopes are designed to meet higher energy performance levels, the impact of thermal bridging—and the need to come up with solutions—becomes even more obvious.

Some general approaches that have been used are:

- Reduce the frequency of the penetrations, and eliminate continuous thermal bridges whenever possible, by strengthening the structure outside of the envelope
- Use lower conductive structural elements, such as

high-strength foams, FRP, wood, or stainless steel (which has a R-value approximately three times that of carbon steel) aligned with the envelope’s insulation within the load path

- Eliminate connectivity though the envelope with independent structural support external to the building envelope insulation
- Specify and accommodate manufactured structural thermal break assemblies (MSTBA’s) for use at canopies and other projecting structural steel elements

Calculations and Details

In order to quantify the amount of building energy that can be lost by thermal bridging and quantify the reduction in energy loss by the use of alternative details, the AISC/SEI Thermal Steel Bridging Task Committee considered a small three-story commercial steel-framed building, 75-feet long by 40-feet wide by 40-feet tall with approximately 9,000 square feet of gross floor area. The building design incorporated five common conditions of thermal bridging. The building is assumed to have R-50 roofing and R-25 exterior wall assemblies. The exterior walls also contain 25% glazing, double-paned windows with an R-value of 3 (including framing effects). (See Figure 3.)



Figure 3: Isometric of model building, with the five details mentioned below.

For each of the five conditions of thermal bridging, an “unmitigated bridging” detail is presented, as well as an alternate detail minimizes the energy impact of thermal bridging. Each of the five alternate details represents a different type of strategy that can be used to minimize building energy loss, as compared to the base case. See Table 1.

Description of Methodology

Each of the five unmitigated bridging details and the five alternate details were modeled using the heat transfer computer program THERM. The program, developed by the Lawrence Berkeley National Laboratory, can be used to model two-dimensional details with thermal parameters of the various materials, and generate an average U-value of the area modeled. The difference in

U-values between the details represents the reduction of energy flow through that section of the building.

To estimate the average annual heating and cooling energy savings using the alternative details, the average heating degree days (HDD) and cooling degree days (CDD) was used for two different cities with different climates: Chicago and Phoenix. Using reasonable assumptions including heating efficiency of 80%, estimated annual energy savings were calculated in dollars and as a percentage of overall building energy cost. It was determined that energy losses were minimal (<0.01% impact on overall energy consumption) for detail 1 (rooftop grillage posts) and detail 5 (cantilever roof canopy).

In order to determine the incremental costs related to implementing the alternative details, steel fabricators were surveyed and comparisons were made between the estimated costs of the details including material, fabrication and erection. Incremental construction costs for the details are presented both as dollars and as a percentage increase in comparison to typical details in current practice.

Using the energy modeling program TRACE 700, the entire building was modeled to determine the estimated average total building energy usage with all of the unmitigated thermal bridging details. The results are as follows:

Chicago:

\$5,092 HVAC +

\$5,954 other (lighting and plug loads) = \$11,885

Phoenix:

\$10,954 HVAC + \$9,972 other = \$20,927

The Phoenix costs are higher than Chicago costs as a result of air conditioning being less efficient than natural gas heating, and higher electricity costs in Phoenix than Chicago.

Two energy models for each detail condition were created. The first modeled the energy consumption for the standard detail while the second measured the energy consumption for the modified detail. The amount of energy saved through the implementation of each of the alternative details was then divided by the total building heating and cooling energy used, to arrive at a percentage of energy saved. It should be noted that the estimated percentage of energy savings is just that—an estimate. As building location, orientation, geometry and the ratio of wall area to interior volume change, so will the percentage of savings. The estimate of savings is an indicator of the relative magnitude of

	Condition	Improvement Strategy in Alternate Detail
Detail 1	Rooftop Grillage Posts	Non-Conductive Shims
Detail 2	Roof Edge Angle	Intermittent Carbon Steel Supports
Detail 3	Shelf Angle Support	Intermittent Stainless Steel Supports
Detail 4	Masonry Lintel	Material Separation
Detail 5	Cantilever Roof Canopy	Manufactured Structural Thermal Break Assembly

Table 1

the impact of the detail, not an absolute statement of the relative efficiency of the proposed detail. The results of the analysis are shown in Table 2.

Estimates from fabricators indicate that improved details 2 and 3 are actually less expensive than the detail typically in current use which is particularly significant in that these two details also hold the potential of the greatest energy savings. It should be remembered that the energy savings listed in the table are applicable only for the structure under consideration. It does not appear that the proposed detail for the masonry lintel is cost justified based on the increase in fabrication cost. However, this does not mean that thermal issues associated with masonry lintels should be ignored. Rather, further investigation should be performed to determine if a more cost effective detail can be developed to address this condition.

It may seem that the energy savings of these improvements are relatively small. However that is not the case when they are placed in the context of being incremental contributions to the overall goal of reducing the energy consumption of buildings. The Architecture 2030 Challenge adopted by the American Institute of Architects, The US Green Building Council, the US

Conference of Mayors, ASHRAE and many others has as its goal to reduce building non-renewable energy consumption in new buildings by 60% by the year 2030. Mayor Bloomberg's PlaNYC initiative seeks to reduce New York City's greenhouse gas emissions by 30 percent by 2030 where nearly 80 percent of the citywide emissions are attributed to buildings' energy use.

For an actual project it would be necessary to determine the financial benefit accruing to the building owner by conducting a return on investment (ROI) analysis based on the actual incremental cost (if any) of the thermal bridging details through consultation with a steel fabricator and general contractor located in the area of the project. This incremental cost would then be offset by the present value of the annual energy savings taking into account inflation and projected grid-based or contracted energy costs over the anticipated service life of the building.

Details Evaluated

It should be noted that even if all bridging were to be eliminated at the location of the detail, energy loss would still occur at the location due to the conductance of the base material.

