ASSESSMENT OF THERMAL BRIDGING OF FASTENERS THROUGH INSULATED ROOF ASSEMBLIES

by

Sarah Rentfro[1], Georg Reichard[2], Elizabeth Grant[3], Jennifer Keegan[3], Eric Olson[1], Cheryl Saldanha[1], and Thomas J. Taylor[4]

[1]Simpson Gumpertz & Heger, [2]Myers-Lawson School of Construction at Virginia Tech, [3]GAF, [4]Building and Roofing Science Consultant

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Figure 1. - Examples of thermal bridging at fasteners on snow-covered roofs.

Roof fastener systems are comprised of metal screws and plates used to attach roof membranes, cover boards, and insulation. These systems can have an adverse impact on the thermal performance of roof assemblies, as the components create thermal bridges that bypass the thermal resistance of insulation in the roof assembly. This in turn allows heat to transfer at an accelerated rate, flowing outward in cold weather and inward in warm weather. **Figure 1** shows an example of this effect on snow-covered roofs. While the thermal performance of 3-D thermal bridges can be numerically simulated with software tools, such simulations are time-consuming and need to be verified by laboratory tests to validate the underlying assumptions made during the simulation.

In this summary, we explain how we used a series of laboratory tests to compare the thermal performance of physical models of simple roof assemblies under controlled laboratory environmental conditions with computer simulations of the same conditions. The outcome is an experimentally validated computer simulation approach that will enable consultants to evaluate a broader range of roof assemblies and roof fastener configurations.

INTRODUCTION

As energy code requirements for thermal insulation have become more stringent, thermal bridges, such as fasteners, are a more significant contributor to the overall heat flow through building enclosure systems. Through this study, we provide a relative comparison of various roofing configurations with and without fasteners.

We compare the thermal performance of a physical assembly, tested under controlled laboratory conditions, with a detailed 3-D computer simulation of the same assembly. By incrementally increasing the complexity of the assemblies in the tests and simulations, we seek to better understand the limitations of simulations, with the ultimate goal of developing an experimentally validated computer simulation approach that will enable the evaluation of a broader range of roof assemblies and roof fastener configurations.

There have been several past simulation studies, discussed in further detail in our IIBEC 2023 International Convention & Trade Show proceedings paper (the Paper), that have estimated the thermal penalty attributable to fasteners in roofing assemblies. As evidenced by the range of conclusions garnered from these studies, more physical experiments and computational simulations addressing fastened roof components in their various permutations are needed to understand how thermal bridging from fasteners quantitatively impacts the overall thermal performance of roofing assemblies. These studies are necessary to support design efforts and the future development of building codes, industry standards, and energy performance certifications, and to lead the roofing industry to develop more thermally efficient assembly technologies.

STUDY SETUP

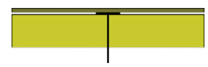
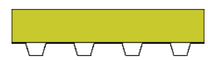
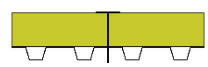
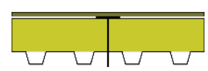
The roofing assembly we tested builds in complexity, in the stepwise fashion shown in **Tables 1** and **2**.

Table 1. - Naming protocol for study.

Fastener Code	**Fastener Configuration**
A	No fastener
B	One #12 fastener, 6 in. (150 mm) long, with a 3-in. (76-mm) diameter plate
Assembly Code	**Assembly Type**
I	Single 4-in. (102-mm) polyiso board
II	4-in. (102-mm) polyiso covered with 0.5-in. (13-mm) high-density polyiso cover board
III	4-in. (102-mm) polyiso on steel deck
IV	4-in. (102-mm) polyiso on steel deck covered with 0.5-in. (13-mm) high-density polyiso cover board
Abbreviations	**Full Term**
PIR	polyiso board

HDB	High-density polyiso cover board
SD	Galvanized steel deck

Table 2. - Assembly cases.

Fastener Code	Assembly Code	Case	Assembly Components	Diagram
A	I	A-I	4-in. (102-mm) PIR	
A	II	A-II	0.5-in. (13-mm) HDB 4-in. (102-mm) PIR	
B	I	B-I	#12 fastener 4-in. (102-mm) PIR	
B	II	B-II	0.5-in. (13-mm) HDB #12 fastener 4-in. (102-mm) PIR	
A	III	A-III	4-in. (102-mm) PIR SD	
A	IV	A-IV	0.5 in. (13-mm) HDB 4-in. (102-mm) PIR SD	
B	III	B-III	#12 fastener 4-in. (102-mm) PIR SD	
B	IV	B-IV	0.5 in. (13-mm) HDB #12 fastener 4-in. (102-mm) PIR SD	

Physical Experiment

We tested the simplified roof assemblies as depicted in **Table 2** in a controllable climate test chamber. The climate chamber configuration is shown in **Figure 2**. We conducted experimental tests in triplicate series to permit a baseline for statistical evaluation of measurements. In the Paper we more fully explain the climate chamber and further detail the study's parameters and thermal conditions.

