The Effects of Thermal Bridging at Interface Conditions

Paul E. Totten, PE   Sean M. O'Brien, PE   Marcin Pazera, Ph. D.

ABSTRACT

Thermal bridging in buildings can contribute to a multitude of problems, including, but not limited to, added energy use during heating and cooling seasons and interior surface condensation problems.

Thermal bridges are discontinuities in any thermal barrier and are more pronounced when the material creating the bridge is highly conductive. This paper presents several examples from previous projects for which we investigated thermal bridging at various building component interface conditions. The resulting problems and the proposed solutions focus on optimizing thermal bridges to minimize energy loss, and, in many cases, limit the risk for condensation.

Typical interface conditions discussed include roof-to-wall, steel stud construction, wall-to-fenestration, balcony-to-wall, and wall-to-wall. Additional examples examine structural penetrations for sun shading devices.

Other conditions that may affect heat transfer at interface conditions such as convective loops and air flow will be briefly discussed, but are not the main focus of this paper.

INTRODUCTION

With the continued growth and acceptance of sustainable building design in the United States, energy efficiency is gaining more and more attention/focus. The United States Green Building Council's (USGBC) LEED Rating System continues to increase requirements for energy efficiency. In addition, federal entities such as the GSA as well as many local government agencies have a renewed focus on the design and construction of their buildings with respect to energy conservation.

Energy modeling software is often used to determine the overall energy efficiency of buildings. The energy efficiency for the building enclosure is typically based on input on the U-values of various components. Thermal bridges formed by steel studs and their overall effect are approximated in the calculations. However, the current available software does not always accurately calculate the true U-value of various interface conditions, such as window-to-wall interaction based on window placement within the wall and unintended thermal bridges at these interfaces. Nor does the software consider thermal bridges formed by steel framing, sun-shades and other penetrations through the building enclosure without user input to "mimic" the effects of these shorts in the rating of the overall assembly. Two and three-dimensional heat transfer software can be used to better determine U-values at these localized thermal bridges; the overall energy analysis can then be carefully modified to better consider these effects and arrive at a more accurate picture of the overall energy efficiency of the building enclosure.

In addition to the heat loss and gain that can occur at thermal bridges, condensation problems may also occur. One of the most prevalent locations for this risk is at fenestration interfaces with adjacent systems. Positioning of skylights, doors, windows, window walls, curtain walls, and other fenestration within the thickness of a wall or roof element may provide a short circuit of the thermal pathway the manufacturer intended in their design and instead provide a thermal bridge. Our firm has seen this problem manifest itself mainly in colder climates; we have also seen issues with condensation in warmer climates due to issues with air conditioning, mainly with oversized equipment that does not cycle properly. In addition, multiple framing elements at fenestration for structural attachment, or for blast considerations, may also create thermal bridges; this can exasperate the quantity of condensation.

Besides fenestration, sun shades have elements including anchorage that bypass the thermal barrier and can lead to significant thermal compromises and condensation. Structural steel framing that extend from the inside to the outside not only makes waterproofing and air barrier details difficult, but also form a large thermal bridge.

In all cases, near perfect installation and continuity of the thermal barrier at these elements is key to lessening the effects of the thermal bridges and their resulting risk for condensation and thermal losses and gains. When this

Paul E. Totten, PE is a Senior Staff Engineer with Simpson Gumpertz & Heger Inc. in Washington, DC
Sean M. O'Brien, PE is a Senior Staff Engineer with Simpson Gumpertz & Heger Inc. in New York, NY
Marcin Pazera, Ph. D. is a Senior Engineer with Simpson Gumpertz & Heger Inc. in Washington, DC

is not practical because of structural design issues or other reasons, various insulation strategies that maintain the thermal barrier through the use of overlapping insulation can also be used to reduce the overall effects of the bridge.

THERMAL BRIDGES, THERMAL BARRIERS, AND THERMAL PATHWAYS

The building enclosure provides a separation of interior environment from the exterior environment. It provides boundary conditions for mechanical designers for HVAC systems based on air tightness, control of diffusive vapor transfer, and thermal efficiency. There are three major systems of the enclosure that require continuity: the air barrier system, the water management system (to control liquid water) and the thermal barrier system. We will concentrate on the thermal barrier for the majority of the paper. As the climate of the United States is quite diverse, the outdoor environment of any building will provide different requirements for the building enclosure and how it controls heat, air, and moisture. The building will have thermal pathways along which temperature differentials will occur. The degree of change in temperature will be dependent on how well the pathway is disrupted by insulating elements.

Thermal bridges occur when a conductive element passes through or bypasses the thermal barrier. Thermal bridges provide a path of lesser resistance through the insulation, allowing more heat to bypass the thermal barrier and raise or lower interior temperatures. Examples of common thermal bridges are wall framing, projecting concrete balcony slabs, parapets, sun shades, and windows misplaced within the wall assembly.

A thermal pathway is the path in three-dimensions that heat travels across any element of the building enclosure. The pathway can be calculated based on material properties and configurations and better visualized using two and three-dimensional heat transfer software, such as THERM (LBNL, 2003) or HEAT 3-D (MIT, 2003).