	Detail	Condition	Area Affected	Annual Building Heating & Cooling Cost	Annual Potential Energy Savings Realized Through Use of Alternative Detail		% Energy Improvement from Standard Detail to Alternate Detail	Potential Average Alternate Detail Implementation Cost Increase (-) or Savings (+) In Entire Structure (Material/Fabrication/Erection)		Percent Cost Increase (-) or Savings (+) from Standard Detail to Alternate Detail
					Dollars	% Impact		Total Locations	Dollars	
Chicago	1	Rooftop Grillage Posts	7.74 sq. ft.		\$1.00	0.01%	19%	12 posts	-\$350	-14%
	2	Roof Edge Angle	957 sq. ft.		\$130	1.10%	30%	230 ft.	\$1,100	17%
	3	Shelf Angle Support	1,035 sq. ft.		\$260	2.20%	77%	460 ft.	\$400	1%
	4	Masonry Lintel	398 sq. ft.		\$39	0.33%	26%	336 ft.	-\$28,000	-98%
	5	Roof Canopy	9.25 sq. ft.		\$1.30	0.01%	27%	7 beams	-\$6,300	-137%
	Total				\$11,885	\$431.30	3.60%	46%		
Phoenix	1	Rooftop Grillage Posts	7.74 sq. ft.		\$1.00	0.00%	17%	12 posts	-\$350	-14%
	2	Roof Edge Angle	957 sq. ft.		\$150	0.70%	31%	230 ft.	\$1,100	17%
	3	Shelf Angle Support	1,035 sq. ft.		\$290	1.40%	76%	460 ft.	\$400	1%
	4	Masonry Lintel	398 sq. ft.		\$43	0.20%	27%	336 ft.	-\$28,000	-98%
	5	Roof Canopy	9.25 sq. ft.		\$1.60	0.00%	30%	7 beams	-\$6,300	-137%
	Total				\$20,927	\$485.60	2.30%	47%		

Table 2

Detail 1: Rooftop Grillage Posts

Thermal Improvement: Non-Conductive Shims

This condition represents steel posts that are supported by steel framing in the interior, conditioned space, and extend up through the roof insulation. This is typical in buildings for the support of mechanical rooftop units or other equipment. A common use of rooftop grillages recently is to support anchored photovoltaic arrays.

The detail with unmitigated bridging has 3.5-inch diameter Schedule 40 steel posts spaced at six feet on center, connected to an interior wide-flange steel beam, and connected on the exterior to a continuous wide-flange steel grillage beam.

The alternate detail adds a one-inch-thick insulating shim plate—expanded polystyrene rated at 100 psi—between the post base and the supporting steel beam. To be effective, an intervention to a thermal steel bridge should occur within the thickness of the roof insulation.

Other low-conducting materials could be used. FRP is a common structural material that has been used in specific structural applications for years. It has high compressive stress properties and good thermal resistance. For any material, requirements include adequate and predictable

compressive stress (for both strength and compressibility), dimensional stability and durability, affordability, and availability. At least one manufacturer is marketing FRP as structural thermal insulation material for this type of use. Although they have been used in limited applications to transfer shear and bending moment as well as axial compression, the authors believe that more research needs to be performed, and design standards developed, before this can be recommended.

- Potential Annual Energy Savings Realized Through Use of Alternative Detail: Chicago: \$1.00 (0.01% Savings), Phoenix: \$1.00 (0.00%)
- Percent Energy Improvement from Standard Detail to Alternate Detail: Chicago: 19%, Phoenix: 17%
- Estimated Incremental Cost of Alternative Detail for Model Structure: Additional Cost of \$350 (14%)

In this case the annual energy savings is minimal and does not justify the additional expense of the proposed detail.

Alternative Improvements:

- Minimize total cross-sectional area of posts passing through the insulation layer
- Use stainless steel post bases with small cross-sectional area

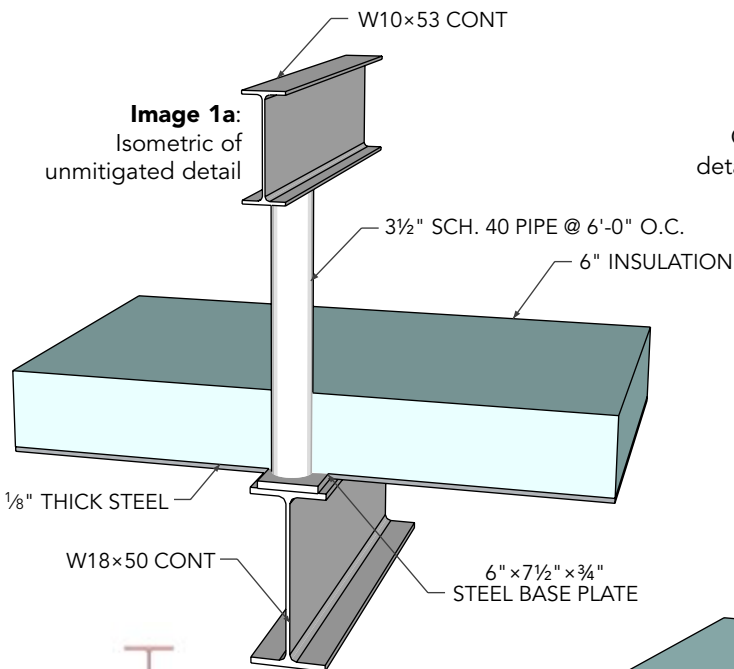


Image 1a:
Isometric of
unmitigated detail

Image 1b: Typical Temperature
Gradient output of unmitigated
detail (Estimated average U-Factor
of Unmitigated Detail: 0.56)

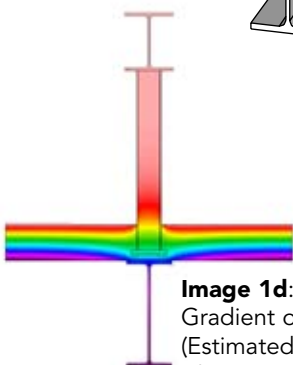
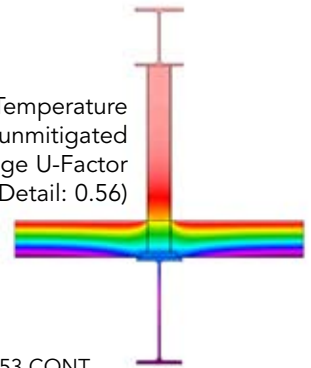


Image 1d: Typical Temperature
Gradient output of alternate detail
(Estimated average U-Factor of
Alternate Detail: 0.50)