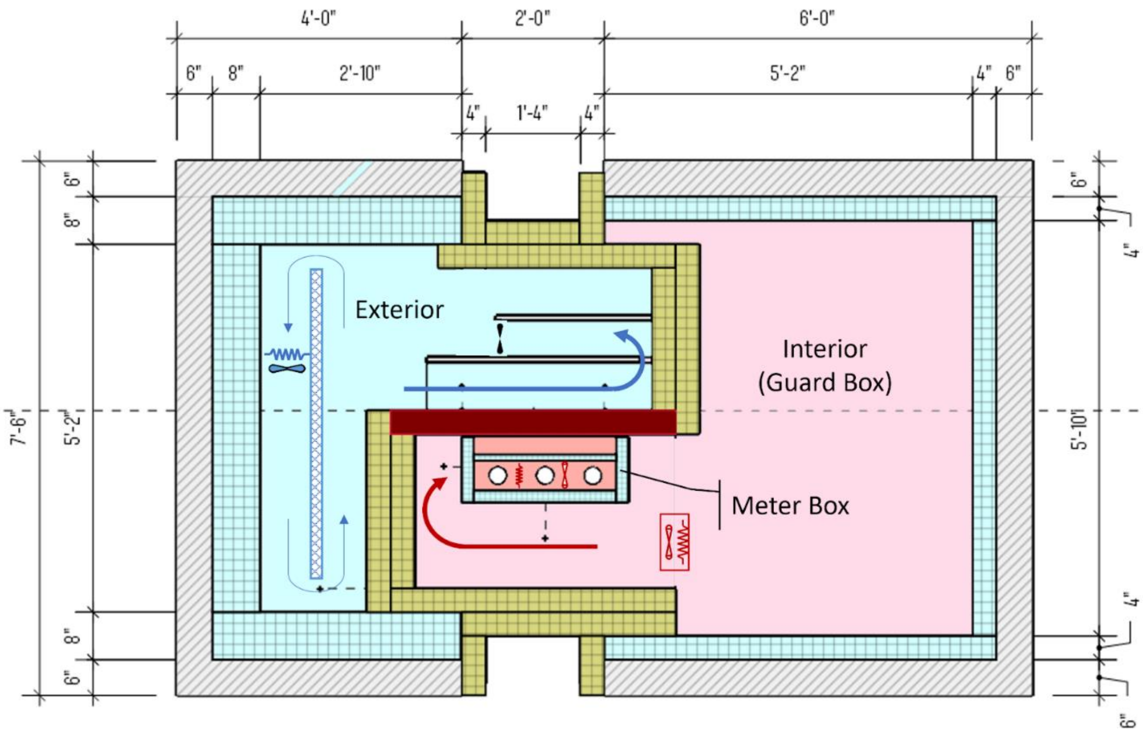


Figure 2. - Open view of assembly frame and meter boxes (left) and guard box with climate control (right) within the climate chamber.

We conducted all tests under steady-state conditions and did not consider the temperature dependence of the insulating materials. A 2-ft. x 2-ft. (0.6-m x 0.6-m) area of the test assembly was monitored and the heat flux across the test assembly was measured. The exterior chamber was held at 50°F (10°C), and the interior chamber was held at 100°F (38°C), resulting in a mean insulation temperature of 75°F (24°C).

The test sequence was developed to minimize the number of times the test chamber needed to be opened on either side to reconfigure the setup of the samples, and to enable the same 4-in. (102-mm) polyiso board (PIR) specimen to be used throughout an entire series of tests, thereby eliminating variation in PIR as a potential error source.

Computer Simulation

We performed a detailed 3-D steady-state thermal analysis of the same roof assemblies tested in the physical experiment (see **Table 2**) using the 3-D FEA tool ANSYS, developed by ANSYS, Inc. ANSYS simulates heat flow through materials, components, and systems based on a defined geometry and interior/exterior environmental conditions, referred to as boundary conditions. The finite-element method utilized in the detailed ANSYS computer simulation allows for a more accurate representation of the fastener geometry than the finite-difference method used in past research since it can mesh irregular (i.e., non-rectilinear) shapes. Refer to the Paper for past modeling efforts, and details of the current model including its geometry, thermal conductivities, and boundary conditions.

