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Thermal Bridging: It Can Be Done Better

Contents

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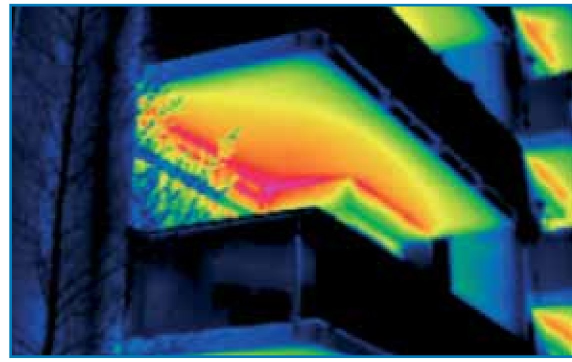

Messages:

Industry Updates:

On the cover: The Centre for Interactive Research on Sustainability (CIRS), located at the University of British Columbia, is one of the greenest buildings on earth… and provides a great example of thermal bridging done right.

Heat Transfer Numerical Modeling Perspectives: Steel-Framed Wall Analysis

By Axy Pagán-Vázquez and Jeff Allen

IN RECENT YEARS, THE BUILDING industry has established priorities to move towards the construction of highly energy-efficient buildings, including the prevention or mitigation of thermal bridges. In the past, when building energy efficient wasn't such an issue, thermal bridge problems were considered to be insignificant or negligible, given that the rest of the losses through a building envelope were dominated by the lack of insulation implementations, infiltration, etc.

Today, as the industry improves the thermal barrier in those areas of the building denominated as "clear wall"—those parts which are free from doors, windows or any other protrusion mainly for structural purposes—the thermal bridge effects tend to be more noticeable. Now that there is a more pressing need to determine how influential the thermal bridge effects can be at various building connection details, the computational modeling approach has been shown to be an attractive method. It can achieve reliable results that can't be determined by physical measurements, such as temperatures inside a composite wall structure or within a building foundation.

Among other sources, the Assessment and Improvement of the EPBD Impact (ASIEPI) project has compiled a number of software programs relating to modeling thermal bridges. The project is designed to give an overview of the status and progress of the many European Union energy initiatives. Stemming from this work, this article independently evaluates a thermal bridge scenario using two software programs that have different levels of capabilities.

The selected software programs comply with Standard ISO 10211: *Thermal bridges in building construction—Heat flows and surface temperatures—Detailed calculations.* This standard defines requirements for 2D and 3D numerical heat transfer software used to determine the heat transfer effects associated with thermal bridges. According to ISO 10211, the thermal bridging modeling software should be able to replicate the calculated heat flow and temperatures for a standard set of thermal bridge scenarios.

The first selected software, COMSOL Multiphysics Finite Element Analysis (FEA) Simulation software, was chosen for its extensible methods for defining the model geometry and its amenability to non-linear material properties. The second software, HEAT3, Finite Difference Method (FDM)-based software, was selected for its concise capability to handle rapid 3D steady state and transient simulations. It also includes a materials library with more than 200 common building materials. **TABLE 1** compares some of the features of both software programs.

ANALYSIS

ASHRAE RP-1365 *Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings* references two separate works; the first one conducted by Desjarlais and McGowan (*Comparison of experimental methods to evaluate thermal bridges in wall systems, 1997*) and the second one by Brown and Stephenson (*Guarded hot box measurements of the dynamic heat transmission characteristics of seven wall specimen-part II, 1993*). These studies were performed in the Building Technologies Research and Integration Center, a division of Oak Ridge National Laboratory (ORNL). In summary, the test procedure, known as Hotbox Testing, consists of placing a large building section (in this case, an 8 ft. by 8 ft. wall) inside a calibrated apparatus that, in turn, measures heat transfer based on heat and temperature inputs. Wind flow inside the apparatus can also be controlled by the tester. For the present analysis, RP-1365 referenced steady state and transient data were selected. This data was used to determine the analyzed specimen R-value. This has been used as a baseline to compare the HEAT3 and COMSOL models. A wall section schematic is shown in **FIGURE 1**.

The HEAT3 and COMSOL models share several common simplifications with respect to the physical specimens. The vertical steel studs and horizontal rails were assumed to be a single, continuous component, eliminating the "rail flange over vertical stud flange" configuration. No screws or any other joint component were included in either model. The rest of the dimensions were modeled exactly as stated in the references.

