

---

# Modeling and Design Approach for Treatment of Highly Thermally Conductive Architectural Elements in High Performance Buildings in Mixed Climates

Peter W. Coats

## ABSTRACT

*Contemporary Architecture often incorporates building envelope components made of highly thermally conductive materials. These components range from light gauge steel framing in the field of walls and roof parapets to metal awning supports and flashing. The effects of these conductive components on adjacent building materials, and the thermal performance of the building, is often overlooked or discounted in the design process, particularly in mixed climates.*

*This is particularly problematic in high-performance buildings such as museums and hospitals where humidity control systems coupled with the air-moisture contributions of occupants can produce interior relative humidity levels ranging from 40% to 60%. In mixed climates, while the exterior climate is mild, evidence shows that the thermal bridges can be detrimental to the long-term performance of the wall.*

*This article discusses the overall lack of design consideration in mixed climates and describes an appropriate design approach to address these issues using heat transfer simulation modeling. We present projects on which our firm has worked for the purpose of illustrating the basic concepts of the design approach. In addition, we discuss considerations in obtaining climate, surface film coefficients and material data for the purpose of modeling thermal bridges.*

---

## INTRODUCTION

Contemporary Architecture has grown, over the past few decades, to involve highly irregular geometries. Exposed steel structure, long cantilevered awnings, and towering decorative roof parapet walls now appear regularly in signature buildings as well as in standard construction. These changes in architecture have created a need for greater amounts of steel in the substructure of these buildings. This architectural boldness has also carried over to the building envelope, where it is now common to see claddings made of aluminum, copper, titanium or any number of other metals. Further, municipal fire codes have eliminated the option of wood framing in favor of steel framing in many cases for reasons of life safety. These and many other phenomena have led to an overall shift in construction to the usage of much more thermally conductive building materials in all facets of a typical building; conductive materials which can serve as “thermal bridges” bypassing thermal

insulation layers and creating a ready path for rapid heat transfer into and out of the building.

Thermal bridges create a challenge for design professionals as they can reduce the effectiveness of interior climate systems as well as increase the potential for condensation at unintended locations in a building. Figure 1 for example shows the window frame of a museum in Washington DC acting as a thermal bridge leading to condensation on interior surfaces because exterior temperatures are below the interior dew point temperature. It has become common in cold weather climates to manage thermal bridges or avoid them all together. Thermal breaks in window frames, for example, are almost universal in extreme climates where owners must avoid the possibility of condensation or frost developing on their interior finishes. In many other cases, professionals designing in cold weather climates have begun to make a concentrated effort to avoid any and all thermal bridges.

---

*Peter Coats is a senior engineer at Simpson, Gumpertz & Heger, Inc., San Francisco, CA.*



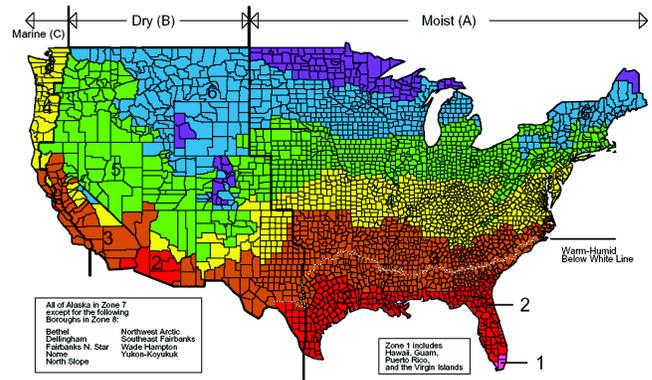
**Figure 1** Window frame of new museum in Washington DC.

However, regions where the effects of thermal bridges are easily overlooked are in mixed climates where exterior temperatures do not reach the high or low levels to make the effects of thermal bridging obvious. Design professionals and builders in mixed climates feel less restricted in using conductive materials through the thermal insulation of the walls without regard to how they will perform. Typically, these building components do not have a significant thermal effect on the building. Although, as the interior conditions are designed for higher humidity and/or temperature levels such as in museums, hospitals and other high performance buildings, the effects of these thermal bridges will manifest. It is also in these cases that it is not a feasible option to simply eliminate these thermally conductive materials. Thus, they are better managed by implementing a series of changes to thermal insulation, vapor barriers, material types and geometries and finally the interior climate system.

This paper presents an overall approach to handling these thermal bridges in mixed climates. First, we discuss some common examples of overlooked thermal bridges and ways to identify them. Then, we discuss the various ways to model these conditions including the most important properties to consider. Finally, we discuss effective management techniques to alleviate the effects of these thermal bridges.