The simulated heat flow in ANSYS was converted into an overall averaged U-factor (and associated R-value) using the projected area of the assembly in the horizontal (i.e., projected-X) plane. **Figure 3** shows the typical temperature output from ANSYS.

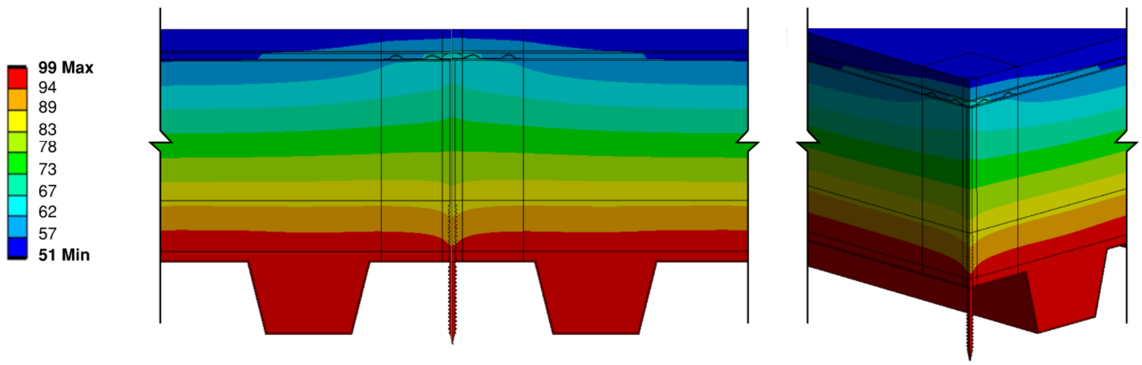


Figure 3. - Color temperature output for case B-IV at fastener (section and isometric views).

RESULTS, DISCUSSION, AND CONCLUSIONS

The following section summarizes results and conclusions from both the physical experiment and the 3-D computer simulation. Refer to the Paper for full results, associated trends, and more specific conclusions.

Figure 4 shows calculated R-values from the physical experiment compared to the computer simulation for each test assembly configuration, and **Figure 5** shows the percent change from the A-cases' R-values to the B-cases' R-values for the two procedures.

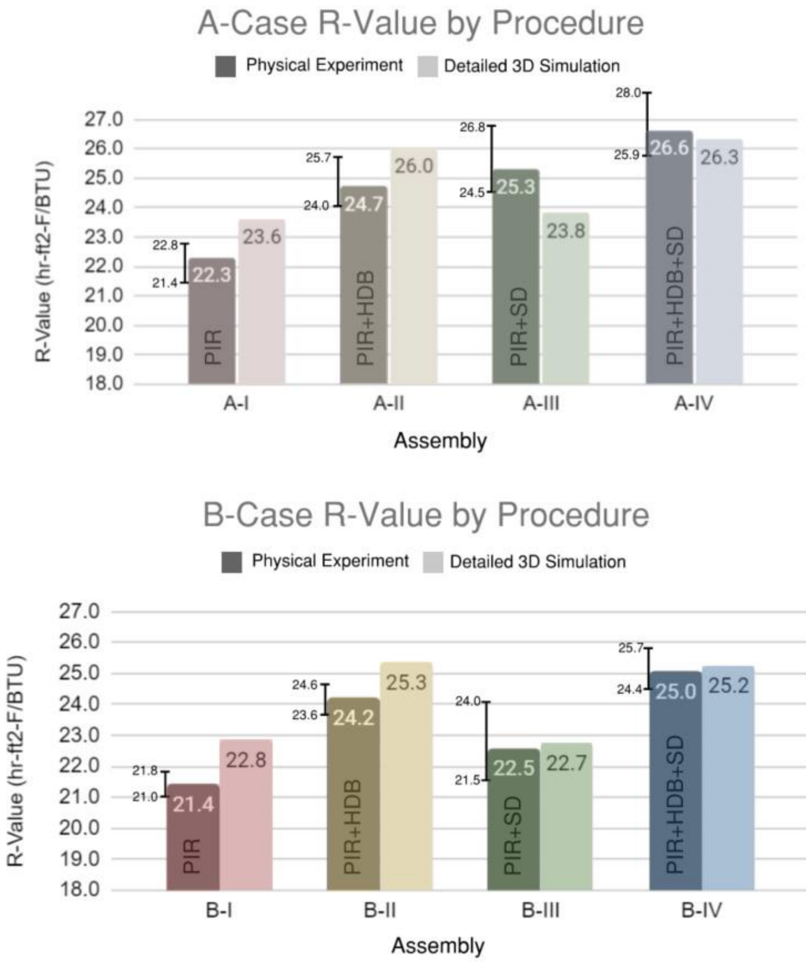


Figure 4. - Comparative R-value results for A-cases (without a fastener) and B-cases (with a fastener).