A thermal barrier is any insulating element introduced into a thermal pathway to disrupt/control heat loss and gain in order to maintain inside temperatures mostly consistent and at or near interior design temperature. The barrier and its greater ability to minimize heat loss and gain across the building enclosure provide a better system for the mechanical designer to control the interior loads for heating and cooling. In walls and roofs, this barrier is typically thermal insulation. In metal-framed fenestration, the thermal barrier is generally a reinforced plastic or fiberglass separator between frame components.

HEAT TRANSFER

Heat is transferred in different modes including conduction, convection, and radiation. At a macro level, the three mechanisms are best described by real life examples. A person sitting with his feet in contact with a cold floor experiences discomfort when heat is transferred by conduction from the occupant’s feet and into the floor. The higher the thermal conductivity of the flooring material, the greater the quantity of heat being transferred into the floor, and resulting level of discomfort. In the same scenario, the occupant’s level of comfort can be improved by supplying preheated air into the surrounding space. At the surface of the occupant’s body, heat is being transferred from the surrounding warm air through a combination of conduction and convection. Increasing fluid motion in this case, air surrounding the occupant can improve heat transfer, and thus improve the level of comfort. The level of comfort can be further optimized by sitting in proximity of a window on a cold but sunny day. The occupant can benefit from direct or indirect sun’s radiation to keep him/her comfortable.

This simple real life example highlights two fundamental principles; all three modes of heat transfer require presence of a temperature difference and heat is always transferred in a direction of a lower temperature (i.e. from high to low). This means that when object is in equilibrium with its surroundings, energy transfer ceases.

Although theoretically possible, temperature balance (equilibrium condition) is never attained and there is always some infinitesimal transfer of energy within objects themselves. At a micro level, energy transfer within objects is a direct result of molecular activity. In gases and liquids, energy transfer is imparted when molecules collide between each other. Within a given volume of space, molecules move about freely and randomly. Each molecule contains a certain amount of energy. The rule of thumb is the higher the temperature of the liquid or gas, the higher the molecular energy and greater the speed at which molecules travel. When molecules collide, energy is transferred from a more energetic particle to a less energetic particle. Even though we cannot sense these interactions, billions of them occur at each fraction of a second.

The effect of these collisions is the transfer of energy manifested by an increase in temperature. In solids, the transfer of energy becomes more complex since molecules are no longer mobile and free to move in a random motion but rather are held in a relatively fixed lattice formation. These molecules vibrate and their activity tends to increase as temperature increases. Heat is transferred by lattice vibrations and by flow of free electrons (Incropera and De Witt, 1990). The material's effectiveness in transferring heat is significantly affected by the lattice arrangement. The more ordered the arrangement, the higher the thermal conductivity of the materials. This is the reason why metals are much better conductors than masonry and wood.

In building enclosure, all three mechanisms aid in transferring energy between the interior and exterior environment. By conduction, energy is transferred across solid materials such as brick, concrete, and metal. Convective transfer within the wall cavity (bulk movement of air as a result of buoyancy effect due to temperature stratification within a cavity space) can enhance transfer of energy between components. Radiation can also induce heat transfer. A good example of radiation mechanism is nighttime radiation from buildings.

For thermal bridging, conduction between adjacent components is the most significant heat transfer mechanism. Materials with high thermal conductivity such as metals transfer significantly higher quantities of heat than materials with lower thermal conductivity such as wood. Attempts in reducing thermal bridge can be as simple as material substitutions: using wood stud versus metal stud or more complex insulation strategies. From a system stand point, highly conductive materials in contact with one another will increase the flow of energy; from indoors to outdoors (in cold climates) and in the opposite direction (in hot climates). It must also be noted that thermal bridging typically requires more consideration in cold climates. Some general guidelines can be considered in reducing thermal bridges by; separating highly thermal conductive materials with insulating materials, selecting less thermally conductive materials at the onset of the design, and reducing surface area in contact between highly conductive materials. Despite these general considerations, the issue of thermal bridging is almost always specific to localized areas and details. Sound building science principles, detailed design and development process, and past experience can aid in reducing localized thermal bridging and improved overall thermal performance of the system.

STRATEGIES TO REDUCE THERMAL BRIDGES

We will examine several strategies to minimizing thermal bridges at the following interfaces: roof-to-wall; steel stud construction, window-to-wall, wall-to-balcony slab; wall-to-wall; and sunshade-to-wall.

Roof-to-Wall Interface

Considerations for the roof-to-wall interface are for walls that occur below the roof as well as walls that rise up above the roof. For the most part, designers will consider the insulation strategy for the wall and the roof; however, the interface between the two is not typically thought through for thermal continuity. For example, a precast wall that forms a parapet that extends above the roof line. The insulation for the wall, if continuous inboard of interior steel stud framing for interior sheathing/wall finish systems, is not typically brought above the underside of the roof deck. This results in a parapet wall that is essentially a heat fin; the amount of effect the fin has is dependent on the amount of hold back from the underside of the roof deck and the thickness of the roof deck, as well as the climate the building is located within. The insulation for the roof may or may not carry up the backside of the parapet portion of the wall. (Figure 1 and 2)

A better means to accomplish the transition is to carry the insulation up between the precast and the roof deck and tie it into the roof insulation system, thus providing thermal continuity. (Figure 3) In cavity walls, insulation in the cavity that is continuous outboard of the wall framing system also requires continuity and needs to be brought up and over the parapet and tied into the roof insulation system. Care must be taken to coordinate with the installation of the air barrier and water management systems to ensure that these systems are not undermined by the insulation strategy. Some degree of thermal bridging may be unavoidable to ensure water and air tightness.