Also, the steady state and transient model's mesh was manually refined on

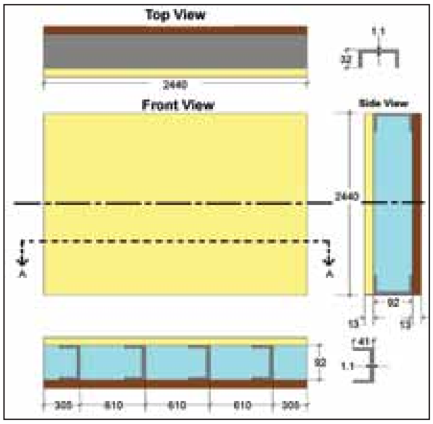

Figure 1. Steel-framed wall tested at ORNL and modeled on HEAT3 and COMSOL. Dimension units given in millimeters. Not shown to scale.

TABLE 1: HEAT3 AND COMSOL MULTIPHYSICS FEATURE COMPARISON

Software Name	Relative Price	3-D Modeling?	Non-linear material property modeling?	Thermo-fluid modeling?	Transient Simulation?
COMSOL	High	Y	Y	Y	Y
HEAT3	Low	Y	N	N	Y

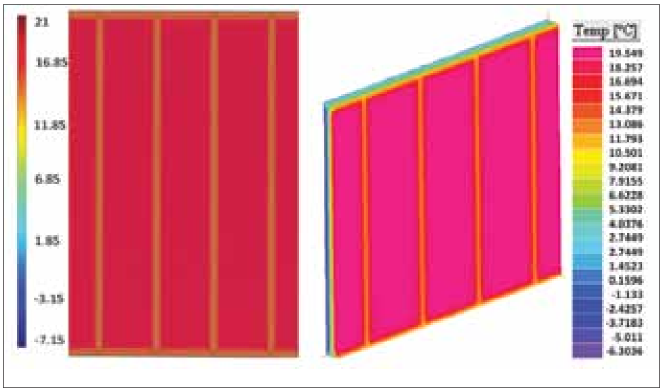

Figure 2. COMSOL Multiphysics (left) and HEAT3 (right) steady state temperature contour profiles (both scales in °C). Section viewed from the interior side of the building.

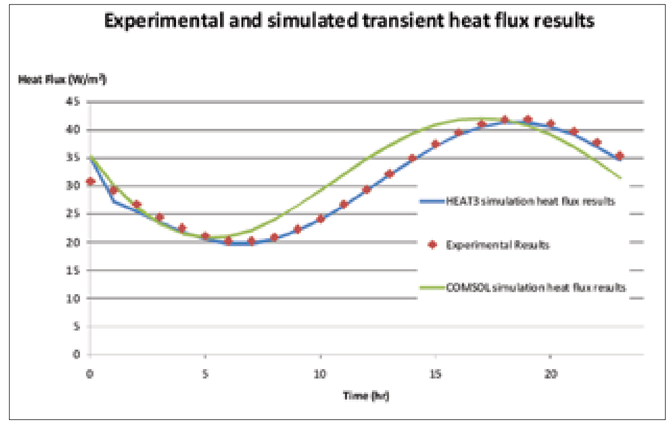

Figure 3. Measured and computed wall heat flux during a 24-hour period (COMSOL, HEAT3 and Hotbox test results).

both software programs. Note that HEAT3 considers surface film co-efficients referenced in the *2009 ASHRAE Handbook - Fundamentals* (34 W/m^2-K for the cold/exterior side and 8.3 W/m^2-K hot/interior side of the modeled wall. These co-efficients were not considered in the COMSOL models. The steel studs were modeled in COMSOL as "highly conductive layers". This user-selected option, in principle, assumes no temperature gradients along steel stud thickness direction. **FIGURE 2** shows the temperature contour profiles for COMSOL and HEAT3. The steel framing reveals its low temperature in relation with the rest of the wall, as indicated by the vertical orange stripes. The high thermal conductivity of the studs causes a much higher heat flux through them than through the insulation, leading to a much lower surface temperature.

