Online exclusive

Thermal Performance of Spandrel Assemblies in Glazed Wall Systems

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GLAZED WALL SYSTEMS, such as curtainwalls and window walls, comprise transparent, translucent, and opaque areas. The opaque areas, known as spandrel assemblies, shown in **Fig. 1**, are often used to hide building components such as slab edges, mechanical equipment, and suspended ceilings. Spandrels are increasingly insulated with the intent of improving thermal performance relative to the transparent portions of the glazed wall system. However, due to thermal bridging from the structural framing components that interrupt the insulation, spandrel thermal performance is often worse than expected. This can contribute to greater-than-expected building energy loss, unexpected condensation risks, and other performance issues.

There is a general notion that insulated spandrel assemblies may be evaluated using similar two-dimensional (2-D) thermal simulation techniques as the vision areas of glazed wall assemblies since they are part of an integrated system with similar framing. However, components within spandrel assemblies, the position of the insulative layers, and other construction realities differ significantly from vision areas. These differences result in heat flow paths that previous techniques struggle to capture effectively, leading to an overestimation of thermal performance by as much as 20% to 30% when compared to laboratory measurements.[1,2] In addition, traditional thermal simulation techniques do not account for a number of conditions typically found in many buildings, such as the impact of nonstandard spandrel sizes and adjacent assemblies.

Without industry guidance to evaluate spandrel thermal performance under these conditions, many professionals struggle to provide accurate spandrel *U*-factors for their projects, the impact of which is an overestimation of whole-building energy performance and a failure to achieve energy efficiency goals. Similarly, many building energy codes and industry standards do not include rigorous requirements to accurately evaluate spandrel thermal performance, making it difficult to enforce thermal requirements for spandrels. As whole-building energy performance comes