## DEFINING CHARACTERISTICS

Though thermal bridges present problems in a variety of building types and site locations, the focus of this paper is to address the way that thermal bridges affect buildings with high relative humidity (RH) levels in mixed climates. For this reason, it is appropriate to further discuss what is meant by a mixed climate as well as what types of buildings would expect to have high RH levels.



**Figure 2** DOE 2003 Climate Zone Map (Briggs 2002).

## Mixed Climate

There is a variety of classifications for the different climate zones, many of which are broad. The Department of Energy has developed a climate zone map that is shown in Figure 2 (Briggs 2002). For the purpose of this paper we have focused on regions 3 and 4 as the mixed climate zone.

More generally, the projects that we describe in this paper are located in regions that experience temperatures cold enough to be of concern for periods of time throughout the year as well as temperatures warm enough to be of concern at other times of the year. These regions do not experience either temperature extreme for such an extended period that a designer may use a single design solution throughout the entire region.

## Specialty Buildings

We use the term high performance building to categorize a building that has been designed to have a controlled interior climate, usually leading to a high interior RH. Some examples of high performance buildings include libraries and museums where the interior air is humidified and stabilized for the purpose of preserving delicate contents. In many cases hospitals are held to particular interior conditions to help occupants feel comfortable and to maintain a state of cleanliness.

## Types of Thermal Bridges

Thermal bridges can range from common building components such as metal framing to less common building components such as structural supports for cantilevered architectural features, through-wall flashing, or custom outward finned window extrusions. In any case, they involve highly thermally conductive materials which has the thermal effect of bypassing the thermal insulation layer of the wall. This may or may not mean that the conductive material physically

bypasses the thermal insulation. It may also mean that the thermal conductance of the building component is so great that it negates the affect of the adjacent thermal insulation. Further, a thermal bridge may be a single building component or a combination of various thermally conductive components that are near each other, which create a combined effect of rapidly transferring heat into and out of the building.

Throughout the rest of this paper, it is assumed that the concern for potential thermal bridges is interior moisture condensing on interior wall surfaces. In cases where there is a concern that exterior moisture will condense on exterior wall surfaces, the same assembly is assessed similarly in reverse. This process is not discussed in this paper.

For the purpose of illustrating our analysis and design approach, we present two thermal bridges that we have studied in past projects. In each of these details, we have identified the effective vapor retarder as the series of material surfaces that create the combined effect of a continuous vapor retarder. We will refer to these two examples through the remainder of this paper.

**Case 1:** The first is a window head detail at a new museum in St. Louis, MO. This detail can be seen in Figure 3. The detail shows a CMU header supported by a carbon steel angle inboard of a layer of rigid insulation within an airspace and a single wythe of stone veneer supported by a smaller carbon steel angle. There is also a sheet metal head flashing shown over the top of the window. The interior gypsum is sealed, thus reducing some of the interior air moisture. We consider the effective vapor retarder along the back of the window frame, along the inside of the steel angle and into the CMU wall. The vapor retarding effect of a single wythe of CMU is highly variable. The effective vapor retarder is indicated by the bold line in Figure 3. The thermal bridge that made this detail suspect is the combination of the large steel header angle, the steel angle supporting the veneer and aluminum window frame as a possible thermal bridge.

**Case 2:** The other detail is a concrete roof parapet wall of a hospital in Santa Clara, CA. This detail is shown in Figure 4 and shows a steel/concrete composite deck separated by a firestop and minimal insulation from a curtain wall which has fins at the horizontal mullions and a composite aluminum coping extrusion. The effective vapor retarder follows along the steel deck and carries across the bottom of the firestop. This is also indicated by the bold line. The thermal bridge that has made this detail suspect is the combination of the steel decking, the curtain wall and aluminum coping as a possible thermal bridge.