Comparing the steady state results from the Hotbox experiment, as well as each of the two simulations, resulted in the following R-values: 1.39 $m^2 \cdot K/W$ (Hotbox), 1.41 $m^2 \cdot K/W$ (HEAT3) and 1.49 $m^2 \cdot K/W$ (COMSOL). Both HEAT3's and COMSOL's R-value relative error stayed under 10 percent. The result deviations are caused, in part, by the exclusion of the contact resistance effects between material surfaces, as well as the exclusion of joint connectors, such as bolts, etc. RP-1365 model validation analysis concludes that contact resistance, such as steel-to-steel interfaces and insulation interfaces, can have significant impacts on the overall wall thermal resistance, particularly on steel stud assemblies without exterior insulation. McGowan and Desjarlais's (1995) work demonstrates the relevant contact resistance impact on steel stud assemblies.

For the transient analysis, the total heat transfer was evaluated for a period of 24 hours. A fixed temperature value was set at the inner wall surface, while a time-dependent temperature was assigned to the outer wall surface.

One notable difference between the COMSOL and HEAT3 transient models was the chosen time step and the selected initial temperature conditions. A time step of one second and one hour were selected for COMSOL and HEAT3, respectively. An homogeneous temperature value of 32.9^{0}F (0.5^{0}C) was assumed for the entire wall system in the COMSOL model, while a non-homogeneous field was assumed on the HEAT3 model. Previous to the HEAT3 transient analysis, a quasi-steady state simulation was performed to determine the temperature field representative of the initial temperature conditions. As a result, a location-dependent temperature field was obtained and included in the model. The transient simulation results were compared with RP-1365 transient testing data, based on Hotbox testing performed by Brown and Stephenson (1993). These results are shown in **FIGURE 3**. Note that all the mentioned possible factors influencing the steady results discrepancy also have influence over the transient simulations.

Even though COMSOL and HEAT3 solve the same partial differential equation (heat diffusion equation), as mentioned, they implement different numerical techniques to solve it. Emerly and Mortazavi (1982) conclude that FDM heat balance appears to be best for problems in which continuity of the heat flux is important, whereas FEM is best suited, among other scenarios, in the examples with concentrated heat sources. Also, the exclusion of the surface film co-efficients on the COMSOL model causes a sub-estimation of the simulated total heat transferred, consequently inducing an over-estimated equivalent wall thermal resistance.

CONCLUSIONS

The software programs' results were specific for the selected scenario. Understanding that thermal bridging problems are developed in building sections having similar geometrical and composition patterns, the use of HEAT3, at least for this particular simulation, appears to be a practical tool, considering its cost and similarity to the Hotbox results. Additional building envelope models, however, should be considered in order to determine if the two software programs consistently match experimental results, or if the results were unique for this particular scenario. ■

Axy Pagán-Vázquez is a mechanical engineer at the U.S. Army Corps Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL). He has been involved with heat transfer modeling of building envelope sections as part of the laboratory's research in prevention and mitigation of thermal bridges in buildings. He's currently pursuing graduate studies focusing on numerical modeling aspects for fluid and solid mechanics.

Jeff Allen is a research mechanical engineer at ERDC's Information Technology Laboratory. He holds advanced degrees in mechanical and aerospace engineering as well as an undergraduate degree in mathematics. His interests include high-performance computational modeling of multiphysics and multi-scale systems.

REFERENCES

1. *Assessment and Improvement of the EPBD Impact (2010), An Effective Handling of Thermal Bridges in the EPBD Context-Final Report.*
2. Morrison Hershfield (2011), *Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings* (RP-1365).
3. International Standard Organization (2007), ISO 10211:2007 *Thermal bridges in building construction—Heat flows and surface temperatures—Detailed calculations.*
4. Brown W. C. and Stephenson D. G. (1993). *Guarded hot box measurements of the dynamic heat transmission characteristics of seven wall specimens-part II.* ASHRAE Transactions 99, 643-660.
5. Desjarlais and McGowan. (1997). *Comparison of Experimental and Analytical Methods to Evaluate Thermal Bridges in Wall Systems.* 3^{rd} ASTM Symposium on Insulation Materials: Testing and Applications: 3^{rd} Vol. ASTM STP 1320.
6. 2005 ASHRAE Fundamentals Handbook Table 5, Chapter 3.
7. InfraMation 2006 Proceedings ITC 115 A 2006-05-22.
8. Emerly and Mortazavi. (1982). *A Comparison of the finite difference and finite element methods for the heat transfer calculations.*