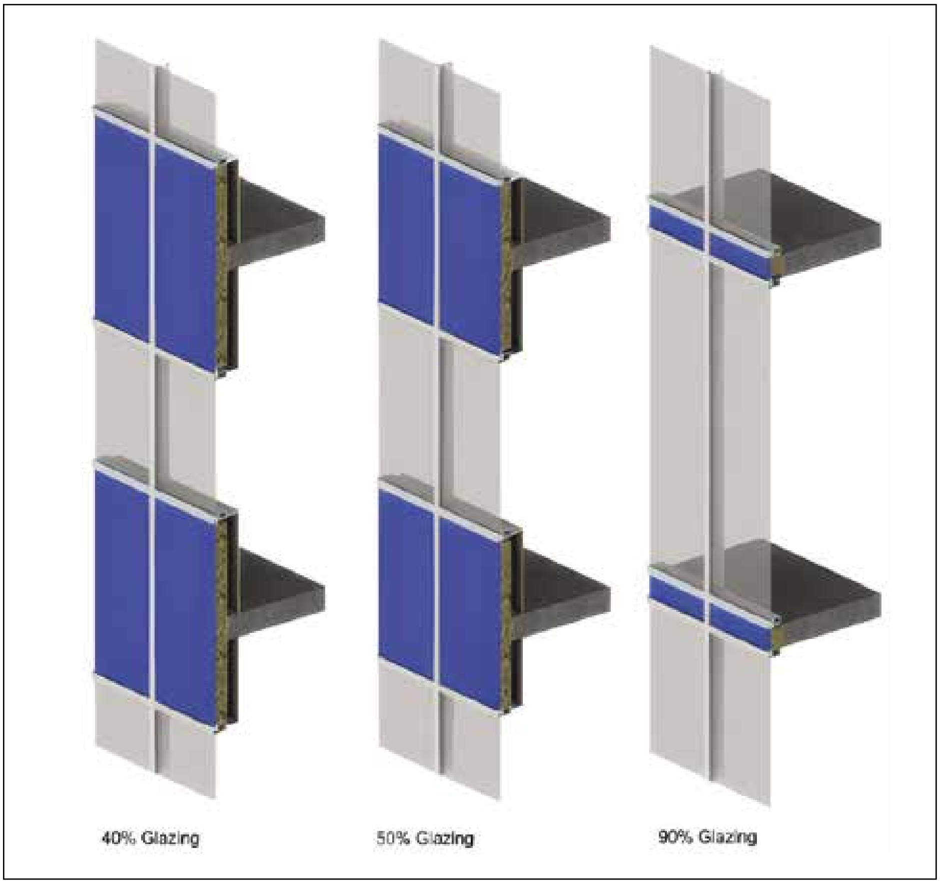

Figure 1. *Various spandrel assembly conditions (blue) at slab edges.*

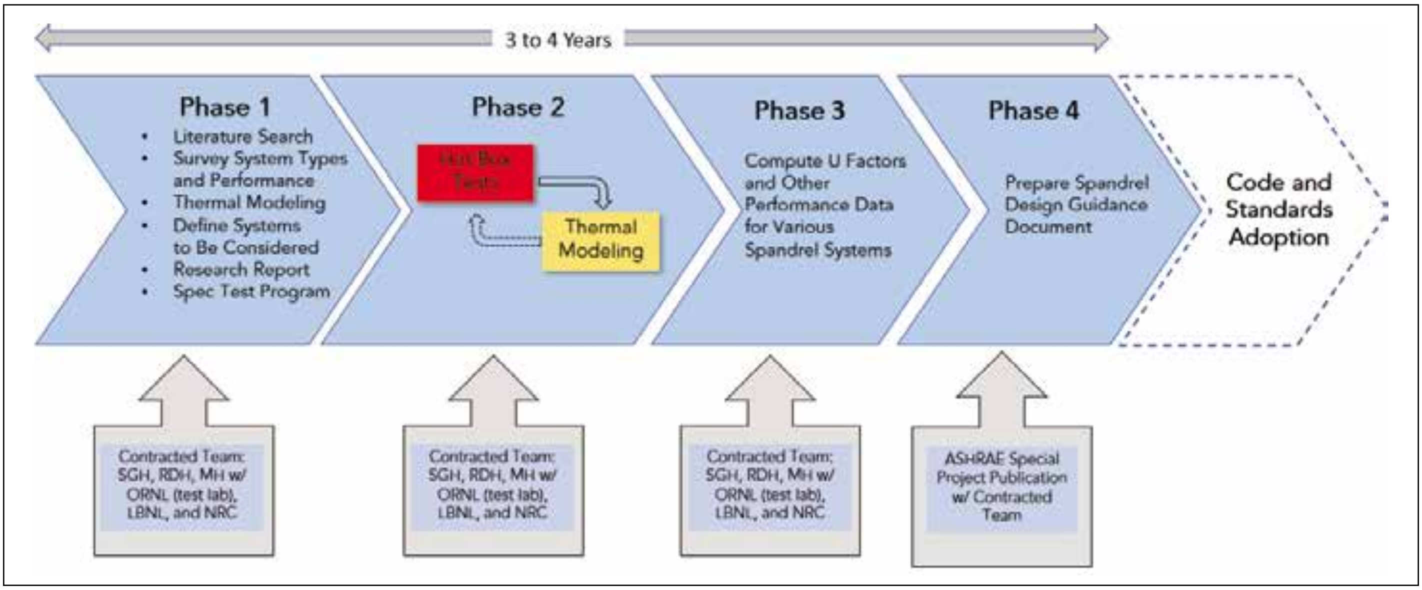

Figure 2. *Project phasing plan.*

to the forefront and building energy codes and standards become more stringent, the industry will inevitably recognize the impact of spandrel assembly thermal performance on whole-building energy performance and will seek accurate values for their designs.

In order to address this shortcoming in industry knowledge, a multiphase research program was created. A key differentiator is the intent of developing a procedure that is valid for the many potential spandrel conditions that may be applied to buildings. Another reason for this research is to foster innovation by providing the industry with an analytical means of assessing improvements in spandrel thermal performance. Jurisdictions may choose to recognize the performance of spandrels in different ways, including requiring the use of the procedure developed as part of this work or by setting targets independent from those of other opaque wall assemblies. With a standardized approach, codes and standards can be tightened over time (for example, step/stretch codes, Passive House) and empower owners to prescribe and obtain desired levels of performance.

RESEARCH PROGRAM OVERVIEW

The research program's main goals are to develop a validated thermal simulation procedure for evaluating the thermal performance of spandrel assemblies and to provide guidance on how to improve spandrel thermal performance.

To meet the study objectives, a multiphase research program that includes a review of the current research and state of industry practice, laboratory testing, 2-D and three-dimensional (3-D) thermal simulations, and publication of a thermal simulation procedure as shown in **Fig. 2**, was developed.

The scope of the research includes various glazed wall systems and spandrel configurations. The systems in the study include stick-built and unitized curtainwall systems, window wall systems, and next-generation designs, such as timber veneer systems and highly insulated unitized systems. Variations in spandrel configurations include spandrel insulation types, slab anchor types, cladding panel types, mullion wraps, and various backpan designs.

This article summarizes Phase 1 of the study and includes a literature review, an industry survey, an evaluation of the current state of practice, computational fluid dynamics (CFD) simulations, and the development of a test program. A summary of the scope and key results are presented in the following sections.