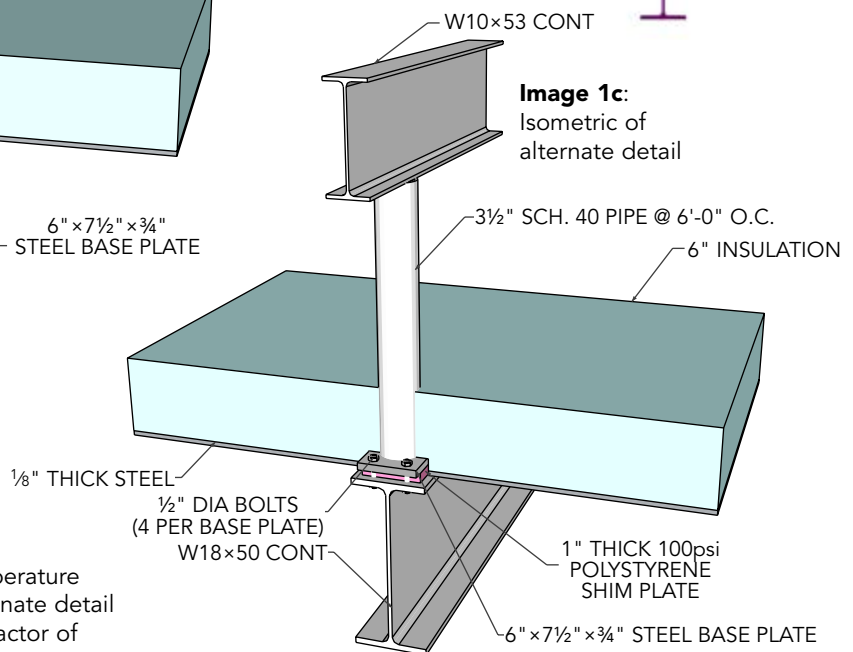


Image 1c:
Isometric of
alternate detail

Detail 2: Roof Edge Angle

Thermal Improvement:

Intermittent Carbon Steel Supports

A commonly overlooked condition in the energy assessment of envelopes, the intersection of the roof and wall planes frequently has continuous steel elements that extend between the interior and exterior. Many codes prescribe minimum R-values for roof and for wall systems, but do not explicitly mention any potential R-value reduction by bridging at their intersection. The effect of these elements should be incorporated into the thermal assessment or calculations for either the wall system or the roof system, or a combination of both, which is how this condition was treated in this document.

The detail with unmitigated bridging has a continuous steel angle along the edge of steel roof deck. This is frequently needed for the collection of lateral diaphragm loads in a building. Connected to this angle in the base case is a continuous angle that extends out through the intersection between the roof insulation and the wall insulation, to support the roof edge blocking.

The alternate detail maintains the continuous steel angle at the roof deck, but replaces the continuous steel angle supporting the roof edge blocking to six inches long, spaced at 24 inches on center. This shortens the continuous thermal steel load path along 75% of the roof edge length. Structurally, it relies on

the flexural strength of the wood roof blocking to span the 24 inches (18-inch clear distance) between the steel support angles. This does not come close to the structural limit of the wood blocking.

In any detail where intermittent supports are used, the detail needs to be carefully analyzed by the engineer of record for structural adequacy. In the case of roof blocking support, the applied loads are fairly low, consisting of gravity loading on the roof edge, wind uplift loading, and in some cases, lateral resistance to planar forces imposed by the roofing membrane.

- Potential Annual Energy Savings Realized Through Use of Alternative Detail: Chicago: \$130 (1.1% Savings), Phoenix: \$150 (0.7%)
- Percent Energy Improvement from Standard Detail to Alternate Detail: Chicago: 30%, Phoenix: 31%
- Estimated Incremental Cost of Alternative Detail for Model Structure: Savings of \$1,100 (17%)

When combining the projected \$130 to \$150 annual energy savings with the projected \$1,100 additional savings in implementation costs, this detail is a good example of a practical solution to thermal bridging challenges.

Alternative Improvements:

- Use wood supports for the blocking
- Modify detail to eliminate exterior steel
- Use an insulating shim (such as FRP) between the steel angles

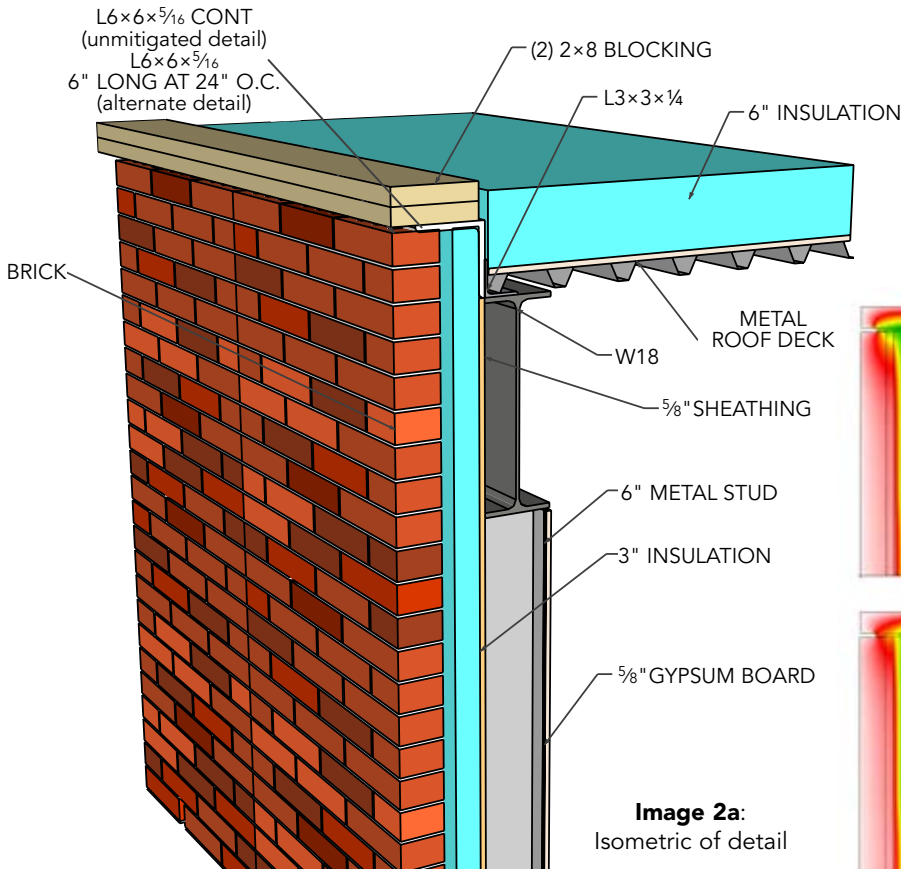


Image 2a:
Isometric of detail

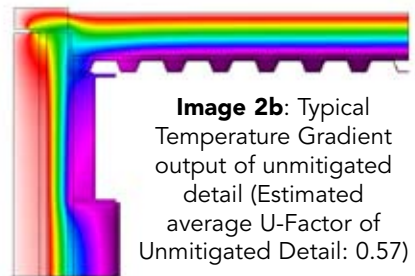


Image 2b: Typical Temperature Gradient output of unmitigated detail (Estimated average U-Factor of Unmitigated Detail: 0.57)

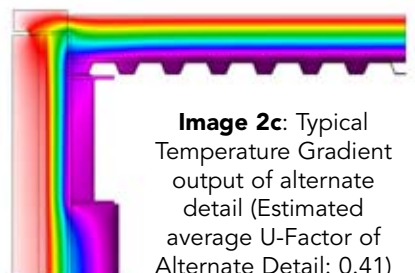


Image 2c: Typical Temperature Gradient output of alternate detail (Estimated average U-Factor of Alternate Detail: 0.41)

Detail 3: Shelf Angle Support
Thermal Improvement:

Intermittent Stainless Steel Supports

Sometimes known as a relieving angle, a continuous steel element that supports one or more stories of the exterior wythe of masonry or stone on a building is thermally paradoxical: The thicker the insulation behind the wythe, the thicker the steel support element needs to be to cantilever out across the insulation to support the facade, and the more thermally conductive the steel support becomes.

