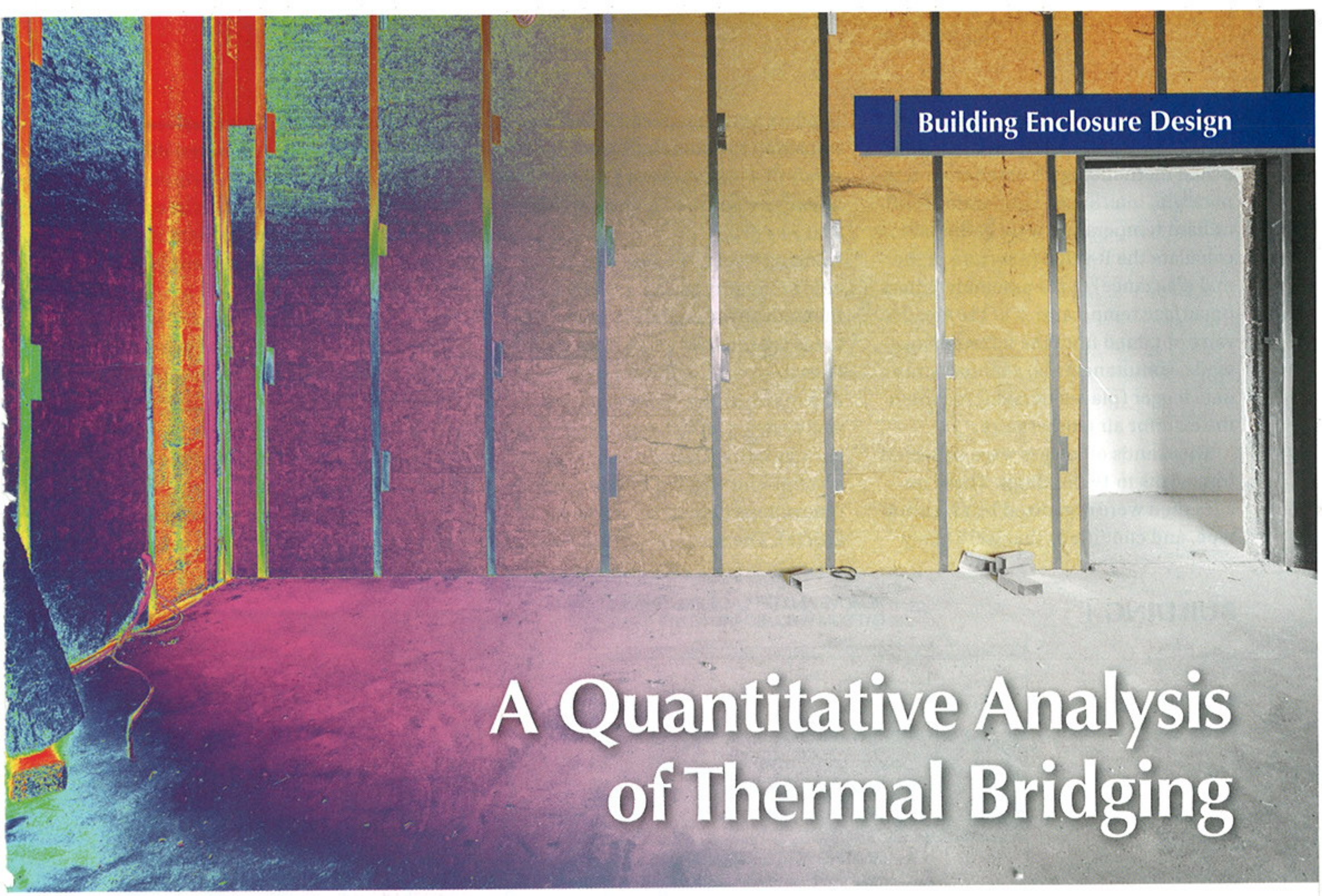

A Quantitative Analysis of Thermal Bridging

By Andrea Love, AIA, LEED AP and Charles S. Klee, AIA, LEED AP

Thermal bridging in building construction is a well-understood phenomenon, resulting most frequently from structural elements made of high-conduction materials that penetrate through insulation layers and create a path for largely unimpeded heat transfer. (Anecdotal reports suggest that thermal bridges in conventional construction may reduce insulation effectiveness by as much as 40 percent.[1]) Although the construction industry has begun to develop materials and assemblies intended to mitigate this effect, there is little available research documenting the extent of the problem or the performance benefit that may result from the use of these new products or techniques.