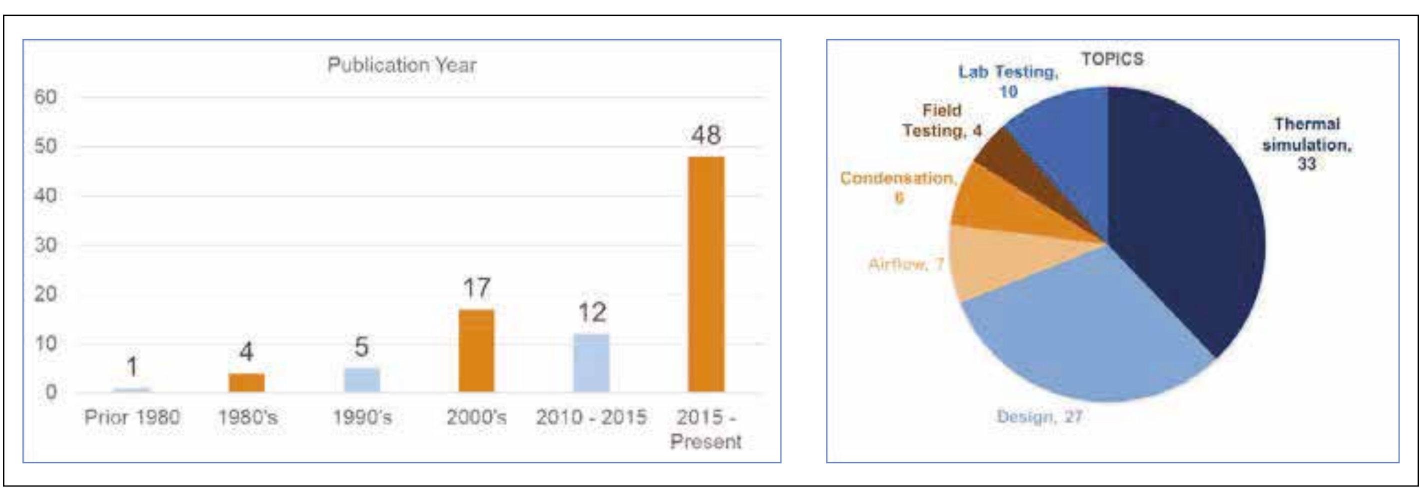

Figure 3. *Breakdown of reviewed documents by publication year and topic from literature review.*

Table 1. Industry gaps from the literature review.

Topic Area	Descriptions
Adjacent Assemblies	• What is the impact of adjacent assemblies on spandrel thermal performance? • What is the impact of the intermediate floor connected to window wall spandrel assemblies?
Thermal Evaluation Techniques	• How can the accuracy of two-dimensional thermal simulation methods, when compared to physical test results, be improved? • What are the impacts of contact resistance of components on thermal performance? • What is the accuracy of current industry standards and guidelines on simulating thermal performance compared to physical testing?
Spandrel Panel Construction	• How do size and configuration impact spandrel thermal performance? • What are the impacts of various spandrel components on thermal performance?
Overall Building Enclosure Thermal Performance	• What are the impacts of accurate spandrel thermal performance values on weighted *U*-factor calculations and envelope backstop calculations for building energy code compliance?

LITERATURE REVIEW

The researchers performed a literature review to discern the current state of understanding and research on spandrel thermal performance, including current research methods, evaluation standards and practices, and problems with spandrel design and associated solutions. The literature review included 87 research papers, codes, standards, industry articles, and guidelines focusing on thermal simulation, condensation risk, airflow, and laboratory testing (**Fig. 3**).

From the literature review, the authors identified several gaps in the industry's knowledge as it relates to accurate evaluation of spandrel thermal performance; these gaps are listed in **Table 1**. Findings from the literature review were used in the development of the test program and to focus research on key areas where additional industry guidance is required.

INDUSTRY SURVEY

The researchers conducted an industry survey to assess the prevalence of specific spandrel types and to assess industry knowledge and expectations of spandrel performance. This survey was also performed to understand which systems and details are most challenging from the standpoint of thermal performance, as well as to understand potential innovation opportunities. The survey reached 35 industry professionals in various roles, including 14 designers, 16 contractors, and 5 industry organization representatives. Key takeaways from the survey results are listed in **Table 2**.

Table 2. Industry survey key takeaways.

Categories	Takeaways
Prevalence of Glazed Wall Systems	• Glazed wall systems are prevalent in modern construction. • Glazed wall systems are used in all eight American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) climate zones. • The most common glazing type is double-glazed insulated glazing units with a low-emissivity coating. • Unitized curtainwall is the most common type of glazed wall construction in downtown core areas. • Glazed wall systems are typically installed on buildings greater than 12 stories. • Glazed wall systems account for more than half of the exterior wall area on projects where they are included, with spandrel areas accounting for 40% to 60% of that area.
Prevalence of Spandrel Panels and Common Characteristics	• Glazed wall systems are primarily selected by the respondents for aesthetics, followed by speed and constructability. • Designers most often specify vented spandrels. In contrast, contractors show no preference for either vented or fully sealed spandrels. • Metal panel was the most commonly specified spandrel cladding, followed by shadow box.
Spandrel Panel Concerns and Innovation	• The most common issues were aesthetics, condensation, and glass breakage. • Thermal performance, code compliance, and lack of industry-accepted analysis techniques are a concern. • Insufficient market demand for higher-performing products, industry education, and lack of industry-accepted analysis techniques are the top three barriers to spandrel innovation.
Spandrel Panel Thermal Performance	• Most are aware of the difference in thermal performance required of spandrel panels compared to transparent glazing. • The average reported thermal performance of spandrels varies widely in the industry, from *R*-3 (*RSI*-0.53) to *R*-10 (*RSI*-1.76). • Based on current technologies, most believe that a spandrel *R*-value between 5 (*RSI*-0.88) and 10 (*RSI*-1.76) is achievable but could be higher. • The most common analysis procedure is the American National Standards Institute/National Fenestration Rating Council (ANSI/NFRC) 100 (two-dimensional).