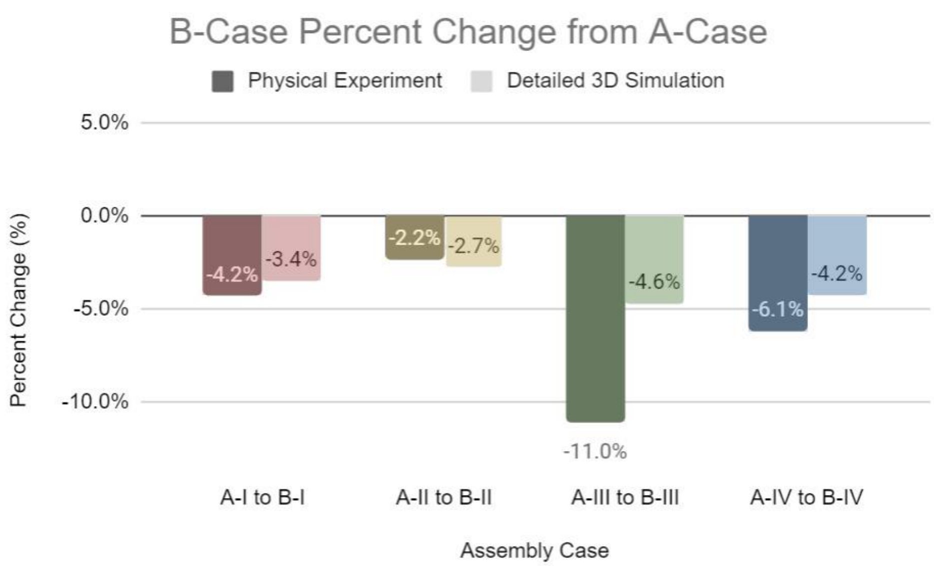


Figure 5. - Comparative percent change from A-cases (without a fastener) to B-cases (with a fastener).

Physical Experiment Conclusions

The experimental results show that adding a fastener (going from "A" to "B" cases) reduces the thermal resistance of the roofing assembly in all cases. The physical experiment results demonstrate that a roof assembly with a high-density polyiso cover board (HDB) adds insulating value compared to the polyiso board (PIR) alone while also reducing thermal bridging from the fastener. Adding the galvanized steel deck (SD) also adds insulating value from the enclosed air pockets within the flutes, but it concurrently amplifies the thermal bridging from fasteners.

It is worth noting, however, that various aspects of the experimental setup proved difficult to maintain and replicate, which likely impacted the results to an extent (as indicated by the variation of R-values across samples for each assembly reported in **Figure 4**). Additional testing (i.e., gathering of additional data points to serve as the basis for a statistical analysis) needs to be performed to evaluate potential outliers in the dataset.

Computer Simulation Conclusions

The computer simulation results also show that adding a fastener reduces the thermal resistance of the roofing assembly in all cases. Similar to the physical experiment, the computer simulation results demonstrate that a roof assembly with an HDB adds insulating value compared to the PIR alone while also reducing thermal bridging from the fastener. Adding the SD amplifies the thermal bridging from the fastener. In contrast to the physical experiment, the computer simulation demonstrates, perhaps incorrectly, that adding the SD has minimal impact on overall thermal resistance rather than increasing the thermal resistance, indicating that the way the computer models account for air spaces and surface (air-film) resistances should be further reviewed.

Comparison of Physical Experiments and Computer Simulation Results

When comparing the results of the physical experiments and computer simulations on a case-by-case basis, the difference between them ranges from 0.8 to 6.7%. The most notable differences were in the III and IV cases with the SD, where the physical experiment showed a greater relative drop in thermal resistance compared to the computer simulation. We did not compare surface or internal temperatures of the test assemblies to computer simulations and so cannot yet fully comment on the validity or accuracy of the simulations and the experimental results. Some trends observed by both approaches were similar, and the diverging trends warrant further review. We intend, through ongoing work, to review the correlations in more detail.

General Conclusions

We conducted physical experiments and computer simulations in a stepwise fashion to isolate the influence of the different layers in the assembly and to see where physical modeling and computer simulation converge and diverge. Both physical experimentation and computer simulation are simplifications of reality, and there are errors inherent in both approaches. The results of this study identify some diverging trends that warrant further analysis. The value of computer simulation, once validated by physical experimentation, is its ability to quickly extend results to a wide range of possible scenarios.

ACKNOWLEDGMENTS

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