Building Enclosure Design

Thermal Imaging Helps Locate Enclosure Air Leakage

By Dave Bohac, PE

Most building professionals used to think large buildings were fairly airtight, assuming that air leakage did not significantly impact on energy consumption. After powerful studies were published by scholars from the National Institute of Standards and Technology (NIST)—one on modeling by Andrew K. Persily; the other on measured data from real-world buildings by Steven J. Emmerich—the emphasis shifted to creating tighter enclosures in new buildings and sealing existing buildings. In fact, 12 states have since incorporated air-barrier requirements into their energy codes for new commercial and institutional (C&I) buildings.[1]

Effective enclosure commissioning often includes a whole-building leakage test and air-leakage investigation. The leakage test determines whether the specified tightness has been achieved, while the investigation finds remaining air leakage that should be addressed. A protocol developed by the U.S. Army Corps of Engineers has found this approach effective, especially when combined with the Army's requirement to pass its required air-leakage test (of 0.25 cfm/square foot total enclosure surface area at a pressure of 75 pascals) before construction payments can continue. To quantify and assist the location of leakage points, the protocol requires a testing agency to perform an investigation in accordance with the air-leakage standard, *ASTM E1186-03*[2], and that such an investigation includes thermal imaging.

One of the most effective investigation methods is to combine thermal imaging (an infrared, or IR, scan) with a visual investigation of leakage sites. The IR scan can investigate large sections of an enclosure surface in a relatively short amount of time to identify likely leakage locations. However, an IR scan alone does not provide sufficient information to eliminate leakage. Identified locations also must be investigated with visual, acoustic and/or smoke puffer methods to determine the leakage path and severity, as well as sealing options. Adding an IR scan to the process helps assure that isolated leakage sites are not missed. Plus, it helps locate leaks that occur over a broad area.

Performing the IR Scan

The optimal approach is to scan under two sets of pressure differences. First, scan with the building pressure adjusted so that air leakage through the enclosure is away from the point of observation. For example, for an exterior scan, start with the building depressurized so that air leakage moves into the building (e.g., infiltration). In this condition, the thermal patterns of the building exterior are not affected by air leakage. Second, repeat the IR scan with building pressure reversed. Changes in the building exterior thermal patterns likely will be due to the outward induced air leakage. During hot weather, the outward air leaks appear as "cold spots" on the exterior. During cold weather, the location of major air leakage appears as "hot spots," as the outward air leakage warms a building exterior.

In addition, an IR scan can be conducted from a building interior. For interior scans, the building first is pressurized (outward air leakage), and then the scan is repeated with the building depressurized (infiltration).

Scanning from inside or out depends on access and weather. From the exterior, larger building sections can be covered, but

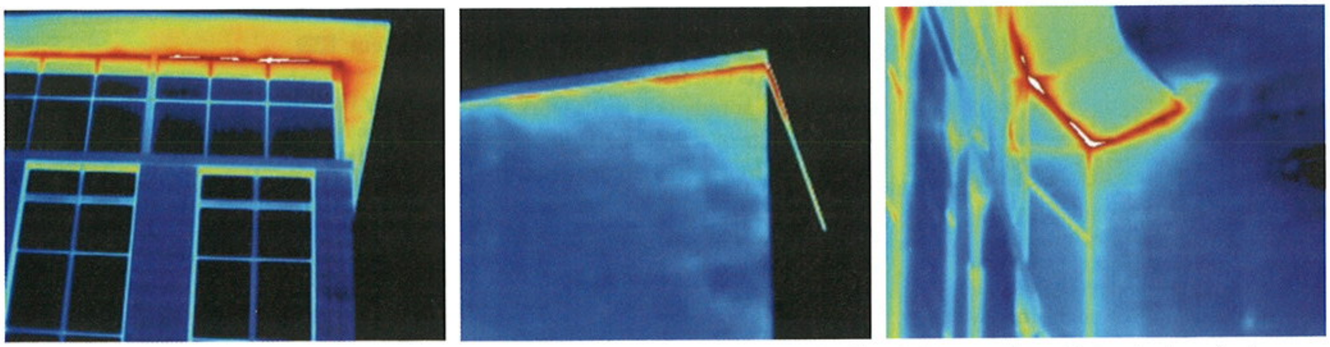

Figure 1: Exterior IR images with the building pressurized. Thermal anomalies indicate roof/wall air leakage confirmed by interior investigations.

