Feature

Can You Feel the Heat?

Cross-Typology Building Facade Performance Evaluations Using Infrared Analysis

By Stephen Holland, RRC, PE, and Terrance Dumoulin, EIT

THE AUTHORS' TEAM was fortunate to conduct a study of 17 structures on a higher education institution's campus in the northeastern US. The institution desired a deeper understanding of performance across its dormitory buildings on the main campus to inform master planning efforts focused on energy-use reduction and future grid electrification. The buildings were constructed between the late 19th century and the mid-20th century and vary in type among wood-framed, mass masonry, masonry veneer, and precast concrete facade structures. All of the buildings are used as housing, regardless of the construction types. The programmatic similarity offers a unique opportunity to study the underlying methodology of infrared (IR) thermographic scans across and between building typologies without having to account for programming as a confounding variable.

ASTM E1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems,*[1] provided the basis for the study. The goal was to identify heat loss through building enclosures, and IR thermography is an excellent way to capture this. In an IR image of a building facade, adequately performing components will appear dark, which indicates colder temperatures. This is because heat is not being transferred through the building enclosure, and the components are the same temperature as the exterior. If a component appears lighter in the image (that is, warmer), it can indicate an anomaly where heat from the building is escaping, generally in the form of thermal bridging or air exfiltration (**Fig. 1**).

Figure 1. *Thermal anomalies across the precast concrete building's facade.*

Relative to building enclosures, thermal bridging refers to heat flow through a thermally conductive element (for example, steel or concrete) penetrating through or bypassing layers of an assembly with lower thermal conductivity (for example, insulation). In IR imaging, this phenomenon often presents as a discrete area of the total facade area registering a notably different color (temperature) compared to its surroundings. Air leakage can occur when warm air is transmitted through gaps in the enclosure along a temperature or pressure gradient to the cooler exterior. Air leakage presents as faint, warm temperature clouding at discrete building areas in IR imagery. Thermal bridging and air leakage both have a negative effect on a building's performance, as the enclosure transfers heat at undesirable rates or experiences increased levels of exfiltration, respectively. For this project, the IR scans were performed in January, providing a sufficient temperature differential between the interior and exterior spaces. Wherever possible, the buildings were positively pressurized to amplify the effects of air exfiltration and make them more visible.

The variety of building types and ages in the study highlighted how

- different typologies present differently in IR studies
- similar anomalies on different building types necessitate different repairs.

OPAQUE WALL ANOMALIES

The field of the wall offered the first insights into typological building differences. At the precast concrete facade structure studied on campus, thermal anomalies were present in discrete dots along horizontal lines across the building. Based on the team's knowledge

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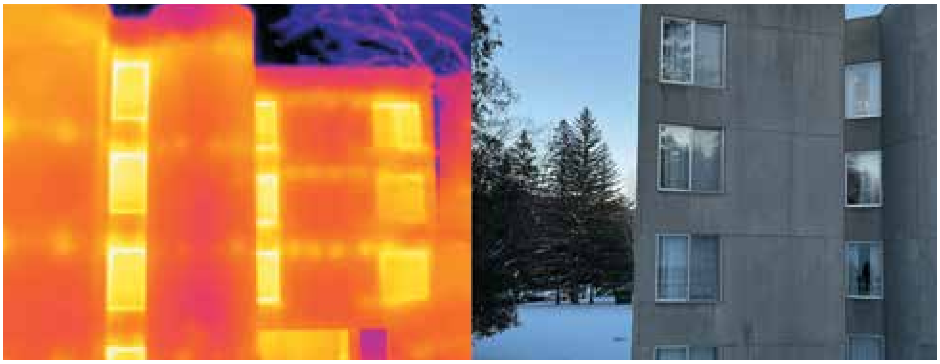