Where walls rise above the roof line such as a tiered building with patios (essentially roofs) or penthouses that may or may not need to be insulated, examination of the interfaces and how they are insulated and tied together thermally is essential. At some of these interfaces, overlapping insulation on opposite sides of an element may be needed. For example, insulation of the wall may be easier to tie in to the soffit than above the roof. If so, carrying insulation across the soffit two to three feet can reduce the effect of the thermal bridge. The minimizing of the bridge will help control localized heat gain and loss and can reduce the risk for condensation.

Steel Stud Construction

Although the effects of thermal bridging caused by steel stud construction when only insulating between studs have been researched and published (PHRC, 1999) and listed in one of the widest use energy standard references (ASHRAE 90.1), we continue to see widespread use of this wall construction type in the United States. Ironically, this includes many buildings that have been built using sustainable design principles. The phenomenon is relatively straight forward: steel is a highly conductive material and therefore requires thermal isolation from exterior conditions. A continuous thermal barrier using the full value of required insulation outboard of the studs is the preferred method to complete construction of this type of wall system to avoid the reduction in the overall thermal resistance of the wall due to the bridging. The location of the insulation will vary by wall type and climate and has to be evaluated for hygrothermal considerations to verify that the vapor permeance of the insulation product will not result in a misplaced vapor retarder. The thermal isolation has to occur at all parts of the wall, including the interface with doors and fenestration.

We have found that approximately 1-in. of continuous insulation that can be made air tight is the maximum thickness of insulation that can be accommodated with mass masonry walls in most climates. This is based on our experience with traditional mass masonry wall systems, when hygrothermal analysis and field evaluation indicate that freeze/thaw risk is minimal and an increased risk is minimal when adding a small amount of insulation to the walls. An uninsulated steel stud wall can then be built inboard of this with no insulation between the studs.

For brick, stone, metal panel, and similar cavity wall construction, the preference is for 2-in. of insulation in the cavity. If plastic (extruded and similar products) are used in the cavity, fire stops are still needed utilizing insulation such as mineral fiber (rock wool) that is intended for a wet environment at floor lines and window penetrations. Continuity of the thermal, water, and air barrier systems must be carefully coordinated, and the vapor permeance of the wall system examined, as the designer may be intending the lower vapor permeance of the insulation product to function as a vapor retarder Again, the stud wall is constructed inboard of the thermal barrier with no insulation between studs.

For precast and cast-in-place concrete walls where the concrete is directly exposed to the weather (i.e. not intended as part of a cavity wall system), continuous insulation is needed along the wall surface. Spray foam is usually the easiest to install; however, extruded polystyrene with spray foam installed at all joints and top and bottom of the wall is another good alternative as long as impaling pins are not used to hold the extruded in place; adhesives are the preferred method. If the insulation is not adhered to the precast and air flow occurs between the precast and the insulation that allows interior humid air to come in contact with the precast in any climate zone where the wall is under colder, typically winter, conditions, condensation can occur, and sometimes freezing. For this reason, mechanical attachment is not recommended.

In some wall systems, it is difficult and cost prohibitive to install the full insulation value outboard of the steel studs due to cavity size, cladding system loads, or other wall system considerations. In this case, local climate considerations need to be evaluated. At Sidwell School in Washington, DC, allowing for 2-in. of insulation was not feasible due to structural considerations for the walls open screen panel system. The maximum amount that could be accommodated was 1/2-in. As such, the combination of two-layers of sheathing (plywood and glass-mat insulation) sandwiching the insulation combined with 8-in. panel studs, and as much as possible, offset interior studs and a 1-in. air gap between studs with insulation between each stud bay allowed the wall to perform in a similar energy-efficient fashion for the local climate to a wall with 2-in. extruded outboard. Multiple evaluations of the wall type were completed to assess the risks versus cost.

Window-to-Wall Interface

In an insulated building, punched windows can contribute significantly to overall conductive heat losses through the building envelope. This is due to the nature of heat flow, which like many transport processes, naturally occurs along the path of least resistance. For a generic building wall (with an insulating value of approximately R-10), adding windows with a U-factor of 0.5 btu/h*ft2*F to 20% of the wall will reduce the overall insulating value of the system by nearly 45%. With such high contribution to overall heat transfer through opaque walls, it is important to design window-to-wall interfaces to avoid thermal bridging and excess heat loss, which can effectively degrade the “tested” performance of the window systems.

Thermally broken window systems are constructed so that the thermal break, typically a low conductivity plastic or urethane material, is aligned with the insulating glass units. This is to maintain a continuous line of insulation in the product and minimize heat flow around the insulating components in the window. Just as these thermal barriers are aligned, so too should the building thermal barrier be aligned with the windows.