## MODELING

After the suspect thermal bridges have been identified, it is necessary to simulate performance of the details under expected conditions. We use a variety of software applications to do this. The two viable software applications are THERM, Finite Element Simulator, Version 5.2 from Lawrence Berkeley National Laboratory and HEAT 3 Version 4.0.0.2 by the Build-

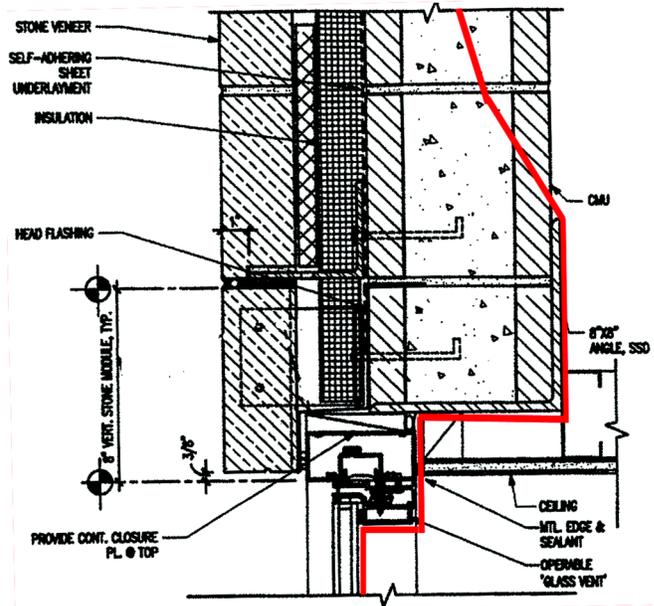


Figure 3 Head at operable window.

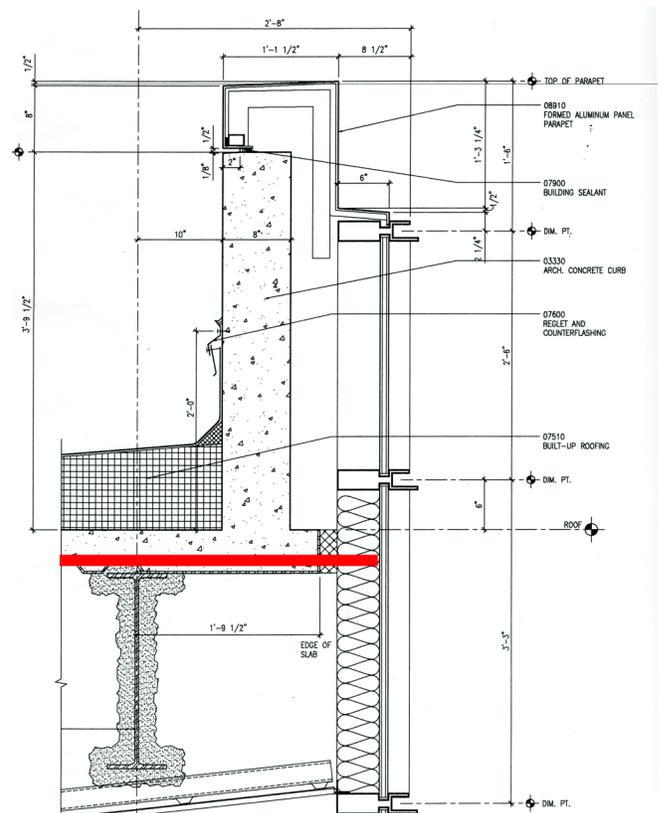


Figure 4 Roof parapet at curtain wall.

ing Technology Group of Massachusetts Institute of Technology (MIT). The overall approach to the thermal bridges does not change between the two software applications, although there is typically a significant difference in how the results are presented. The two examples that are shown have been analyzed

using THERM. The software has a straightforward interface and provides for expedient model production where modeling in three dimensions is not necessary.

Regardless of the software application used, we must collect information about the climate of the site location, the mechanical system of the building, and properties of the materials used in the details.

## Climate

The two inputs that are typically necessary for the models with regards to exterior boundary conditions are temperature and surface film coefficient. It is generally suitable to assume exterior temperatures to be the ASHRAE 99.6% heating dry bulb design threshold temperature for the nearest given site location (ASHRAE 2005). In some cases such as when the site location is a significant distance from the location provided in Table 1 in Chapter 27 of the ASHRAE Handbook, this design threshold is not adequate. In such a case, it is prudent to research historic climate data collected from a weather station location closer to actual site location and then make proper adjustments based on the location of the component. For Case 1, historic data for the St. Louis area indicated low temperature of 5 °F whereas the ASHRAE Handbook suggested a temperature of 37°F for San Francisco Airport; the nearest listed location to the job site.

The surface film coefficient is a product of various factors, namely the emittance of the material and the air velocity over the surface. Using design wind data for the site for the exterior boundary condition and the emittance for the subject material, the exterior surface film coefficient can be found using Tables 1 and 3 in Chapter 25 of the ASHRAE Handbook. Since this value is based on physical attributes and exposures each individual material, they vary throughout the perimeter both cases.