Figure 2. *Thermal bridging at slab-to-wall connections.*

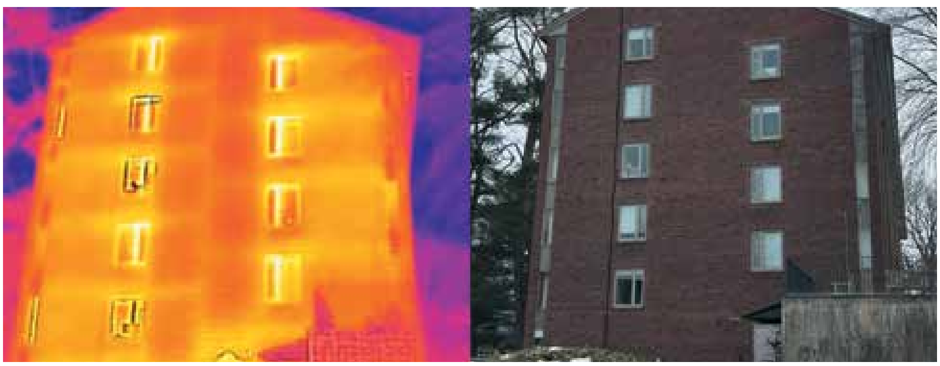

Figure 3. *Slab thermal bridging at a masonry veneer assembly.*

Figure 4. *Missing bays of insulation at a wood-framed building.*

of this building's age, the precast concrete panels are likely hung off of the floor slabs. These discrete dots of increased heat transfer align with steel connections from the interior structural slab anchors to the wall outside. Without any insulation to impede the flow of heat, every individual connection appeared brighter than its surroundings (**Fig. 2**).

Across the five masonry veneer structures studied, thermal bridging took a different form. Whereas the precast concrete panel system had individual anchor locations along intermediate floor slabs, the concrete slab itself extended into the wall cavity at locations with a masonry veneer. The result in the thermal imaging was clear, bright lines showing exact locations of slab intersections (**Fig. 3**). In contrast, the expected point thermal bridges resulting from masonry tiebacks to the superstructure behind did not appear on thermal images.

At the wood-framed buildings, there were full-floor-height thermal anomalies with what appeared to be significant thermal bridging. This building type and vintage presumably includes wood stud walls filled with insulation. However, it would not contain wide, vertical structural members that would explain the thermal bridging. This led to the realization that the culprit was missing insulation between the wood studs, not thermal bridging (**Fig. 4**).

For all three examples, each uncovered anomaly dictates a different repair:

- **Precast Concrete Panel Building:** Because the panel-to-slab connections are integral to the structure of the building, they cannot be removed. However, continuous exterior insulation installed over the concrete would mitigate these thermal bridges. The team opted for an overclad solution with exterior insulation and cladding added over the concrete surface. This was chosen for a myriad of reasons, but it is an ideal solution for addressing the anchor thermal bridges.
- **Masonry Veneer:** In this instance, an overclad option was not possible because masonry veneer cannot support the loads of new cladding. At the same time, interior insulation would not reduce thermal bridging at slab edges. Instead, the wall type would require a reclad where the brick is stripped down, insulation is added, and the brick is replaced. This was deemed impractical for the project and was not pursued.
- **Wood-Framed Building:** The easiest solution of the three, the insulation was installed into the missing bays.

WINDOW ANOMALIES

The next variety of thermal anomalies was present at the windows. At the mass masonry and wood-framed buildings, each window included a single-paned, single-hung, wooden fenestration with a single-paned exterior storm window. The assembly was identical at each window, but the IR scan showed a very different story. Some windows were cold, some were hot, and some appeared to be open despite outside temperatures below 10°F (–12°C) for the duration of testing. During the daytime analysis, it was apparent that occupants often had either their window or storm window closed, but not both (**Fig. 5**). During interviews with occupants, some were unaware they had two windows to close. Others said they enjoyed the external cooling to counteract their robust heating units. The project team noted this as an opportunity for facilities to align heating set points and loads with occupant thermal comfort. While the human element was affecting performance, the windows were free

Figure 5. *Varying window positions reveal opportunities for educating occupants on proper closure practices.*

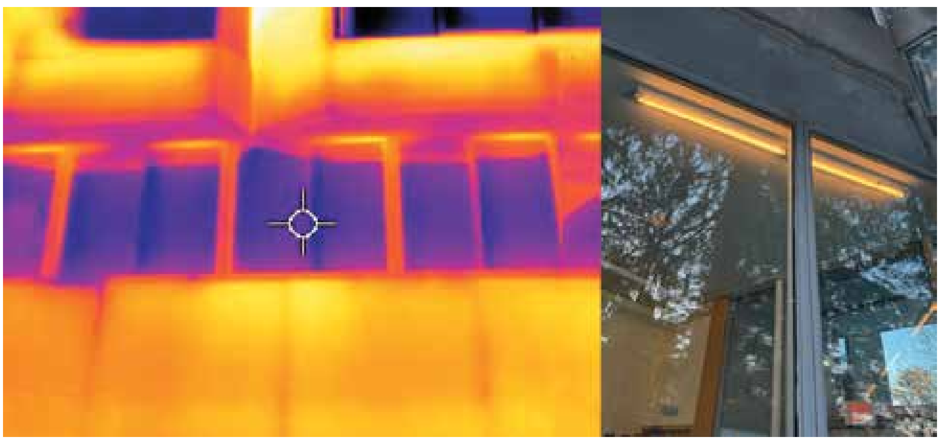

Figure 6. *Air leaks present along window heads and meeting rails.*

Figure 7. *Air leakage at a mass masonry wall to roof transition.*

of any thermal anomalies if they were properly closed. The sealant joints between the windows and rough openings proved to be intact here as well.