Table 3. Summary of industry interviews.

Category	Common Responses
Industry Knowledge	• Across the industry, there is limited knowledge of thermal modeling standards and resources specific to spandrel panels. • Misunderstandings persist regarding the difference between the one-dimensional center-of-spandrel performance and the effective thermal performance of spandrel panels (two-dimensional [2-D] or three-dimensional [3-D]).
2-D Versus 3-D Modeling	• All the interviewed manufacturers report their performance based on 2-D thermal simulations. • Manufacturers identified access to 3-D performance data as a market differentiator but acknowledged the improved accuracy (and decreased *R*-value) as a risk when approaching markets or teams with a poor understanding of the results.
Codes and Standards	• Impediments to innovation include current code language, which allows and sometimes requires less accurate 2-D thermal simulation or tabulated performance, and inconsistent enforcement of the existing performance documentation process. • Suggested solutions included code updates to recognize spandrels as a unique wall construction type and a standardized modeling procedure.
Innovative Technologies	• The most common areas of product development are limited to internal system components (for example, thermal breaks). • Achieving an "all-glass" visual intent is cited as a significant constraint when considering other areas of improvement (for example, exterior insulation).

CURRENT STATE OF USE

Recognizing the importance of manufacturers' role in advancing the state of the industry and in providing solutions for higher-performing spandrels, the researchers conducted a series of interviews with glazing system manufacturers. The focus of the interviews was to identify barriers to the future development of spandrel panels and to identify opportunities for innovation. The interviews were limited to those with relatively large manufacturers of spandrel assemblies. **Table 3** lists common themes that emerged from 10 interviews.

In addition to the information gathered from the interviews, the researchers analyzed the prevalence of glazed wall systems in North America. Eight of the largest cities in North America were selected to review the prevalence of glazed versus non-glazed buildings in downtown commercial areas. The cities reviewed were New York City, Phoenix, Houston, Chicago, Columbus, Jacksonville, Los Angeles, and Vancouver, British Columbia. The cities are all located in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Climate Zones 2 to 5.

Results show that glazed wall systems represent roughly 40% of the building facade systems in downtown cores. Results also show that high- and mid-rise glazed buildings are dominated by curtainwall systems rather than window wall systems.

In summary, the industry appears to recognize that a 3-D thermal simulation procedure would produce more accurate results when compared to 2-D thermal simulations, but it is waiting for building codes and standards to "raise the bar." In the absence of a more accurate and enforceable standard, it is likely that the industry will continue to proceed with "business as usual."

CFD SIMULATIONS

In response to the prevalence of vented and sealed spandrel assemblies highlighted by the industry survey, the researchers evaluated the impact of airflow through spandrel assemblies on thermal performance with CFD simulations. While the researchers anticipated this effect would be minimal based on previous studies of ventilated rainscreens, 3-D CFD simulations were performed, as shown in **Fig. 4**, to quantify the potential impact of varying ventilation parameters and examine the need, if any, to adjust the test program design.

The 3-D CFD simulations evaluated the impact of airflow on spandrel panel thermal performance, specifically studying the impact of vent openings, air volume modeling assumptions, and film coefficients. Other variables that can influence airflow include spandrel panel size, cavity depth, frame type, backpan profile, insulation type, the roughness of surfaces enclosing the air cavity, and emissivity. However, these variables were all deemed secondary compared to vent openings and exterior air velocity and were excluded from the study at this time. The 3-D CFD simulations were compared to the 2-D finite element analysis (FEA) thermal simulations more commonly used by practitioners.

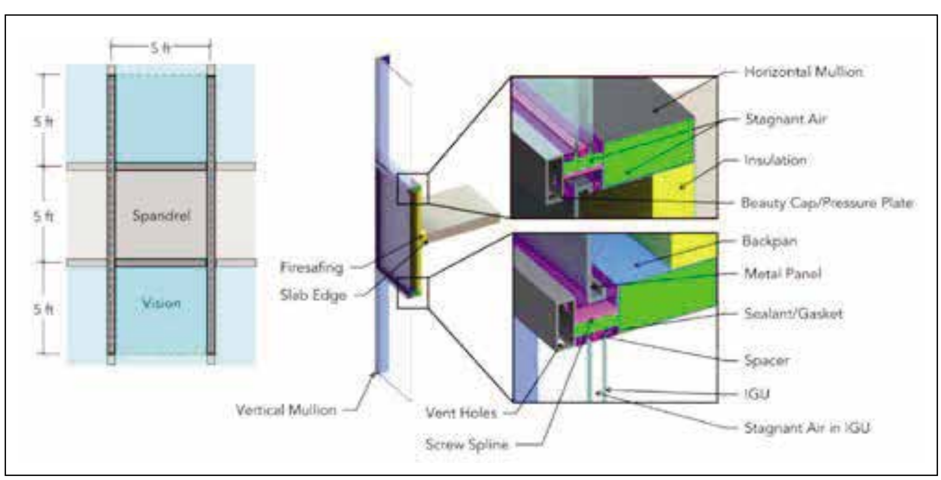

Figure 4. *Three-dimensional computational fluid dynamics (CFD) simulation geometry (excerpts from CFD model).*