The detail with unmitigated bridging models a fairly modest steel angle support, with the horizontal leg of the angle extending across the exterior wall insulation. On the interior, the angle is continuously connected to a steel bent plate that acts as a slab

edge. The intervention introduces ¼-inch 3-inch wide vertical stainless steel knife plate supports at 24 inches on center, across the insulation plane. This brings the support of the shelf angle out past the insulation, and shortens the horizontal leg of the angle.

The different types of stainless steel vary in material properties. A306 and A316 have similar structural and thermal properties, and have been selected for this model. One caution while using stainless steel in a welded detail is the need to carefully select the welding electrodes to ensure compatibility with the type of metals being connected.

Some manufacturers have developed complete stainless steel systems for the support of facades. This can be an advantage for the engineer who can simply specify a proprietary system without needing to

Image 3a: Isometric of unmitigated detail

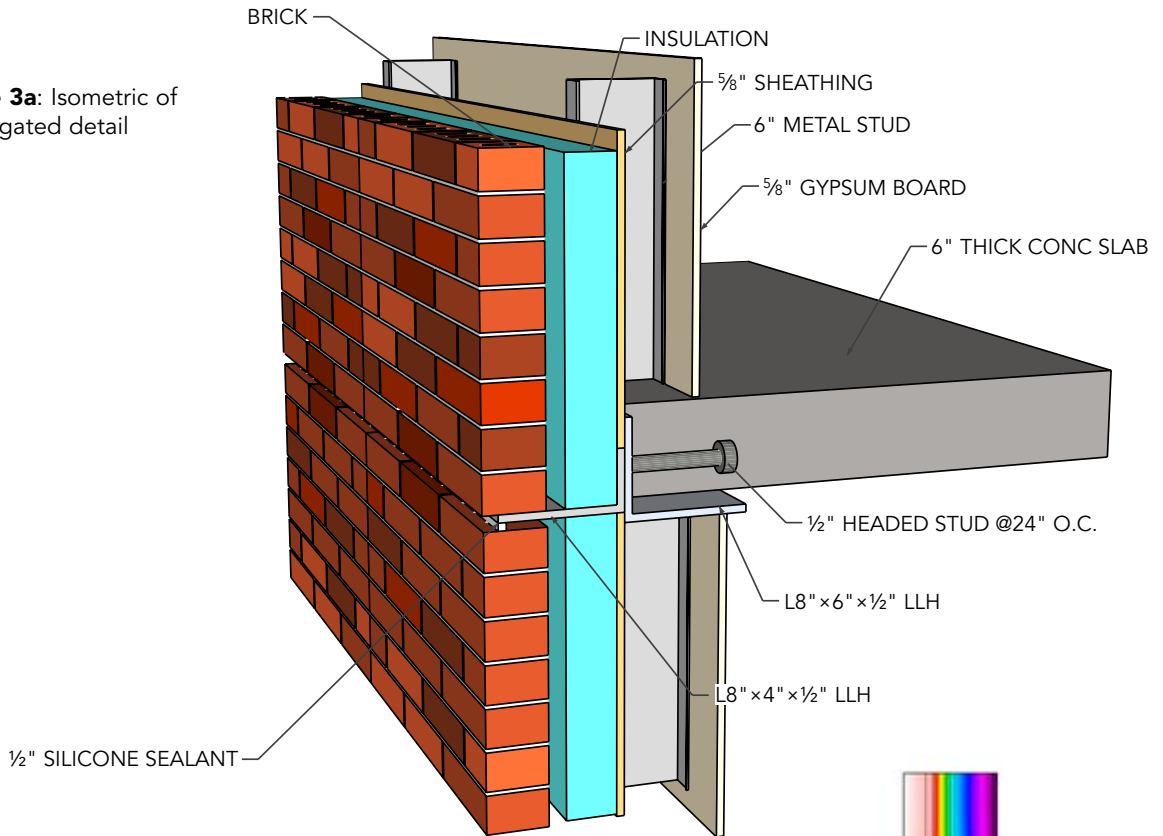
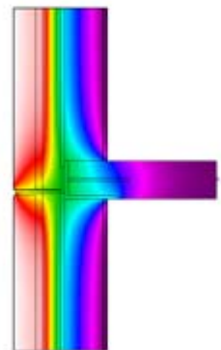


Image 3b: Typical Temperature Gradient output of unmitigated detail (Estimated average U-Factor of Unmitigated Detail: 0.44)



perform the full structural design on all of the elements. Another potential advantage is the use of stainless steel in the continuous support angle, which likely reduces the thermal energy transfer further. Frequently, however, these manufacturers offer similar systems out of corrosion-protected carbon steel, which is significantly less expensive but more conductive (carbon steel being roughly three times as conductive as stainless steel), and are selected during the design or review process in order to reduce the initial construction cost.

- Potential Annual Energy Savings Realized Through Use of Alternative Detail: Chicago: \$260 (2.2% Savings), Phoenix: \$290 (1.4%)
- Percent Energy Improvement from Standard Detail to Alternate Detail: Chicago: 77%, Phoenix: 76%

- Estimated Incremental Cost of Alternative Detail for Model Structure: Savings of \$400 (1%)

When combining the projected \$260 to \$290 annual energy savings with the projected \$400 additional savings in implementation costs, this detail is a good example of a practical solution to thermal bridging challenges.