## Mechanical System

In preparing the heat transfer model, it is also necessary to obtain information about the interior climate so that the boundary conditions for the interior side of the model will be accurate. A discussion with the project mechanical engineer and a review of the project mechanical construction documents is typically enough to determine what the dew point temperature and temperatures of the interior air will likely be. It is also important to determine what the general air velocity where the detail occurs for the purpose of calculating the surface film coefficient. With this information, in the same manner as is discussed in the Climate section above for the exterior surface film coefficient, the interior surface film coefficient can be determined.

## Material Properties

Most common building materials are included in the software application databases. However, in cases where a building component that is located near or along the suspected

thermal bridge is not provided in the material database it is necessary to obtain this information from an outside source. In Case 2 for example, we obtained information related to the thermal conductivity and emittance of the polyethylene/aluminum composite coping from the product manufacturer.

## MODEL CONSIDERATIONS AND INTERPRETATION

Once the model is drawn with the correct material properties applied to each component, the boundary conditions are set in accordance with the climate data, and the calculations have been run, it is helpful to identify the isotherm for the interior air dew point. An isotherm is a line of constant temperature through a body. Figures 5 and 6 show the two cases including their isotherms for the interior dew point temperatures. The two figures show the interior dew point isotherm passing inbound of the effective vapor retarder. This is a graphic indication that there is some potential for condensation along the surface where the interior dew point isotherm passes inbound of the effective vapor barrier.

Each of these Cases has a critical path of thermal bridging. The critical path of thermal bridging is the primary path that the heat takes in transferring from one side of the assembly to the other. It serves as the true thermal bridge since it is at the location in the assembly where a substantially greater amount of heat flux occurs than the rest of the assembly. It is important to identify this critical path to eliminate the potential for condensation. It can also help in identifying specific conductive materials that are problematic. Some software applications have functions, which show the paths of heat flux throughout an assembly. Alternatively, one can get a general idea of where the critical path of thermal bridging is located by observing where the isotherms for the model dip either inward or outward. In Figures 5 and 6 a generalized critical path of thermal bridging is illustrated by an arrow in the direction of heat transfer.

The basic intent from this point is to make alterations in each of the models so as to shift the interior dew point isotherm outboard of the effective vapor retarder, thus eliminating the condensation potential. There are a number of alterations that the designer may make that will achieve this. The options that the designer has are as follows: shift insulation, shift the effective vapor retarder, change component geometry, change component material and shift component location. This is the general order of ease in which the alterations may be performed though this order may be different for each project. Each alteration is discussed below.

## Insulation Location

Perhaps the easiest and most cost effective method for eliminating the potential for surface condensation is installing insulation at strategic locations in the assembly. This can isolate the highly conductive materials from the cool exterior temperatures. This is typically a straightforward practice of installing insulation in airspaces either flanking the critical

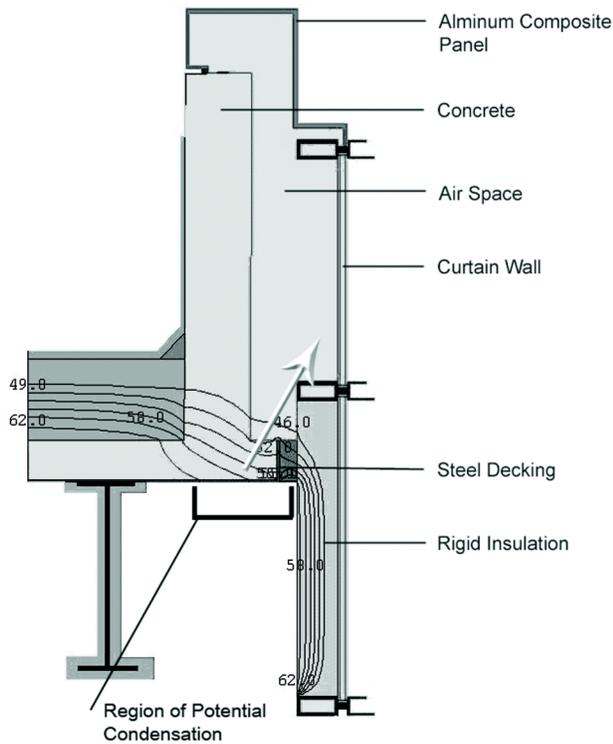


Figure 5 Case 2, including interior dew point isotherm.