Current architectural trends often favor a flush appearance on the building exterior, with windows and curtain walls “pushed out” so that the glass is flush with the surrounding facade. Unfortunately, this shifts the insulating glass and thermal breaks outboard of the building insulation and provides a pathway for heat flow around the window frames (Figure 4). In this case, the added heat loss (during winter conditions) and/or heat gain during warm weather is due to the offset reduces the overall insulating value of the window-to-wall interface by approximately 15%. As shown in Figure 5, aligning the windows with the building insulation maintains a relatively continuous line of insulation through the interface and prevents the excess heat flow associated with misalignment. Misalignment of the insulation and window systems is more of a problem where non-insulating cladding, such as brick veneer or precast concrete panels, is used. If exterior insulation and finishing systems (EIFS) or insulated metal panels are used, the insulating cladding can be aligned with the windows to maintain continuity. However, if recessed, rather than flush, windows are installed, the same problems with heat flow around the windows will exist (Figure 6).

Even if windows and curtain walls are properly aligned with the building insulation, highly conductive elements at opening perimeters can still lead to increase heat loss. Metal components such as clip or attachment angles, steel studs, and other structural members are significantly more conductive than thermally broken windows or thermal insulation materials. In the instance of blast-resistant construction, the use of heavy steel anchors and other typical construction methods to resist blast loads are commonly an issue from a thermal standpoint. As such, they provide a relatively easy path for heat flow around the insulating components of windows and curtain walls. In retrofit applications, insulating windows and curtain walls are often installed into existing openings. Uninsulated, solid masonry buildings or buildings with continuous steel support members around openings require careful attention when performing thermal upgrades, as these perimeter conditions can have a significant effect on the performance of new windows and curtain walls. This is one of the most common thermal bridges in buildings, and one of the most common reasons why installed windows in actual construction (as opposed to the laboratory window only mock-up) may not provide the same thermal performance as stated in test reports or experimental data. Laboratory testing of windows and other fenestration systems is performed with the component installed in an insulated panel, effectively limiting heat flow to the horizontal (i.e., perpendicular to the plane of the glass) direction. In real constructions, even with perimeter insulation, some heat flow will always occur perpendicular to the frame and increase the total heat flow through the component.

Figure 7 shows a generic thermally broken aluminum window frame (sill) in the “tested condition” with zero heat flow through the outside edge of the frame. Figure 8 shows the same window installed in a 3-wythe thick, uninsulated brick masonry wall. Although interior surface temperatures are similar between these two cases, installation in the brick masonry wall increases heat flow through the window frame by approximately 10%. In the extreme case, installation against a solid steel framing member (Figure 9), heat flow increases through the frame by over 20%. As previously discussed, any increase in heat loss through windows can have a significant impact on overall building heat loss, making careful design of window and curtain wall openings critical to overall building performance. The actual performance of window and curtain wall systems must be taken into account when calculating building loads, since, as described in this section, placement within the wall can cause performance to deviate significantly from the “tested” performance that most designers and mechanical engineers use in their calculations.

Wall-to-Balcony Slab Interface

At the wall-to-balcony slab interfaces on many apartment and condominium complexes built in the United States, the balcony is framed or built continuous with the interior floor. As such, the balcony passes through the thermal barrier and creates a “heat fin” to the exterior of the building. We will be using the example of a concrete balcony below. Depending on the climate, the continuous concrete may result in a heightened condensation risk. Regardless of climate, heat loss and gain can occur through this bridge.

There are two methods that can be used to eliminate or at best limit the effect of the bridge. The first is to construct the exterior and interior as separate elements with a thermal buffer. This can be accomplished by providing separate structure to build the balconies or using proprietary systems that are seeing use in Europe that are comprised of insulation and low conductance material post-tensioning cables that can tie the exterior structure to the interior structure without the typical thermal problems. (Figure 10 from WBDG).

The second method that can be utilized is careful use of insulation above and below the slab for a certain distance into the building to reduce the effect of the thermal bridge. This is not always feasible and can be affected by the interaction with the walls, the type of floors intended for use, and the ceiling system that is intended for the design.

This particular thermal bridge at balcony slabs is one that is commonly not dealt with because of the difficulty in accomplishing a solution within the structural constraints.

Wall-to-Wall Interface

Wall-to-wall interfaces that result in thermal bridges commonly occur when different wall types intersect. We provide an example below for a cavity wall to precast wall interface.

In these circumstances, lapping of the insulation beyond the plane of the wall is necessary. For a precast wall to stone or brick cavity wall interface where the stone or brick is exterior insulated, insulation for the precast wall along the interior needs to be carried beyond the end of the precast to isolate the interface. The amount of distance that the insulation is required to carry beyond depends on climate and intended interior conditions. In addition, air sealing considerations are necessary to ensure that the insulation is not compromised. Difficulties may arise at floor lines; however, fire stop and the insulation installed typically for these systems will usually provide the required continuity. Only through 2 and 3-dimensional analysis and field verification can this transition’s thermal bridge be properly evaluated. The use of localized additional insulation and overlapping of exterior and interior insulation or insulation in different planes of the wall is necessary to maintain the thermal barrier’s intent of continuity, even if the barrier is not physically continuous.

In many retrofit projects, and in particular, modern type construction added to historic projects, modifying insulation strategies between wall types is not always feasible.