Based on the results of these simulations, the following conclusions were drawn:

- Discrete vent openings in spandrel assemblies have a marginal effect on the average velocity and air temperature in the spandrel cavity and the simulated interior surface temperatures (less than 1°F [0.5°C] difference) and have little to no effect on the overall heat transfer across the spandrel assembly.
- Simulated spandrel cavity temperatures using 2-D FEA and 3-D CFD simulations differ by as much as 19°F (10.5°C), notably near vent openings.
- Interior convective film coefficients vary from floor to ceiling and are higher below the slab edge than above the slab edge. The common practice of using a single interior film coefficient does not account for such variations. In addition, the interior film coefficients vary with exterior air velocity but are much less pronounced.
  - The CFD-calculated film coefficients in this study reflect an approximation of laboratory testing conditions, not real-world conditions. They should not be compared to standard values, which are derived using different air velocities.
- Overall thermal performance (that is, *U*-factor) varies minimally (0% to 6%) when calculated using 2-D FEA thermal simulations versus 3-D CFD simulations.

This agreement is generally supported by recent National Fenestration Rating Council (NFRC) updates to spandrel simulation procedures and the associated physical validation testing. However, the authors note that this conclusion does not apply to typical installed spandrel conditions, which include elements not captured in the simulated configuration (for example, deflection headers, adjacent glazed wall systems).

The primary differences between the 2-D FEA and 3-D CFD simulations are the geometry simplifications, radiative film coefficients, and air volume modeling assumptions used in the 2-D FEA thermal simulations.

Different levels of convective heat transfer exist within spandrel cavities depending on exterior wind velocity, but differences between ventilated and sealed panels are negligible, even at high wind velocities. Therefore, spandrel panel ventilation will not be considered in the laboratory testing program or in future simulations.

The 3-D CFD simulations in this study focused primarily on convection at two exterior air velocities. Additional study should be performed to evaluate the variability of interior convective air film coefficients based on geometric surface configurations and mechanical systems. In addition, future work on the subject should study the effect of radiative film coefficients and solar radiation (heat flux to simulate the solar heat gain).

LABORATORY TEST PROGRAM

The setup of the laboratory testing program was included in the first phase of the research program. The objective of the laboratory testing program is to provide data to validate 2-D and 3-D thermal simulation methods for the development of simulation guidelines to evaluate the thermal performance of spandrel assemblies (**Fig. 5**).

The laboratory tests are designed to cover multiple systems and configurations that are intended to capture conditions typically found in commercial buildings. These configurations include the impacts of:

- Spandrel panel size
- Adjacent assemblies (for example, transparent vision glazing sections, non-spandrel opaque assemblies)
- Intermediate floor attachments and anchorages
- Spandrel construction (for example, backpan configuration, insulation type, cladding type, interior wall construction)
- Airflow around the spandrel assembly

The impacts of the above factors have been missing from previous and current industry standards and research. As a result, there is little guidance on how to consider these factors when evaluating spandrel thermal performance through thermal simulations; this lack of guidance has led to confusion and improper evaluations in the industry.

The configuration of the test articles includes various spandrel panels at different sizes and a truncated reinforced concrete intermediate floor slab to simulate the impact of floor slab anchorages and connections to glazed wall systems. This arrangement is shown in **Fig. 6**.

The laboratory tests are being carried out at Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, using hot-box equipment capable of testing large articles at steady-state conditions. Temperatures at critical locations will be measured and compared to 2-D and 3-D thermal simulations. The test procedures are similar to ASTM C1199, *Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods*, and ASTM C1363,