Alternative Improvements:

- Use manufactured stainless steel support system
- Use an insulating shim (such as FRP) between the angle and bent plate
- Modify detail to support exterior masonry completely outside plane of envelope insulation

Image 3c:
Isometric of
alternate detail

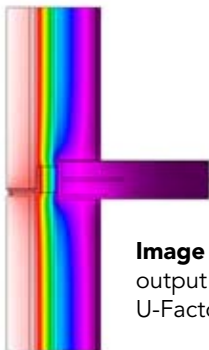
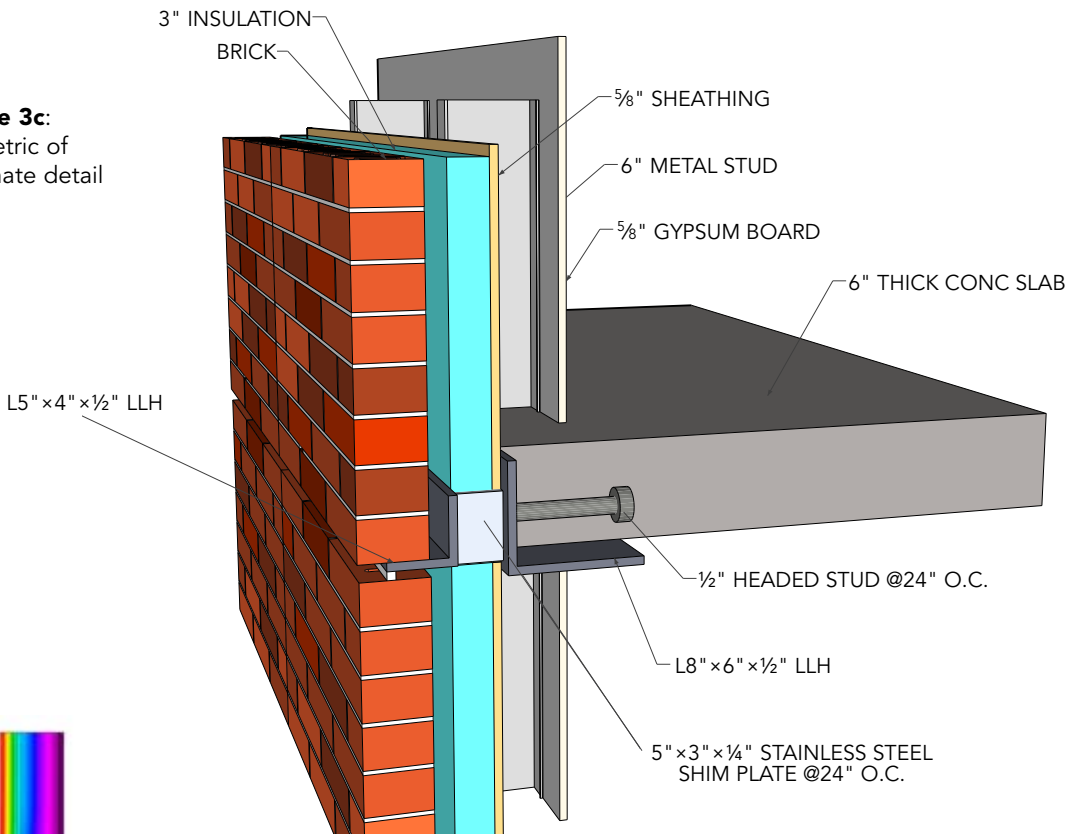


Image 3d: Typical Temperature Gradient output of alternate detail (Estimated average U-Factor of Alternate Detail: 0.13)

Detail 4: Masonry Lintel
Thermal Improvement: Material Separation

There are many variants of this condition, involving structural support of masonry above an opening in an exterior wall. Similar to shelf angle details, a common practice is to maintain continuous structural steel across the insulation plane to support the exterior wythe. Lately there has been a lot of focus on improving the energy efficiency of windows, including thermal breaks in the window frames. A steel plate that runs continuous across the head of the window opening is inconsistent with the energy efficiency goals of a high performing window system.

The unmitigated bridging detail is a pair of 5/16-inch thick continuous steel angles that span across the opening and transfer vertical loads from the brick above. The alternate detail includes a continuous thermal separation—a 1½-inch thick piece of wood—between these angles. This interrupts the steel bridge between the interior and exterior space with a layer that is several hundred times more insulating (R-wood is approximately 400 times R-steel).

The strategy of separating the exterior steel structure from the interior can take many different forms. It usually involves creating an alternative structural load path, exterior to the building's insulation plane. Vertical support can be in the form of an exterior masonry

Image 4a:
 Isometric of unmitigated detail

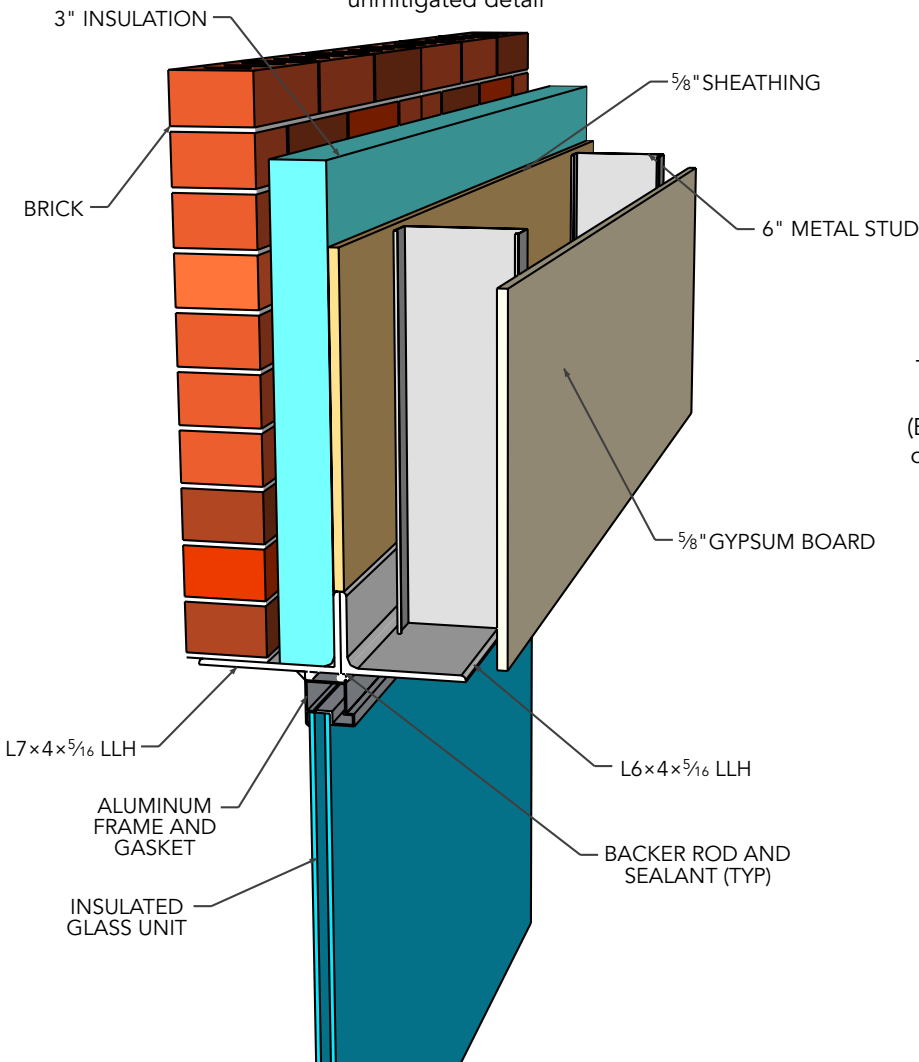
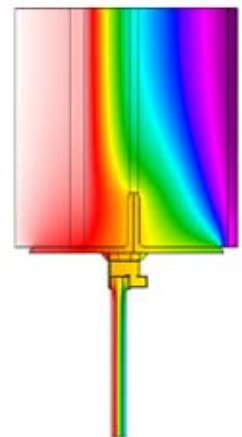