Sunshade-to-Wall Interface

Exterior sunshades are a feature that has gained popularity on commercial buildings, largely driven by the green building movement. The use of properly designed shading devices can help reduce energy costs related to solar heat gain. However, the structural attachment of the shades, which can be substantial components, typically results in a thermal bridge. When installing sun shades, lapping of insulation at the shade anchor is necessary to eliminate or limit the effect of the thermal bridge. When combined with light shelves on the interior, many designers simply connect the light shelf to the sun shade, which results in making the thermal bridge at the anchor worse. Separation of these two elements by independently anchoring them to different framing and then isolating them using lapped insulation is the only effective way to eliminate or limit the bridge. At Sidwell School, this was accomplished by anchoring sun shades to the panel system’s steel stud framing and light shelves to inner wall system framing and providing insulation separation between the two. Figure 11 shows the wall where only a sun shade was installed.

1.7 Conclusions

As can be seen from the various examples discussed in this paper, several principles need to be followed in order to significantly reduce thermal bridging. These principles are:

- A continuous thermal barrier is needed in the building enclosure; the location of this barrier for most buildings should be outboard of highly conductive materials.
- Reduction and elimination of potential and actual thermal bridges are needed.
- Lapping of insulation where direct continuity is not possible can mitigate thermal bridges.
- Window-to-wall interfaces create additional challenges that need to be carefully reviewed for energy considerations and condensation risk due to positioning of the fenestration within the rest of the assembly.
- Reducing and limiting thermal bridging in buildings will typically reduce energy needs for the building.

Only through careful design and evaluation can thermal bridging be dealt with on any construction project.

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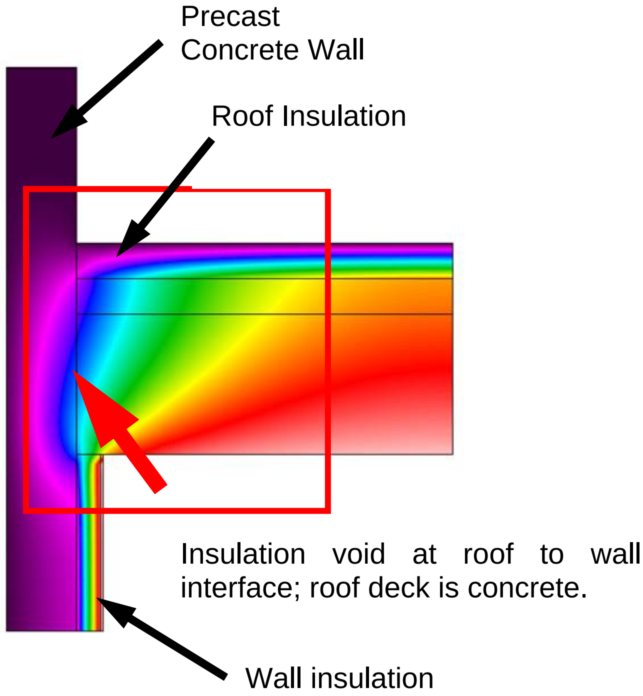
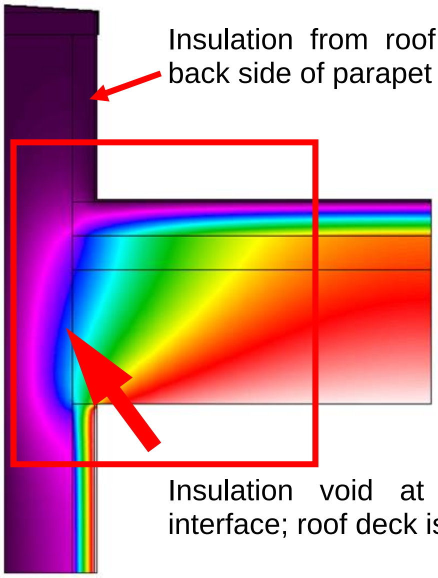


Figure 1

Results of a THERM model showing a thermal bridge at the roof to wall interface of a precast wall where roof insulation is not tied to wall insulation.

$T_{interior}$ = 72°F
$T_{exterior}$ = 7°F



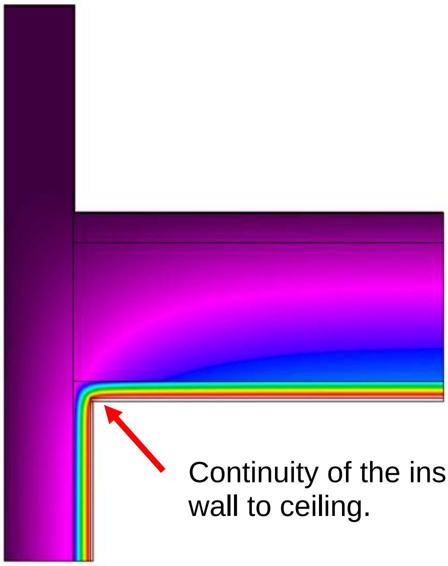
Insulation from roof is carried up back side of parapet wall.

Insulation void at roof to wall interface; roof deck is concrete.

Figure 2

Results of a THERM model showing a thermal bridge at the roof to wall interface of a precast wall where roof insulation is not tied to wall insulation; although insulation now carries up the backside of the parapet wall, there is still no major effect on the bridge.

$T_{interior}$ = 72°F
$T_{exterior}$ = 7°F



Continuity of the insulation from the wall to ceiling.