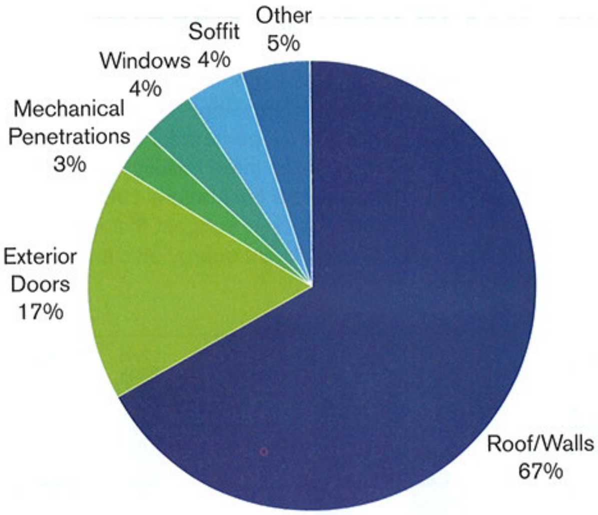

Figure 2: Distribution of leakage area by type of leak, according to a recent State of Minnesota-funded project.

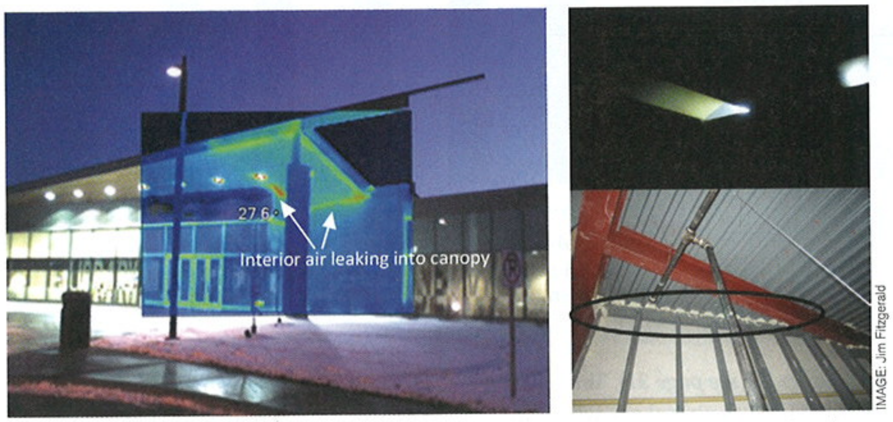

Figure 3: IR image of canopy air leakage (left), with gaps circled (right) between the wall and the corrugated roof deck.

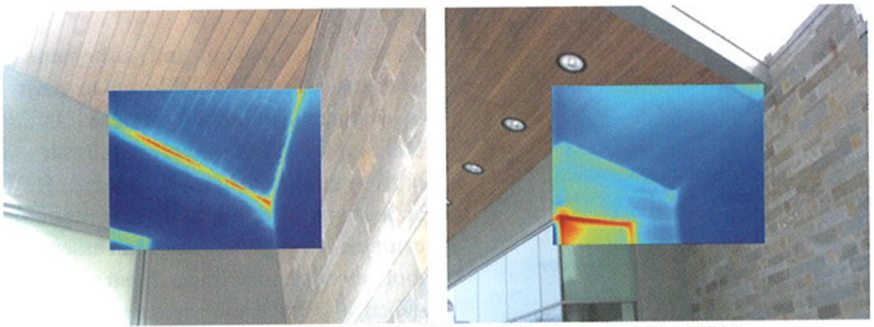

Figure 4: IR images of wall/roof joint before (left) and after foam air sealing (right).

direct sun on surfaces, windy conditions, acute viewing angles and reflections may not result in useful images. *[Author's Note: Bret Monroe's article, pages 26-27, includes suggestions on handling wind, sunlight, occupant activities and reflections when conducting a building scan.]* Oftentimes, these issues are not as much of a concern with interior scanning, but viewing may be difficult—particularly in existing buildings with finished surfaces and the associated clutter of furniture blocking an IR camera's view of an exterior wall.