Image 4b: Typical Temperature Gradient output of unmitigated detail (Estimated average U-Factor of Unmitigated Detail: 0.62)



wythe, as in this example, or small exterior vertical steel posts. This can be done with canopies and balconies, as well, with posts adjacent to the exterior building wall. In some cases, the exterior structure must be braced back to the main, interior building structure, possibly with stainless steel ties or discrete bracing elements.

- Potential Annual Energy Savings Realized Through Use of Alternative Detail: Chicago: \$39 (0.33% Savings), Phoenix: \$43 (0.20%)
- Percent Energy Improvement from Standard Detail to Alternate Detail: Chicago: 26%, Phoenix: 27%

- Estimated Incremental Cost of Alternative Detail for Model Structure: Additional cost of \$28,000 (98%)

In this case the annual energy savings is marginal and does not justify the significant additional expense of the proposed detail.

Alternative Improvements:

- Use an insulating shim (such as FRP) between the interior and exterior lintel elements
- Use a masonry lintel
- Use a proprietary manufactured FRP lintel system

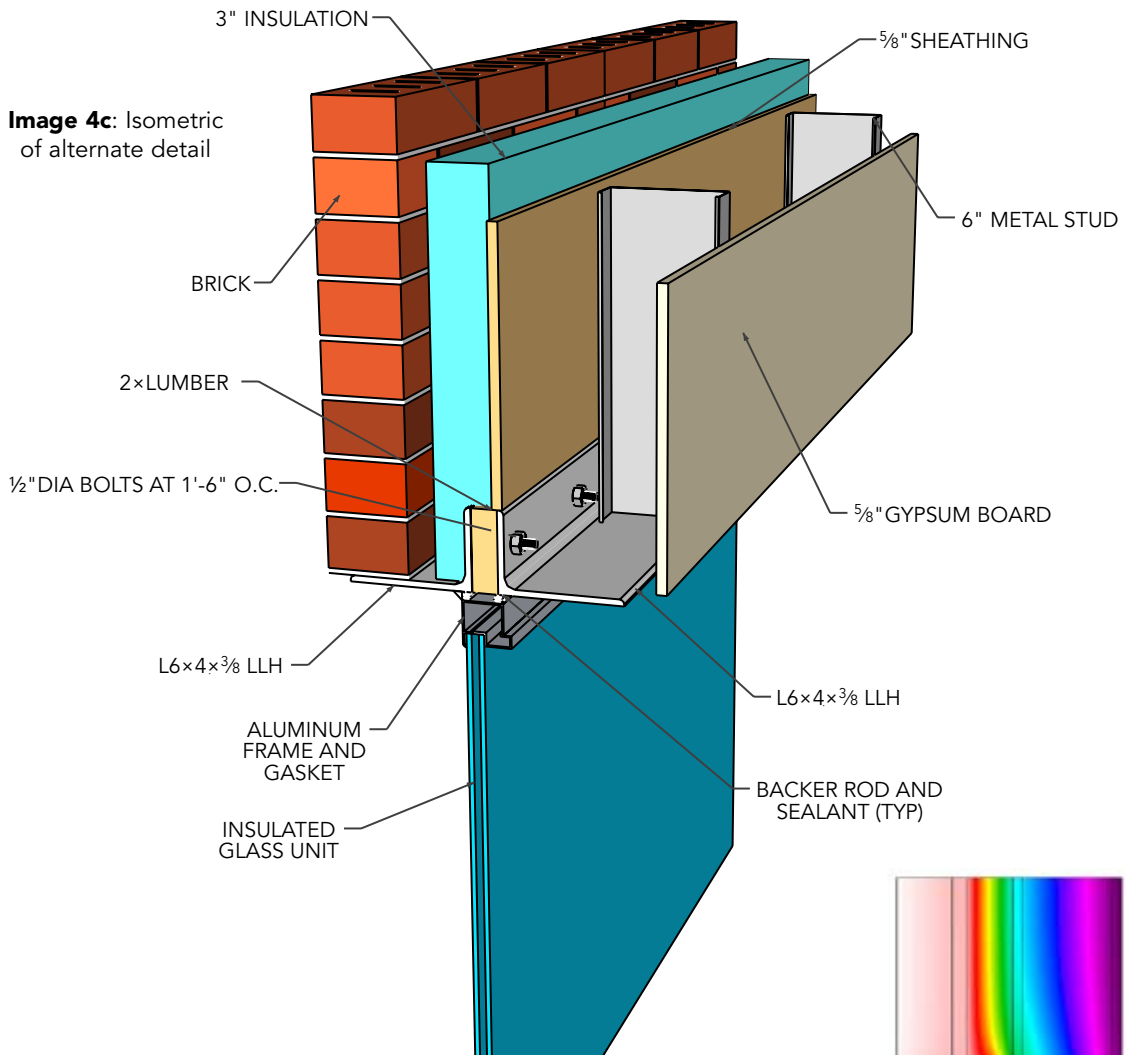


Image 4d: Typical Temperature Gradient output of alternate detail (Estimated average U-Factor of Alternate Detail: 0.54)

Detail 5: Cantilever Roof Canopy Beam

Thermal Improvement:

Manufactured Structural Thermal Break Assembly

Cantilevering elements extending out from the faces of buildings represent the versatility of structural steel to accommodate architects' visions. The most common conditions are for framing of entrance canopies and balconies. In some buildings, steel beams dramatically extend out of buildings for aesthetic purposes. In others, the support of vertical mechanical elements or other structural purposes require cantilevering steel beams.