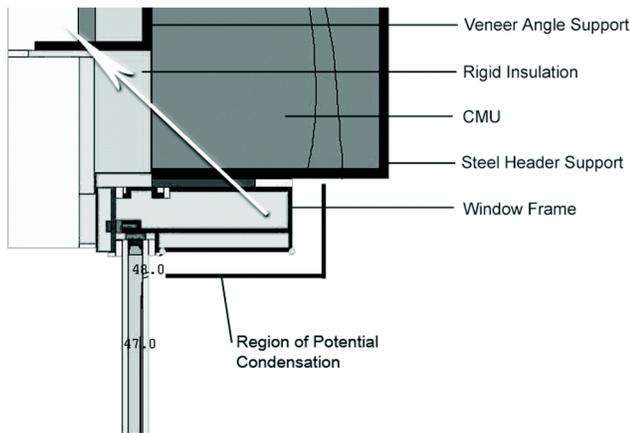


Figure 6 Case 1, including interior dew point temperature.

paths of thermal bridging, or better breaking them by installing insulation along the critical path of thermal bridging.

In Case 2, we have identified the critical path of thermal bridging as including the upturned portion of the steel deck. By installing a block of thermal insulation directly above the edge of the upturned leg, we have created a thermal break. By running the calculation for this assembly, we see that this has eliminated the potential for condensation along the underside

of the steel deck by shifting the isotherm outboard of the effective vapor retarder. This is shown in Figure 7.

Similar attempts do not appear to have a significant affect on Case 1. Thus, it is necessary to explore other possible alterations.

### Effective Vapor Retarder Location

Another relatively non-disruptive alteration that can be made to eliminate the potential for surface condensation is to move the effective vapor retarder inboard of the interior dew point isotherm. Ways that this can be achieved vary greatly based on the types of materials involved in creating the effective vapor retarder.

In Case 1, it may be possible to make the ceiling a vapor retarder by detailing all joints with sealant and installing plastic sheeting above the drywall. Although, such a system may be less desirable than seeking another alteration because it is labor intensive and prone to installer error.

In Case 2, should the addition of insulation not have been effective, we may have attempted to install a vapor impermeable foam insulation under the outer edge of the steel decking. This would have had the effect of pulling the isotherms inward. However, since the foam is vapor impermeable, the effective vapor retarder would now be lower, inboard of the dew point isotherm.

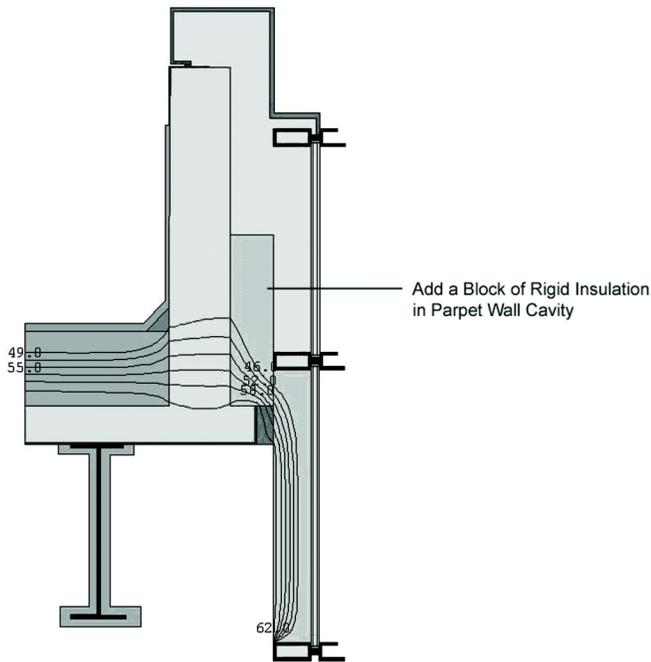
### Component Geometry

If less disruptive alterations prove ineffective, it may become necessary to change the geometry of particular components of the assembly. For highly conductive materials located along the critical path of thermal bridging, this is done by increasing the surface area of the conductive material on the warm side of the assembly or decreasing the surface area of the thermally conductive material on the cold side of the assembly. The division between the warm and cold sides of the assembly may be assumed as the interior dew point isotherm prior to the alteration.