At the precast concrete facade building, the typical upper-floor window included an aluminum-framed sliding window that exhibited significant air leakage from the head and meeting rail (**Fig. 6**). This was not surprising, as sliding windows and hung windows are difficult to gasket seal. This is further compounded by age, as the windows are nearly 50 years old. While the sealant joints were generally continuous, they appeared brittle and otherwise showed their age. All masonry veneer buildings on campus experienced similar window deficiencies to the precast concrete structure.

The repairs for the windows broke down into the following categories:

- **Mass Masonry and Wood-Framed Buildings:** The team opted to inform occupants and facility members about the importance of closing both their windows and storm windows. The mechanical equipment was also reviewed for better occupant control. These windows are earmarked for replacement over the next 10 years, but the institution is utilizing these temporary measures to improve performance in the interim.
- **Precast Concrete Facade and Masonry Veneer Buildings:** These windows will be replaced with modern fenestrations due to widespread air leakage and lack of feasible retrofit options.

GENERAL THERMAL ANOMALIES CAUSED BY AIR EXFILTRATION

Looking more generally at air exfiltration through the enclosure, many different thermal anomaly types were present at transitions. Every building studied on campus experienced air leakage through at least one assembly or location. While much of this can be attributed to the fact that buildings were constructed prior to the widespread adoption or codification of air-control layer design, air leakage may also be a result of worker-quality defects during construction, inadvertent enclosure defects during maintenance, or the natural breakdown of elements as buildings age.

The mass masonry buildings rely on their homogenous mass to mitigate air infiltration. The structures investigated displayed little dramatic air leakage. Air leaked from window surrounds, but exterior-applied storm windows often mitigated this phenomenon. Air exfiltration was most prominent at the roof eaves, where the walls transitioned into the steep-slope slate or low-slope membrane roof replacement systems (**Fig. 7**). This is unsurprising given that watertightness was often prioritized over airtightness at these transitions for buildings of this vintage.

Similar to the mass masonry structures, the precast concrete panel building's continuous wall system acts as a generally adequate air barrier within the field of the panels. Unlike the mass masonry structures, the precast concrete building was originally designed with a single-ply membrane flat roof. This membrane could be easily integrated with precast concrete panels for an airtight connection. For sealing purposes, air barrier continuity is maintained by sealing the windows and doors directly to the surface of the concrete. During the investigation, windows had to be carefully examined to determine whether a thermal anomaly was present at the entire window surrounds or only at parts of the window. While most of the punched windows leaked, the larger curtainwall at the front of the building was generally performing adequately, save for discontinuous sealant joints at the sill (**Fig. 8**).

The wood-framed and masonry veneer buildings likely do not have modern continuous self-adhered air barriers, but a combination of unadhered building wrap, roofing felts, and mastics that help mitigate air infiltration. Most air leakage occurred at facade plane transitions, such as at corners or into the roof. At highly complex transitions where multiple assemblies converged, air flowed uninhibited to the exterior (**Fig. 9**). Air exfiltration findings at these locations highlighted the complex nature of wall-to-roof transitions, especially at steep-slope roofs.

Yet again, the different causes of thermal anomalies required different treatments:

- **Mass Masonry Buildings:** While these buildings have minimal air leakage, the team has discussed installing spray foam on the interior at the roof-to-wall connection to mitigate the thermal bridging. This same repair would be difficult to perform on the exterior without significant roofing work. Spray foam installation also mitigates air leakage through the field of the wall.
- **Precast Concrete Panel Building:** Because the team considered the precast concrete to be the component providing airtightness, air barrier continuity can be maintained by re-establishing the seals of the concrete panels to the curtainwall. Any discontinuous sealant joints were replaced.
- **Wood-Framed Buildings:** These walls represent primitive versions of rainscreens, which rely on a sacrificial cladding capable of shedding most bulk water. However, they are not the assembly component providing weathertightness. While not an ideal air