Figure 3

Results of a THERM model shows continuity of insulation below the roof deck; another option not shown here is to carry the wall insulation up by the roof deck and tie it into the roof insulation; structural considerations must be evaluated for this option. Window head below either option also requires careful evaluation.

$T_{interior}$ = 72°F
$T_{exterior}$ = 7°F

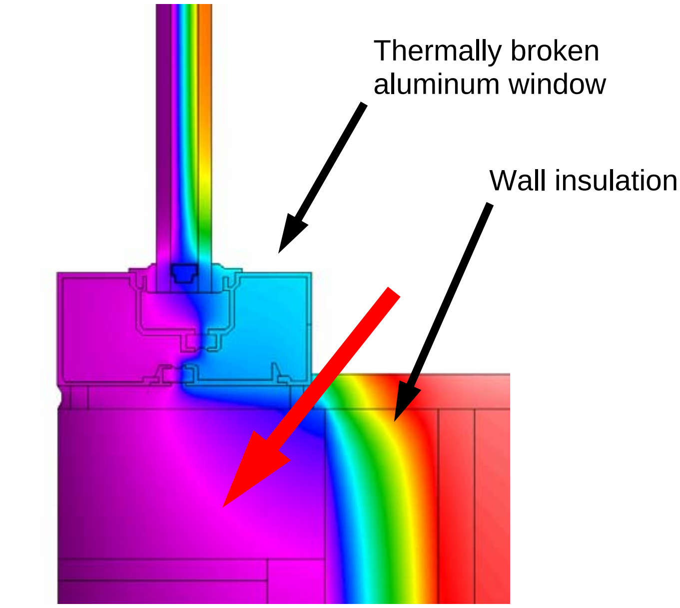


Figure 4

THERM model results showing heat flow path between insulation and window frame (red arrow)

$T_{interior}$ = 70°F
$T_{exterior}$ = 0°F

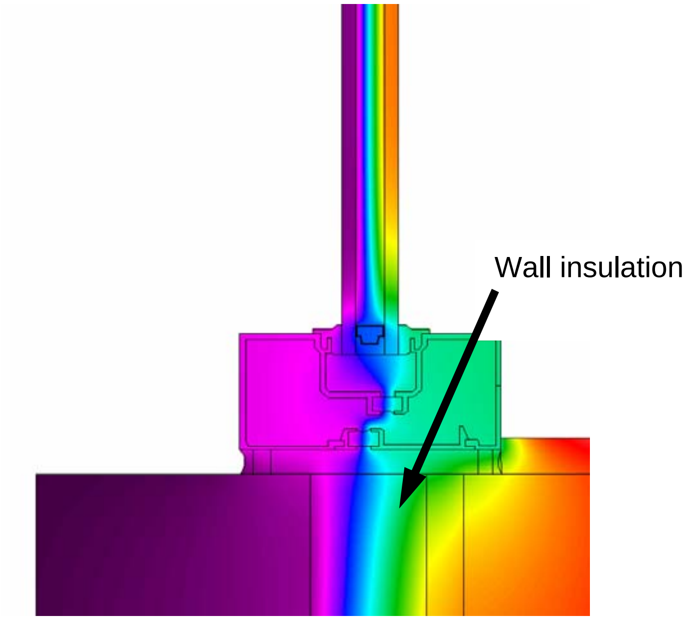


Figure 5

Alignment of the window with the wall insulation provides better continuity between insulating components and lowers heat loss at the window perimeter

$T_{interior}$ = 70°F
$T_{exterior}$ = 0°F

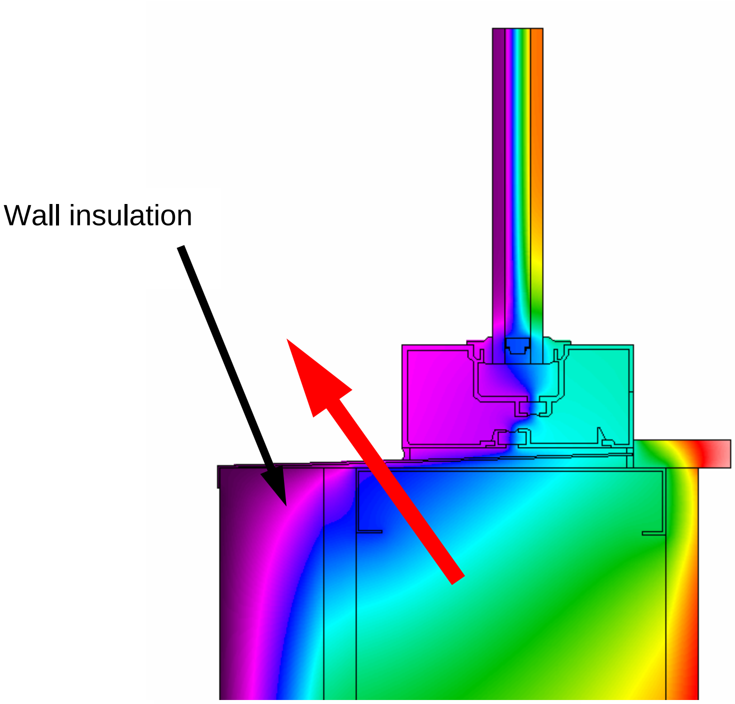


Figure 6

Recessed window in exterior-insulated wall system exhibits similar heat loss (red arrow) at window perimeter to window in Figure 4.