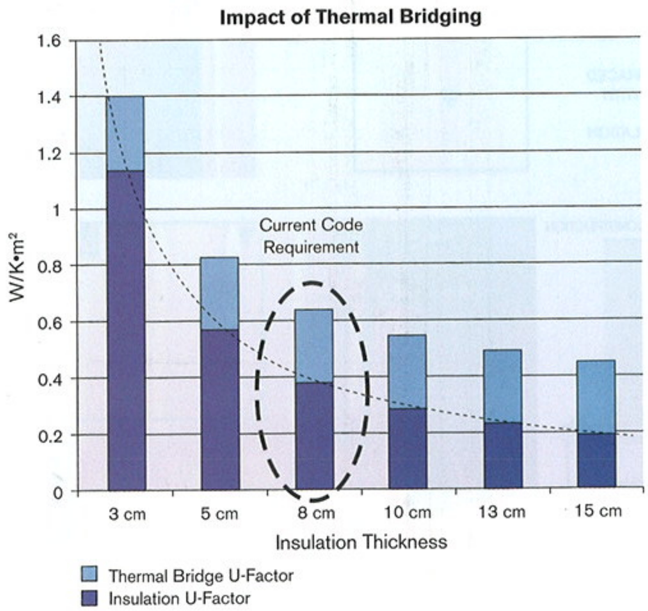

Figure 1: This thermal bridging diagram shows the U-factor (measure of heat loss) in a building as insulation increases.

Part of a research initiative by architecture firm Payette is to bring more substantiated data to the investigation of thermal bridges in commercial construction. By using thermal imaging equipment to quantify actual performance of built installations, the results can be used to suggest—then analyze—performance improvements. Presently, preliminary results of the study imply that it is possible to affect 50-percent or greater reductions in the impact of common thermal bridges by using careful detailing and readily available products.

Methodology of the Research

In order to understand how façades performed in the field, a thermal imaging camera was used to identify sources of thermal bridges in recently completed projects. Two-person teams were deployed to locate and document a range of façades and conditions.

Equipped with floor plans, elevations and a thermal imaging camera, the researchers located areas of increased