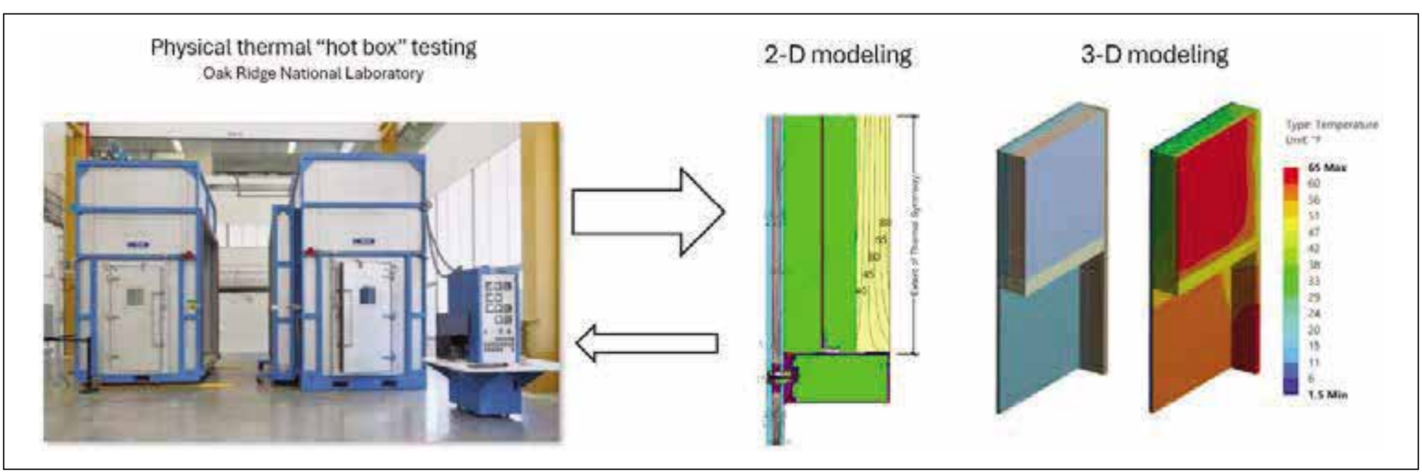

Figure 5. *Left: Hot-box testing image, courtesy of Oak Ridge National Laboratory. Right: Two-dimensional (2-D) and three-dimensional (3-D) computational models.*

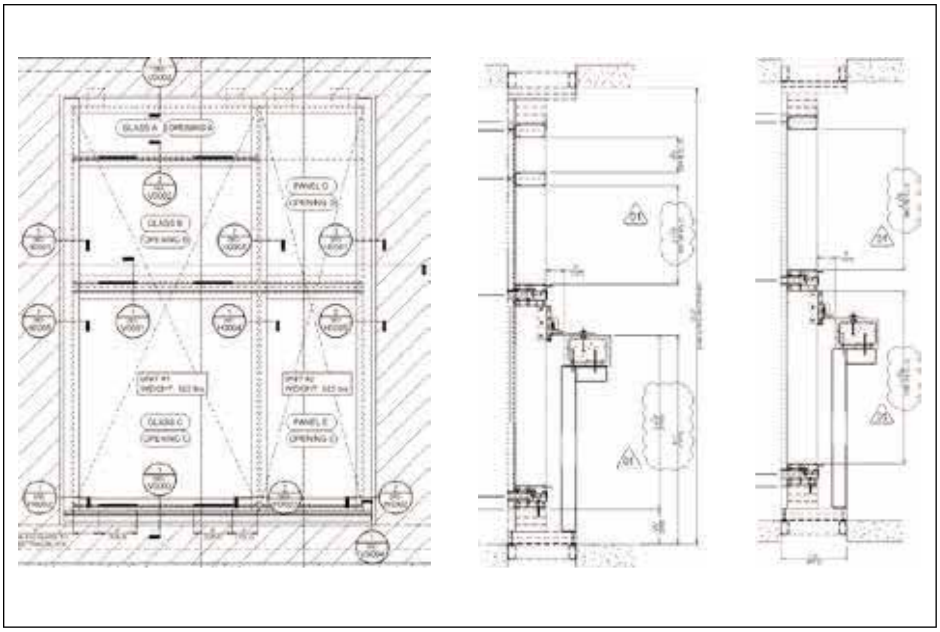

Figure 6. *Left: Test article spandrel panel configuration. Middle and right: Section views of the test article.*

Table 4. Laboratory test conditions.

Conditions	Temperatures	Airflow
Warm side (indoor)	100°F (37.8°C)	Natural convection conditions
Cold side (outdoor)	35°F (1.7°C)	Winter wind conditions

Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus, with the exception that heat flow metering will not be required since only surface temperatures, air temperatures, and airflow around the test article will be measured. The articles will be tested under the conditions listed in **Table 4**.

Over 150 sensors will be installed at critical locations in the test articles, as shown in **Fig. 7**. The sensors are to be located at key areas such as the center of the panel, the edge of the panel, the glazed wall system frame, and intersections between horizontal and vertical mullions. The temperature sensors will measure temperatures throughout the components within the spandrel assemblies to capture the temperature profiles of the spandrel panels and overall system throughout the test.

The research program will test both curtainwall and window wall systems with various configurations and spandrel construction components, as shown in **Table 5**, through multiple rounds of hot-box testing at steady-state conditions. A total of 6 test articles and 18 variations will be tested.