$T_{interior}$ = 70°F
$T_{exterior}$ = 0°F

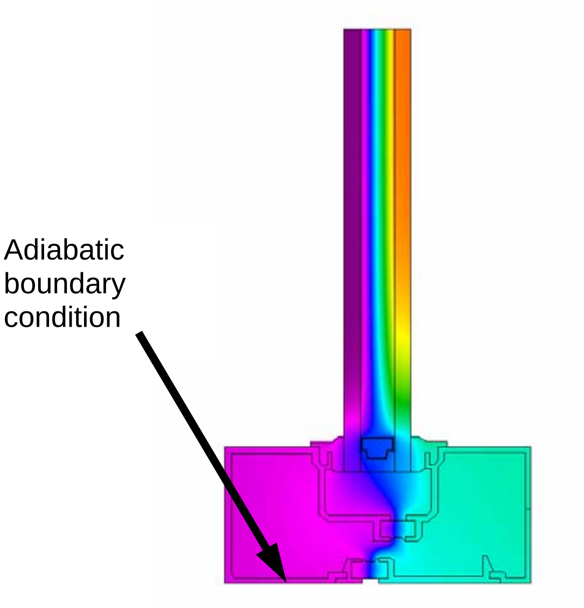


Figure 7

Model of window system only in “tested” condition, with adiabatic boundary condition at perimeter.

$T_{interior}$ = 70°F
$T_{exterior}$ = 0°F

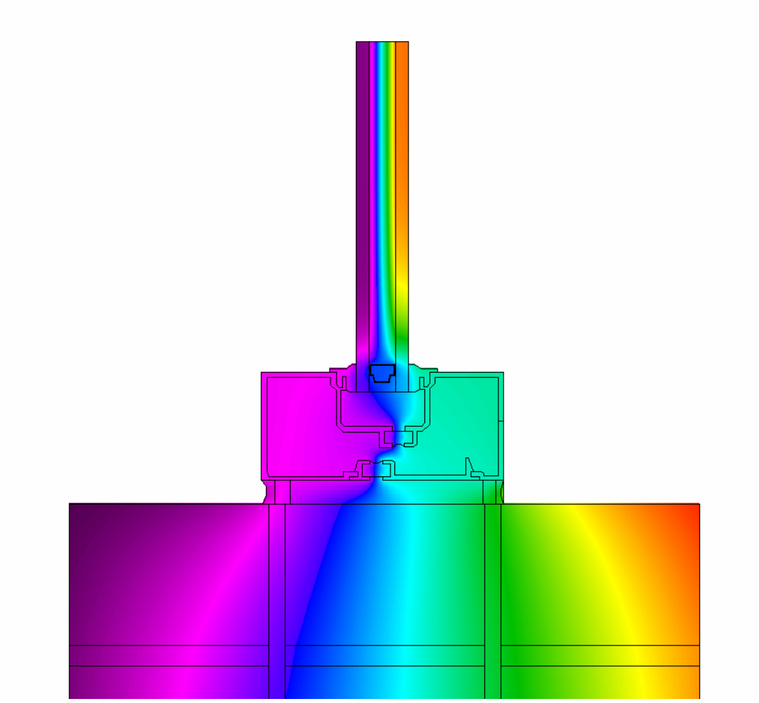


Figure 8

Model of window shown in Figure 7, installed in uninsulated brick masonry wall opening. Heat loss through window perimeter increases by approximately 10%.