The unmitigated bridging detail represents a cantilever beam for the support of a roof canopy. The beam is an HSS 4×3×¼ spaced six feet on center, and is rigidly connected to a steel tube steel spandrel beam on the interior side of the wall insulation. The alternative detail is the same condition with the inclusion of a Manufactured Structural Thermal Break Assembly (MSTBA).

MSTBA's are proprietary connection elements that have the capacity of transferring axial, shear, and flexural stresses, while minimizing the thermal heat transfer. Their structural and thermal properties are compiled by the manufacturers. Based on the project requirements, the MSTBA's can be specified as a performance item by the project's structural engineer, with responsibility for the structural adequacy of these ancillary structural components delegated to the manufacturer's engineer.

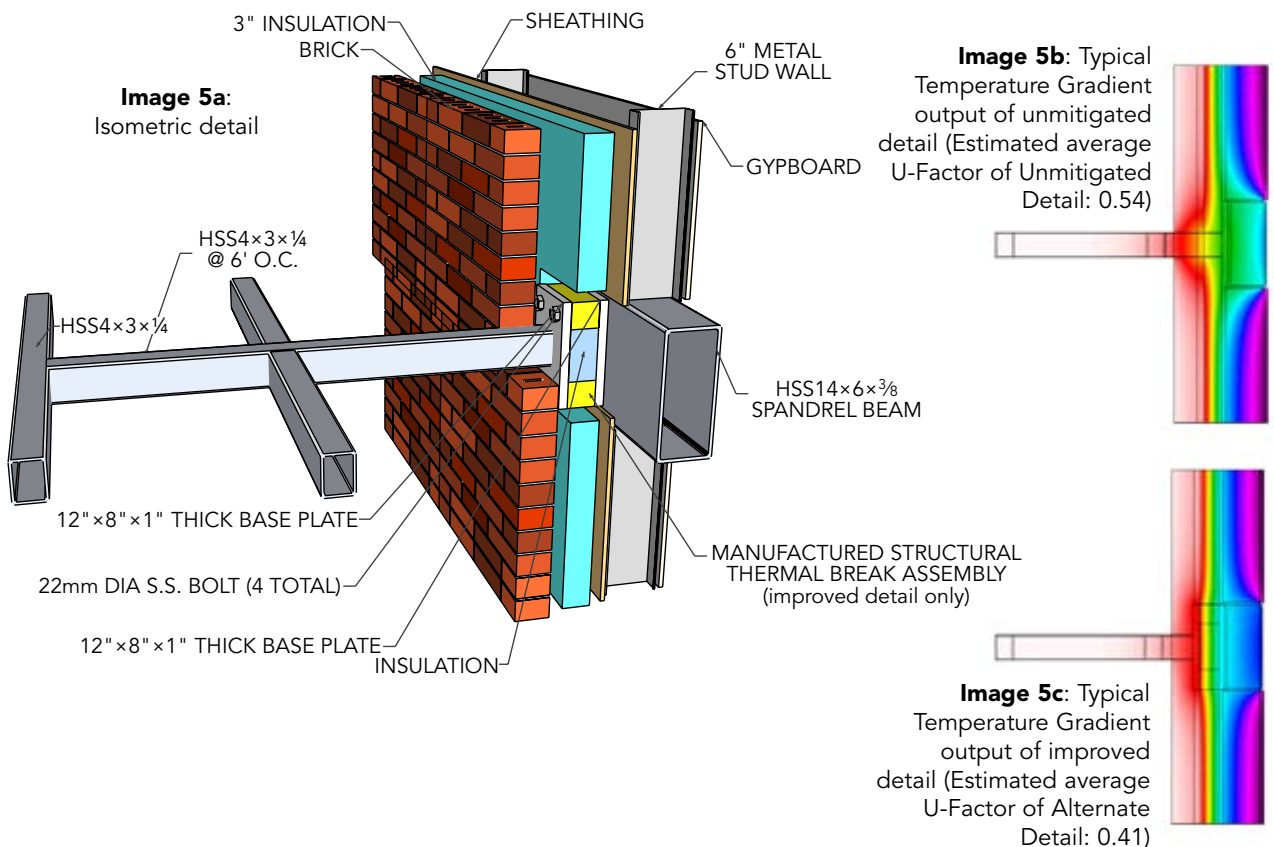
Although most or all of these systems are currently designed and fabricated in Europe, they are readily available in the U.S. The major manufacturers have a variety of options available, and MSTBA's can be customized to address the requirements of nearly any specific application. The systems have been successfully used in other parts of the world for years. The alternate method is only recommended when a third-party manufactured assembly supplier has been brought on board, research has been performed, and structural integrity of the assembly is fully evaluated.

- Potential Annual Energy Savings Realized Through Use of Alternative Detail: Chicago: \$1.30 (0.01% Savings), Phoenix: \$1.60 (0.01%)
- Percent Energy Improvement from Standard Detail to Alternate Detail: Chicago: 27%, Phoenix: 30%
- Estimated Incremental Cost of Alternative Detail for Model Structure: Additional cost of \$6,300 (137%)

In this case the annual energy savings is minimal and does not justify the additional expense of the proposed detail.

Alternative Improvements:

- Use minimal number of small-area stainless steel cantilever supports
- Modify detail to provide some exterior support, reducing the cross-sectional area of steel required to pass through the building envelope
- Modify detail to provide complete exterior support



Assumptions, Limitations, & Other Strategies

These results should not be considered to be representative of all details of that type. Nor should the strategies used in the “alternate” details to minimize energy loss be evaluated based on this very limited study. Rather, each detail is intended to model a fairly reasonable condition of thermal bridging, and the alternative details are one way of providing a reduction of bridging. Energy losses under real-world conditions can vary considerably in either direction. For example, a 5/8-inch thick continuous steel plate would transmit much more energy through the building envelope than the Detail 3 condition.

The U-values for the structural details were calculated using THERM, a two-dimensional software. In several cases, these assemblies contained intermittent three-dimensional members whose interactions cannot be modeled to a high degree of accuracy. The simplifications made for these details are considered to be acceptable as the goal of the study is to measure the relative performance of the details and calculate an approximate energy savings associated with improved detailing. As this topic is explored in more depth, three-dimensional modeling of these kinds of details is recommended to obtain results with an even greater degree of accuracy.