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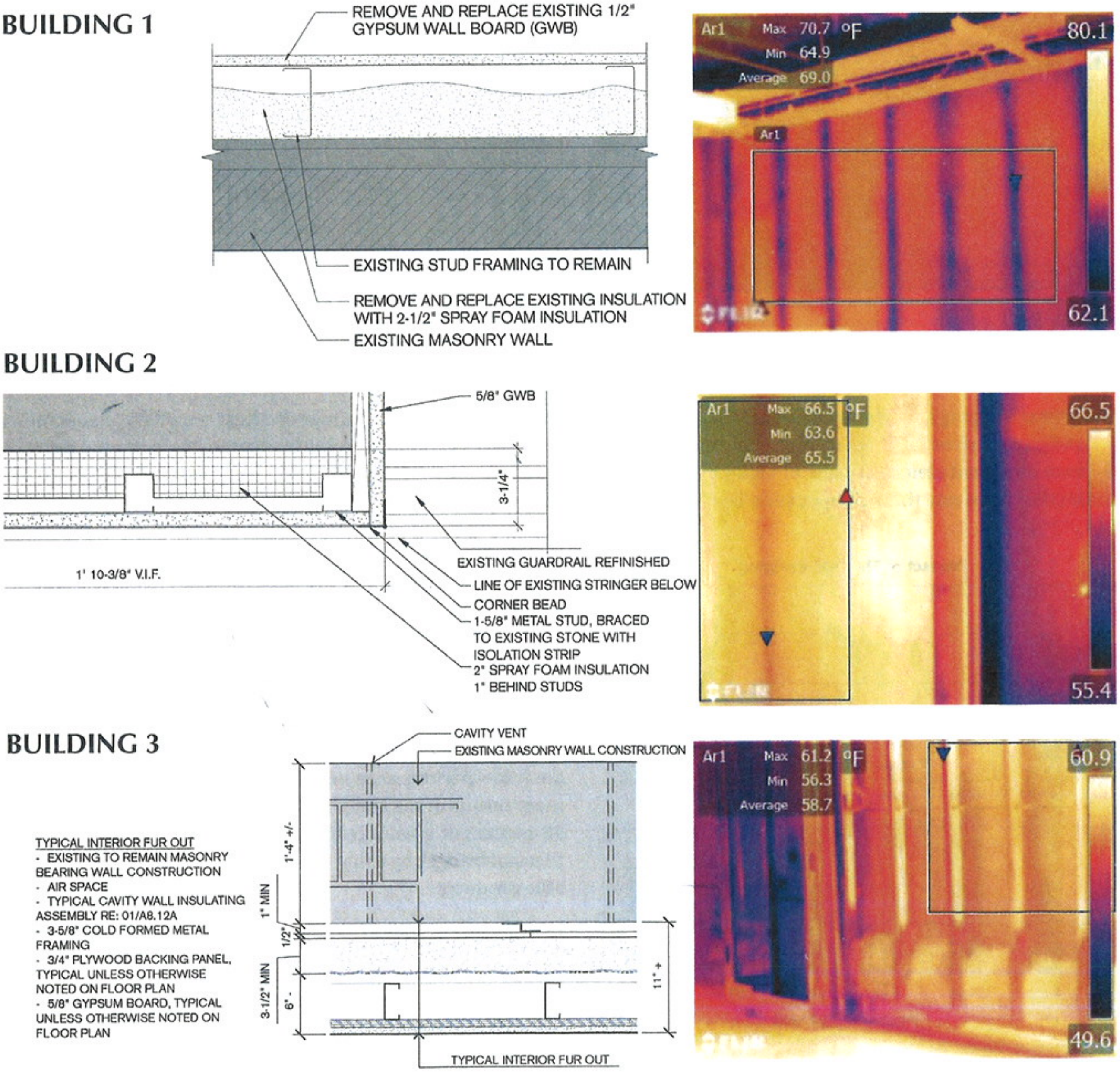
heat loss in these building enclosures. Using the data from a formerly published methodology[2], exterior air temperature, interior air temperature and radiant temperature were gathered to calculate the R-value (measure of thermal resistance) of the assembly. Interior surface temperatures of the façades were obtained from the infrared image, while, simultaneously, a temperature data logger (placed outside) recorded the exterior air temperature.

Thousands of images were collected from visits to 16 buildings. These images then were organized by assembly type, and conditions that were likely to affect performance (such as the transition to a foundation wall or adjacency of a window) were noted. Having already established a library of data that was primarily focused on thermal bridging issues, the research team was able to identify typical problem areas thematically. Generally, these problem areas fall into two categories. One relates to structure that supports façade and roof systems, including masonry wall systems, metal panel wall systems, curtain wall systems, rainscreen wall systems and existing building façade renovations (which is the focus of this article). The second concerns material transitions, such as those between new and existing façades, between different wall systems, between windows and walls, foundation to walls, roof to walls, roof parapets or penetrations, soffits, seismic and movement joints and louver openings.

Alternative designs were studied, using such software as the Lawrence Berkley National Laboratory's THERM (a 2-dimensional building heat-transfer program). Payette researchers prepared THERM models of the areas being studied, which then were calibrated to the performance measured in the field with the thermal imaging



Payette surveyed the renovation of three existing buildings using spray-applied, closed cell polyurethane foam insulation. Thermal imaging helped researchers determine that adding more insulation to further improve the thermal performance of façades sometimes can result in a diminishing return.

camera. Because neither the technique used for R-value calculations nor the camera are without error, the process of calibrating the simulations with the thermal images allowed the team to ensure that the models were reasonably accurate representations of field observations.