In order to evaluate the impact of various components on spandrel thermal performance, variations to the spandrel panel construction will be made to the test articles for multiple rounds of testing. These variations will consist of discrete modifications of key

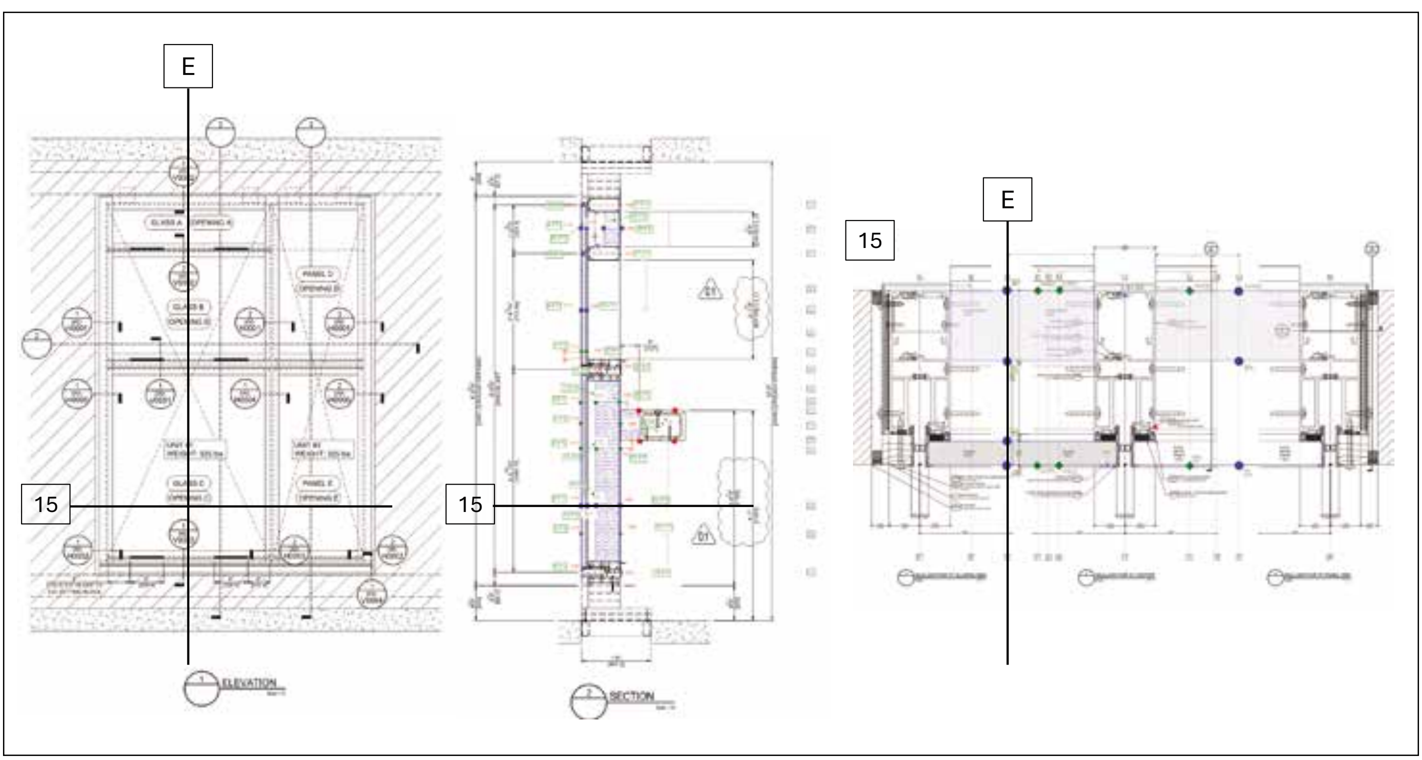

Figure 7. *Left: Elevation view of temperature sensor layout. Middle: Section view of temperature sensor layout. Right: Chamber sensor layout.*

Table 5. Proposed curtainwall and window wall system test articles and variations.

Description	Description
Stick-Built Curtainwall	**Unitized Curtainwall**
• Thermally broken aluminum captured system • Commonly used in industry • Individual components installed on-site	• Thermally broken aluminum structural glazed system • Commonly used in industry • Prefabricated panels shipped to and assembled on-site
Window Wall (Top Slip Anchor)	**Window Wall (Deflection Header)**
• Thermally broken aluminum • Supported on slab edge; mullion above and below slab • Greater integration with intermediate floor slab; less space available for insulation, leading to greater heat loss	• Thermally broken aluminum • Significant interaction with intermediate floor slab • More space for insulation outboard of slab • Opportunity to thermally break deflection header
Veneer System	**Next-Generation High-Performance System**
• Alternative to typical curtainwall systems allowing for wood or steel back sections • Individual components installed on-site	• Industry state-of-the-art high-performance systems • Aluminum-framed systems with insulation (*R*-40+)

components and will not impact the common panel layout of all tested systems. Temperature and airspeed sensors will be placed on, within, and adjacent to each test article to capture data that can be compared to simulations.

All laboratory testing will be carried out as part of Phase 2 of the research project.