All upfront assembly costs mentioned above with each detail are approximations. Material availability, regionality, and current construction trends all directly impact various material and labor factors with any structure. It is recommended that each detail be investigated early on with all parties of the construction team to best anticipate true cost of detail implementation. Also, these are schematic, representative details developed for the purposes of this document only. Any structural detail used in an actual building project should be carefully designed by a structural engineer to ensure that the structural strength, deflection, and other serviceability requirements are satisfied. Further research on these details and other thermal bridging challenges is being pursued by AISC. Over time, updates to the data in this document, new findings, and other background information on the topic will be available at www.aisc.org/sustainability.

Other Thermal Bridging Challenges

The building under consideration in this model does

not include every potential source of thermal transfer resulting from steel bridging. For example, an exterior steel column that extends up to support a conditioned building structure would represent a thermal bridge, if no intervention is implemented. If this is a single column, its effect will not be as great as a continuous or repetitive condition, but it does represent a location of potential building energy loss. Ways to address such a condition include:

- Wrapping the column in insulation up to the building's main insulation plane and down to the foundation insulation, if there is any, effectively enclosing the column in the conditioned space. In buildings that require fire protection on steel members, the insulating properties of the fire protective coating serve as an insulating blanket reducing thermal losses.
- Creating a thermal break at the top of the column, either by the use of a bearing pad of thermally resistive material, or with an MSTBA.

Another strategy for reducing heat loss through thermal bridging is by wrapping a steel beam or column that extends to the exterior, on the inside of the insulated building envelope. Due to the thermal conductivity of steel, the insulation would likely need to extend several feet into the building in order to have a significant effect. Fire protective coatings can help provide these insulating properties.

One solution that typically does not work for a cantilever beam is to cut the cantilever, add steel end plates to each side, and bolt a stainless steel plate sandwiched between the end plates. While this can be designed to perform structurally, the thermal effect can actually be worse than no intervention at all—i.e., the “improved” connection could cause even more heat to transfer through the beam than an unbroken cantilever. This is because the plate has a much larger area than the cross-sectional area of the steel beam, and it serves as an efficient thermal collector and dissipater.

The examples presented in this document are meant to be examples of how steel framing systems can perform both structurally and thermally. There are other structural conditions that may not be similar to any of these examples. In those cases it is hoped that the broad strategies outlined to reduce thermal bridging can be a basis for addressing these situations.

Lessons Learned

So what are some of the conclusions that can be drawn from these results? First of all, continuous conditions, such as roof edge angles, brick shelves, and lintels, represent a much higher potential energy loss due to thermal steel bridging than discrete conditions, such as posts through roofs and individual steel beam projections through walls.

Secondly, the magnitude of heating energy loss in colder climates and cooling energy loss in warmer climates, due to thermal bridging, are in the same

general range. However, the relative efficiency of heating and cooling systems do differ and energy costs can vary geographically. This can cause an even wider range of energy impacts between different climate locations, as shown above.

In addition, while the amount of energy saved due to thermal bridging mitigation may not be significant on an annual basis in all conditions, it represents an ongoing expenditure for the life of the building. Only a present value analysis including energy cost savings and

incremental front end construction costs can provide an accurate evaluation of actual savings.

Finally, although this supplement focuses on thermal bridging of steel, it should be kept in mind that thermal bridging occurs through any material that is more thermally conductive than the insulation that it bridges across. Concrete canopies and balconies, for example, can be responsible for a great deal of building energy loss. While not as conductive as steel, the cross-sectional area of a cantilever slab is much greater than the structurally equivalent area of a cantilever steel beam. In addition, the steel reinforcing bars in the concrete cantilever slab greatly increase the thermal transfer.

In today's market, reducing both construction and operational building cost are more important than ever before. By working in a collaborative environment to reduce embodied energy and design structures for long-term energy savings, structural engineers, as valuable members of projects teams, can help create high performing, cost-effective steel framed buildings.

Acknowledgments

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References and Recommended Reading

- "Energy Standard for Buildings Except Low-Rise Residential Buildings," ASHRAE Standard 90.1-2007, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
- Morrison Hershfield, "Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings" (1365-RP), for ASHRAE Technical

Committee 4.4, Building Materials and Building Envelope Performance, July 2011.

- "Thermal Design and Code Compliance for Cold-formed Steel Walls," Steel Framing Alliance, 2008
- "Avoidance of Thermal Bridging in Steel Construction," The Steel Construction Institute, UK, 2008.
- "Sustainability Guidelines for the Structural Engineer," report of the SEI Sustainability Committee, ASCE Press, 2010
- Schild, Peter G., Blom, Peter, "Good Practice Guidance on Thermal Bridges & Construction Details," ASIEPI, March 2010
- "An Effective Handling of Thermal Bridges in the EPBD Context," Final Report on the IEE ASIEPI Work on Thermal Bridges, ASIEPI, March 2010

Material and Product Listing

Manufactured Structural Thermal Break Assemblies and Systems

- Armadillo NV Inc.
www.armadillonvinc.com
- Halfen Anchoring Systems
www.halfenusa.com

- Insula
www.insula.ltd.uk
- Schoeck Canada Inc.
<http://www.schock-us.com/>

Fiberglass Reinforced Plastic

- Bedford Reinforced Plastics, Inc.
www.bedfordplastics.com
- Fabreeka
www.fabreeka.com
- XC Associates, Inc.
www.xcassociates.com

Recommendations: Practical Things You Can Do

Based on the results of the analysis in the examples, the recommendations below should be considered:

1. Refer to the five examples of thermal bridging and mitigation strategies in the detailing of structural steel projects. Try to especially minimize conditions of continuous thermal bridging, such as at continuously supported steel brick shelves.
2. Pay particular attention to minimizing thermal bridging for buildings that fall into one or more of the following categories:
 - A. Buildings with a long estimated service life, such as institutional buildings, hospitals, etc.
 - B. Buildings in extremely warm or cold climates
 - C. Buildings where highly climate-controlled conditions exist, such as medical facilities and senior residence facilities
3. Consider the use of two-dimensional heat transfer modeling software to analyze unusual conditions where thermal bridging may occur in conditioned buildings.
4. Discuss the issue of building envelope energy performance with the other members of the design team, in order to develop coordinated strategies to minimize building energy loss through thermal bridging.
5. Confirm the structural integrity of any design solution for the project under design.
6. For informational purposes, take advantage of any opportunity to obtain feedback of the building envelope energy loss of buildings you have designed, using an infrared thermal camera.
7. Perform a full ROI analysis of proposed details before preparing construction documents and obtain the approval of the owner.