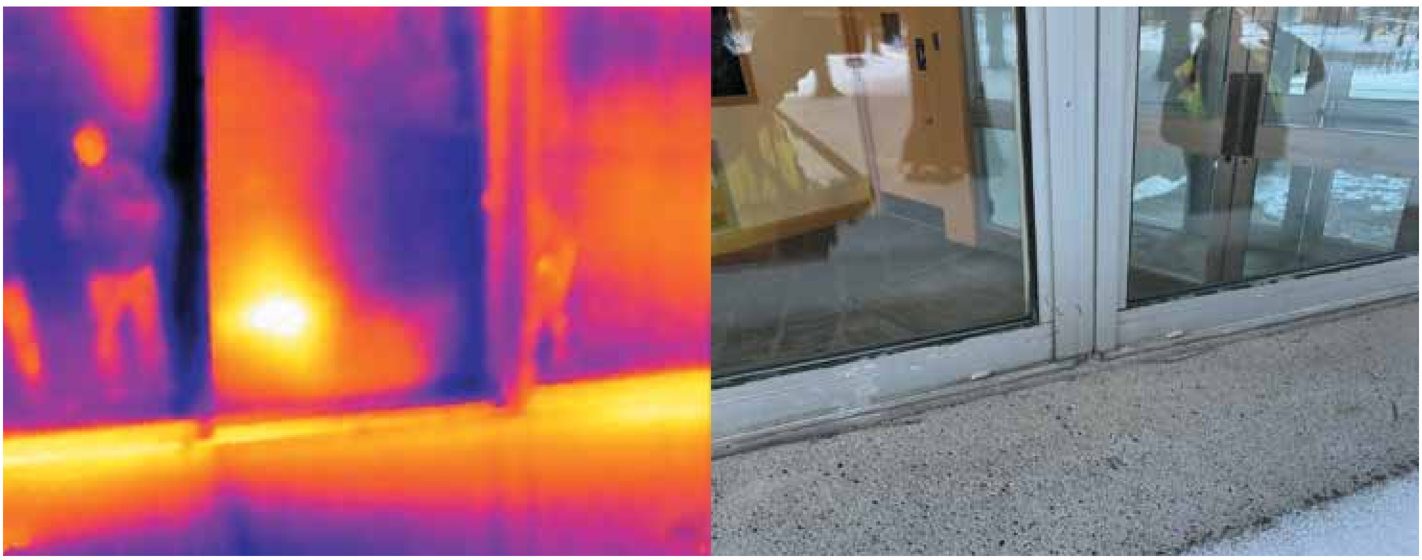

Figure 8. *Air leakage at a discontinuous sealant joint at the curtainwall-to-concrete connection.*