$T_{interior}$ = 70°F
$T_{exterior}$ = 0°F

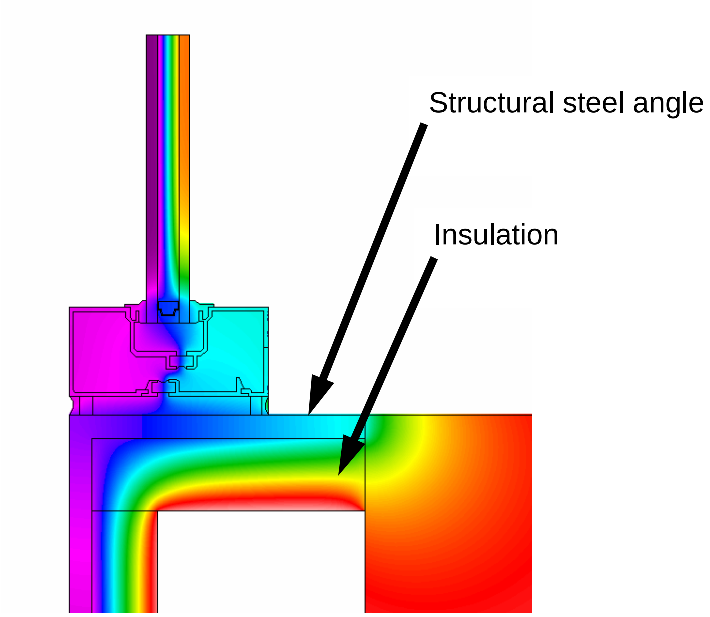
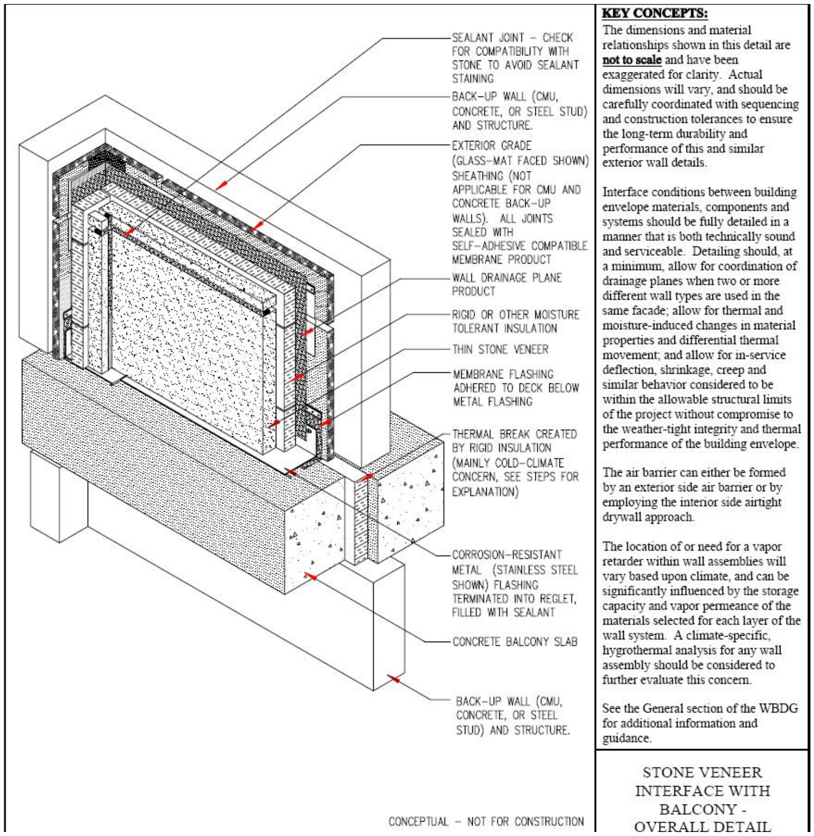


Figure 9

Model of window shown in Figure 7, installed over solid structural steel angle. Heat loss through window perimeter increases by approximately 20%.

$T_{interior}$ = 70°F
$T_{exterior}$ = 0°F



KEY CONCEPTS:

The dimensions and material relationships shown in this detail are **not to scale** and have been exaggerated for clarity. Actual dimensions will vary, and should be carefully coordinated with sequencing and construction tolerances to ensure the long-term durability and performance of this and similar exterior wall details.

Interface conditions between building envelope materials, components and systems should be fully detailed in a manner that is both technically sound and serviceable. Detailing should, at a minimum, allow for coordination of drainage planes when two or more different wall types are used in the same facade; allow for thermal and moisture-induced changes in material properties and differential thermal movement; and allow for in-service deflection, shrinkage, creep and similar behavior considered to be within the allowable structural limits of the project without compromise to the weather-tight integrity and thermal performance of the building envelope.

The air barrier can either be formed by an exterior side air barrier or by employing the interior side airtight drywall approach.

The location of or need for a vapor retarder within wall assemblies will vary based upon climate, and can be significantly influenced by the storage capacity and vapor permeance of the materials selected for each layer of the wall system. A climate-specific, hygrothermal analysis for any wall assembly should be considered to further evaluate this concern.

See the General section of the WBDG for additional information and guidance.

STONE VENEER
INTERFACE WITH
BALCONY -
OVERALL DETAIL

Figure 10

Balcony Slab detail from the WBDG showing concept of a thermal break at balcony slabs; structural elements are shown in step-by-step details available through the guide.

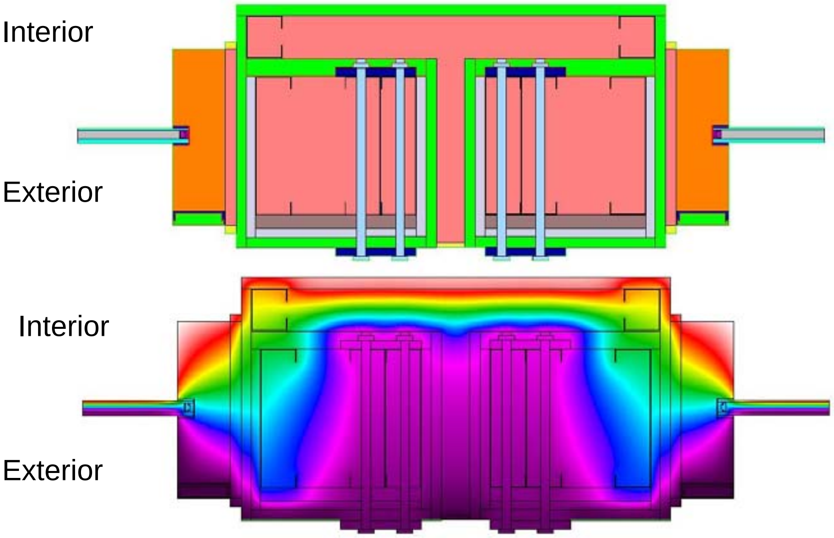


Figure 11

Sunshade evaluation at Sidwell School in Washington, DC. There is minimal effect due to thermal bridging due to the insulation strategies used.