Currently, the research team is testing the quantitative impacts of potential design improvements using the THERM model to represent field observations. Working from both the graphical and quantitative output from THERM, the research team then will be able to strategically probe the model to identify the significant heat-transfer elements within a given detail—and predict the performance improvements that result from changes in detailing. This is particularly beneficial in the context of comparing different techniques or products directed towards a common problem.

Case Study: Insulating Existing Building Walls

Preliminary findings in the research show that the actual R-value of many façades is on the order of 40- to 70-percent less than the design's nominal insulation R-value. As the amount of insulation specified continues to increase, the conductive losses through thermal bridging will continue to grow as a percentage of the building's total energy load (*see "Figure 1," page 23*). In fact, adding more insulation to further improve the thermal performance of façades will have a diminishing return, as the heat flow through the envelope is increasingly dominated by thermal bridges. Better detailing will improve overall performance more than increasing insulation thickness. A simple illustration of this is found in the renovation of three existing masonry façades, as follows.

Spray-applied, closed cell polyurethane foam insulation is gaining popularity, particularly because of its ability to fill irregular voids and provide an integral air and vapor retarder. In the northeastern United States, it is a particularly popular technology for renovating existing uninsulated masonry façades. Conventional details often call for metal studs to support interior gypsum board; these studs live in the same space as the insulation, creating discontinuities at 16- or 24-inch center spacing. (Steel studs are highly effective heat-transfer devices because of the conductivity of the material and the flanges that provide significant contact area to collect and disperse heat.)

Thermal images of the renovation of three existing buildings (*see illustrations on opposite page*) revealed dramatically different results. "Building 1" had applied three inches of insulation between the studs, an assembly R-value of 18. "Building 2" had employed just two inches of insulation, an assembly R-value of 17. For "Building 3," four inches of insulation resulted in an assembly R-value of 30. While nominal values of the thermal resistance normally would show the façade with the least insulation to be the poorest performer and the one with the most insulation to be the best, the thermal images revealed a different story. The steel studs in Building 1 were flush against the exterior construction, resulting in an R-value that was 54-percent less than the calculated R-value (R-8 instead of R-18). In Building 2, the studs were pulled back one inch, allowing for half of the applied insulation to be continuous, thereby decreasing the R-value by only 16 percent (R-14 instead of R-17). In the research, Building 2 was observed to have a higher effective R-value than Building 1, despite having less insulation. For Building 3, however, the studs were even farther back, completely separating them from the plane of the insulation and resulting in an effective R-value that was nearly identical to the nominal insulation value (R-29).

The study shows that the continuity of the first inch is critical for the efficiency of the spray foam insulation performance. By simply pulling the studs in-board, even by a small dimension, a percentage of the insulation was allowed to remain uninterrupted. The result can be an increase in effective R-value of the assembly. (It is important to remember, however, that other factors—such as an uninsulated existing slab penetrating through the insulation, or window openings—can still decrease the thermal performance in existing buildings. Still, small changes in the design can lead to dramatic improvements in performance.)

Conclusions

The significant impact observed from thermal bridging suggests it needs to be considered a far more substantial problem than simply one of condensation risk. The data collected in the Payette study thus far suggests that thermal bridging can easily double the conductive heat transfer over that which would have been mathematically anticipated. While the thermographic images are easily used to highlight in-field conditions with poor thermal performance, this research confirms that the quantitative information gained from the camera can be used to derive rigorous and measurable detailing improvements.

Although the examples in this article are limited, the majority of typical problems identified in this research have centered on transitions between systems and the structural assemblies necessary to support exterior cladding. (These will be available when the full report is published.) Building products exist that can reduce thermal bridging, but easily implemented alternative designs can improve thermal performance, too. As the industry seeks to achieve higher-performance buildings, careful attention and analysis is needed during design to minimize thermal bridges and deliver buildings that perform as anticipated.

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