CONCLUSIONS

Phase 1 of the research program has identified many gaps within industry research and the state of practice in relation to spandrel thermal performance within glazed wall systems. Some of the key findings of knowledge gaps within the industry from the literature review, industry survey, and interviews regarding the current state of use include:

- Glazed wall systems are prevalent across North America.
- Reported spandrel *U*-factors relying on 2-D thermal simulations may differ by more than 30% relative to 3-D thermal simulations and physical testing.
- The impact of adjacent assemblies, such as vision glazing and slab edges on spandrel performance, is not generally being accounted for, nor is it recognized by industry or associated codes and standards.
- Impediments to innovation include current code language, the lack of a procedure to accurately account for spandrel performance, and inconsistent enforcement of existing procedures.
- Ventilation of spandrels has a negligible impact on the product *U*-factor and temperatures.

These findings confirmed some of the industry gaps of the researchers and revealed additional gaps that the research program should address for the industry. One such topic was the impact of airflow through the spandrel in ventilated spandrel assemblies on thermal performance. 3-D CFD simulations were used to confirm whether ventilation through spandrel panels would impact thermal performance. Findings from the CFD simulations include:

- Discrete vent openings in spandrel assemblies have a marginal effect on the overall spandrel assembly *U*-factor. Spandrel ventilation will not be considered in laboratory testing and future simulations.
- Interior convective film coefficients vary from floor to ceiling and are higher below the slab edge than above the slab edge. The common practice of using a single interior film coefficient does not account for such variations.
- Overall thermal performance (that is, *U*-factor) varies minimally (0% to 6%) when calculated at standard size and configuration using NFRC 100 procedures with 6 in. (15.24 cm) edge using 2-D FEA thermal simulations versus 3-D CFD simulations.
- The primary differences between the 2-D FEA and 3-D CFD simulations are the geometry simplifications, radiative film coefficients, and air volume modeling assumptions used in the 2-D FEA thermal simulations.
- Future CFD studies may assist with an investigation into interior/exterior air film coefficients, which have been shown to significantly impact interior temperatures of assemblies with relatively low *R*-values.

Based on these results, ventilated spandrels were not included in the test program. Instead, the test program focused on laboratory testing of 6 test articles with 18 spandrel variations that represent various glazed wall systems and spandrel configurations. The test program will measure surface temperatures throughout the spandrel assemblies through multiple rounds of hot-box testing at steady-state conditions. The test articles will be arranged to include multiple spandrel panels of different sizes and a truncated concrete intermediate floor slab to evaluate the thermal bridging impact of slab anchorages and bypass details. The test articles will be designed such that multiple components may be replaced in between rounds of testing to allow for variations in spandrel components and configuration.

NEXT STEPS

The researchers have developed a detailed plan for Phase 2 in collaboration with the research team, test laboratory, and industry champion that includes testing and modeling of the 6 test articles, each with 3 variations, for a total of 18 variants. Supplementing the measurements with 2-D and 3-D simulations will enable the development of procedures that can be universally applied, developed into standards, and adopted by building energy codes and standards. Specifically, Phase 2 will include the tasks noted below:

- **Laboratory Testing:** Laboratory testing will be performed at ORNL and will collect temperature measurements for comparison with 2-D and 3-D simulations. A summary package that includes relevant documentation and measurements that enable independent researchers or professionals to conduct additional investigations or calibrate future 2-D and 3-D simulation techniques/software will be provided.
- **Thermal Simulations:** Construct 2-D and 3-D simulations of select details. Compare simulated and measured test results of select details. A detailed comparison will be provided in Phase 3.

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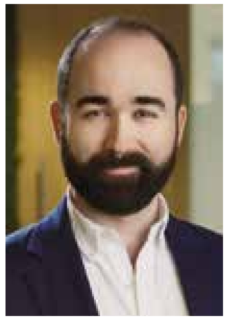
ABOUT THE AUTHORS



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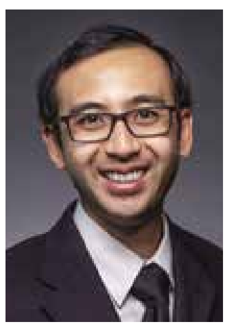
As a principal and senior building science engineer, **Daniel Haaland** *supports RDH Building Science's core practice areas, including building enclosure consulting and facade engineering, while also contributing to numerous training activities and publications. He leads a team of engineers dedicated to assessing the thermal performance of building enclosure systems and assisting clients in achieving their low-energy/high-performance targets. As the lead author of several industry guidelines and standards related to thermal modeling, including the CSA Z5010 standard and the THERM Passive House window simulation procedure, Haaland is an industry leader in the field.*



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With over 14 years of experience, **Ivan Lee** *is the leader of Morrison Hershfield's component modeling team, focusing on hygrothermal and thermal modeling. He applies his background in building science and modeling to evaluate the performance of building assemblies. Using 2-D and 3-D thermal simulations, he evaluates thermal bridging and condensation risks in building assemblies to establish effective thermal performance of the building envelope for manufacturer products and systems, new construction, and low-energy retrofit projects. He is also the co-chair of the Thermal Bridging Working Group of the Structural Engineering Institute Sustainability Committee, bringing awareness of thermal bridging to engineers in the industry.*

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