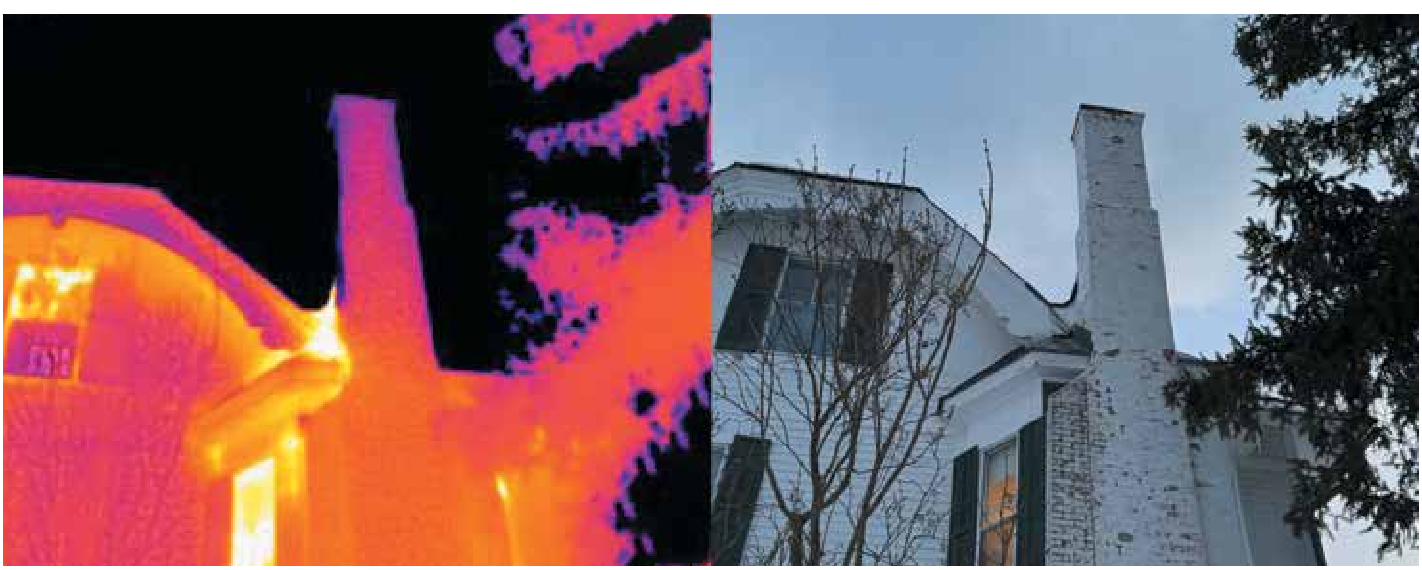

Figure 9. *Complex transitions at wood-framed buildings result in barrier discontinuities.*

barrier, the unadhered building wrap behind the wood siding and roof was identified as the best location to establish an air barrier. Unlike precast concrete panels, the component providing airtightness is not at the surface and requires cladding removal. The wood siding was temporarily removed, and a modern air barrier was integrated with the existing building wraps and roofing papers as best as possible given their aged nature. Last, a sealant joint to the masonry chimney was installed.

CONCLUSIONS

IR scans proved to be an effective tool to identify the sources of heat loss in the building enclosures that were evaluated by the authors' team. Improving building enclosures is an essential component in mitigating energy consumption by reducing the need for space heating and cooling. In a 2023 study performed by the US General Services Administration, air leakage alone accounts for as much as 4% of the energy used in the US.[2] As the industry progresses toward decarbonization, net-zero buildings, and a general reduction of consumption, enclosure retrofits are important to consider.

While new buildings have the benefit of modern technologies that can provide robust thermally broken and airtight assemblies, many institutions need to continue using their existing building stock. A recent study asserts that an estimated 80% of 2050 building stock in the northeastern US has already been built.[3] On top of the practical and financial reasons for reuse, existing buildings provide the historical and cultural fabric that institutions identify with.

As we use these IR tools, it will be important to understand how different building typologies are designed to work. The designer needs to ask themselves the following: What components form the air barrier and thermal barrier layers? How can we maintain and improve these layers? What modifications are each of these buildings capable of? Overcladding can be an option for precast concrete facade buildings, but not for brick veneers. Storm windows and their proper use have successfully improved many residential-sized hung windows, but they might not be an option for larger-format windows. Replacing sealant joints will improve mass masonry and precast buildings, but buildings with rainscreens will require their outer cladding layer to be removed to reseal the air barrier.

The depth of impact of this type of study, particularly across building types, highlights the importance of incorporating enclosure consulting efforts at the earliest stages of building design. It is essential to have a qualified building enclosure consultant as part of an IR thermographic analysis team to help analyze the data and aid in developing design recommendations. Anomalies are easy to identify, but selecting the correct repair can be difficult. With the combination of IR scan results and enclosure consultants' knowledge of these different building vintages, the appropriate repairs can be selected.

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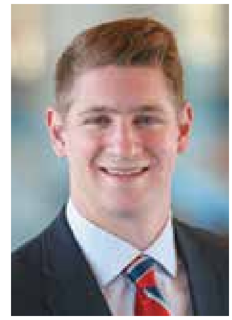
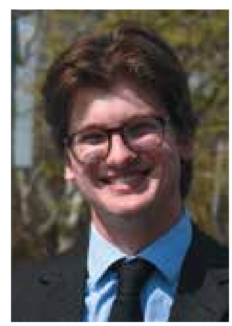
ABOUT THE AUTHORS



STEPHEN HOLLAND, RRC, PE

Stephen Holland *is an enclosure engineer at LeMessurier Consultants Inc., practicing in the Greater Boston area. He has experience in the investigation, rehabilitation, and design of a variety of enclosure systems, including roofing, glazing, masonry, cladding, waterproofing, insulation, and below-grade systems. He has specialized in the restoration and retrofitting of enclosure systems in existing and historic buildings. He is a registered Certified Passive House Consultant through Passive House Institute US and a Registered Roof Consultant through IIBEC. He has served as a chair of the Boston Building Enclosure Council and is an active member of ACE Mentoring.*



TERRANCE DUMOULIN, EIT

Terrance Dumoulin *is an enclosure professional at LeMessurier Consultants Inc., practicing in the Greater Boston region. His experience includes investigative, restorative, and design work with roofing, historic wall assemblies, glazing, below-grade systems, and waterproofing. His focus lies at the intersection of enclosure assembly simulation and deep energy retrofit design. He is a registered Engineer-in-Training.*

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