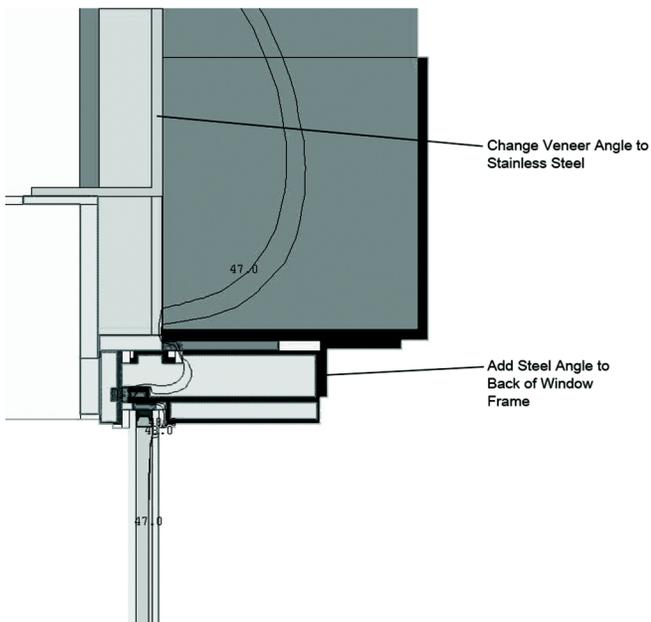
In Case 1, we have modeled an additional angle profile made of highly conductive carbon steel to the backside of the steel angle supporting the CMU header so that there is additional surface area of the highly conductive material exposed to the warmer interior temperatures. This is shown in Figure 8.

### Component Material

Another somewhat disruptive alteration option is changing the materials of particular elements in the assembly. This entails finding the critical path of thermal bridging and changing the materials on the warm side of the assembly to more conductive materials and elements on the cold side of the assembly to less conductive materials. One difficulty that is presented in this alteration is selecting a material that is as conductive as is necessary, yet has all of the physical proper-



**Figure 7** Case 2 with insulation installed above the upturned edge of steel decking.



**Figure 8** Case 1 with an additional carbon steel angle installed against the existing angle header and the veneer support changed to stainless steel.

ties necessary to prevent other adverse effects such as structural failure or poor weathering qualities.

In Case 1, in addition to changing component geometry, we changed the material of the carbon steel veneer support

angle to stainless steel because stainless steel is less conductive than carbon steel. It was necessary to have the project Structural Engineer review this change. The combination of the two alterations was effective in shifting the dew point isotherm outboard of the effective vapor retarder.

### Component Location

The final alteration option available before drastically affecting the detail by removing the thermal bridge or changing the mechanical system is to change the location of particular elements in the assembly. This entails shifting highly conductive materials inward toward the warm side of the assembly or shifting less conductive materials outward toward the cold side of the assembly. This alteration has the same effect as changing the geometry of components by increasing the surface area of conductive materials on the warm side of the assembly.

Were it is feasible to do so, we could attempt to shift the steel angle supporting the CMU header inward.

### SUMMARY AND DISCUSSION

In order to fulfill architectural and economic requirements, contemporary Architecture continues to include many forms of thermal bridges as highly conductive materials bypass the thermal insulation systems of building walls. Thermal bridges both reduces the effectiveness of interior climate control systems and presents a potential for condensation at unintended locations in the wall. These thermal bridges are easily overlooked in mixed climates, and it is often not feasible to simply eliminate them. Instead, design professionals can mitigate the effect of these thermal bridges through implementing one or various alterations to the subject drawing details.

In order to assess what alterations to a suspect building detail are necessary, the assembly can be modeled using one of a number of steady state two or three dimensional heat transfer software applications such as THERM or Heat 3D. Using these software applications for this purpose requires an understanding of the climate at the building site, the nature of the interior climate control system and thermal attributes of the materials involved in the assembly.

Once the suspect assembly has been modeled, the interior dew point isotherm, the effective vapor retarder and the critical path of thermal bridging should be identified. It is then possible to graphically observe whether there is a potential for condensation by determining if the interior dew point isotherm passes inboard of the effective vapor barrier. If it is confirmed that assembly has a thermal bridge, it is then possible to input alterations to the model that will reduce this potential for condensation. The alteration options available to the design professional, short of completely eliminating the thermal bridge or changing the mechanical system, are as follows; Shift or add insulation, shift the effective vapor retarder, change the geometry of conductive components, change the

material of components and move components. The design professional should choose the easiest to implement and most economically feasible alteration option to model first. Once the alteration or series of alterations is shown to shift the isotherm outboard of the effective vapor barrier, the potential for condensation at this location will be reduced.

## REFERENCES

- ASHRAE. 2005. *2005 ASHRAE Handbook-Fundamentals*, Atlanta: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.
- Briggs, R.S, R.G. Lucas, Z.T. Taylor 2003. *Climate Classification for Building Energy Codes and Standards*