When pressed for time, experienced thermographers often conduct a scan only under a single pressure difference. Usually, the thermal pattern of most air leaks can be distinguished from other thermal issues and shortcomings. Still, the IR scan must be followed up with a visual inspection to confirm air leakage and sealing options. Visual inspection will limit the potential for "false positive" findings from thermal images that are not due to air leakage.

Where to Look and Seal

Although the durability of air-barrier materials is important, air-barrier continuity is the primary requirement for limiting air leakage—in short, no gaps, cracks or holes. The greatest challenge is to effectively seal joints, interconnections and penetrations. As noted by Appendix E of the *IEA ECBCS Annex 46 Energy Assessment Protocol*[3] the highest priorities for sealing air leakage are: (1) top of the building; (2) bottom of the building; (3) vertical shafts; (4) outside walls; and (5) floor-to-ceiling compartmentalization (separation between floors).

Recent field measurements confirm that air leakage tends to be greatest at the top of a building. ASHRAE measured 16 recently constructed buildings[4] and found the most common large leakage sites were:

- Intersections of roofs and vertical walls.
- Roof soffits and overhangs.
- Connections that join conditioned spaces to non-/semi-conditioned spaces (e.g., mechanical rooms, garages, basements, loading docks).
- Roll-up exterior doors, primarily at the top of those doors.

"Figure 1" (*see opposite page*) displays IR images of roof/wall air leaks for one of the measured buildings.

Contractors also are air sealing existing building enclosures using the same investigation techniques. Recently, a State of Minnesota-funded project was conducted to expand the limited data on measured whole-building, air-leakage reductions from sealing. Another research goal was to discover and confirm methods for estimating any resulting energy savings. This project measured 26 C&I buildings and performed air sealing for eight of those buildings. Air sealing targeted larger gaps that were accessible, with little or no damage to surrounding materials. Over the 26 buildings, 67 percent of the area to be sealed occurred at accessible wall/roof joints; 17 percent at exterior door weatherstripping; and the remaining 16 percent spread fairly evenly between soffits, windows, mechanical penetrations and other locations (*see "Figure 2," above*). Only two of the buildings had less than 40 percent of the sealing for the roof/wall joint. This

Continued on page 22

Mechanical Systems Contribute to Enclosure Leakage

When ventilation systems are operating and dampers are opened to regulate airflow, damper leakage is typically not a concern. However, when air handlers and exhaust fans are off, the dampers become part of the building's air barrier, and damper leakage causes additional building air infiltration or exfiltration. This includes outside air, relief air and exhaust fan dampers. Damper leakage is more of a concern for buildings in which the mechanical systems are off a greater amount of time.

Whole-building, air-leakage tests are typically conducted with temporary seals on mechanical dampers or penetrations. For a recent project, researchers also conducted a single-point test with the seals removed. Findings showed mechanical-system leakage increased the enclosure leakage by 17 percent, to 103 percent (*see "Figure 5"*).

Not surprisingly, higher mechanical leakage often occurs in older buildings. For the four buildings in the project built before 1985, the average mechanical leakage (as a percentage of envelope leakage) was 64 percent; in contrast, it was only 21 percent for the two buildings built after 1985. Moreover, the three buildings with the greatest mechanical leakage were built before 1968. These results, as well as other similar studies, suggest that improving damper tightness offers a significant energy-efficiency opportunity to existing buildings.

Gaps at the top and bottom of an outside air damper.

IMAGE: Jim Fitzgerald

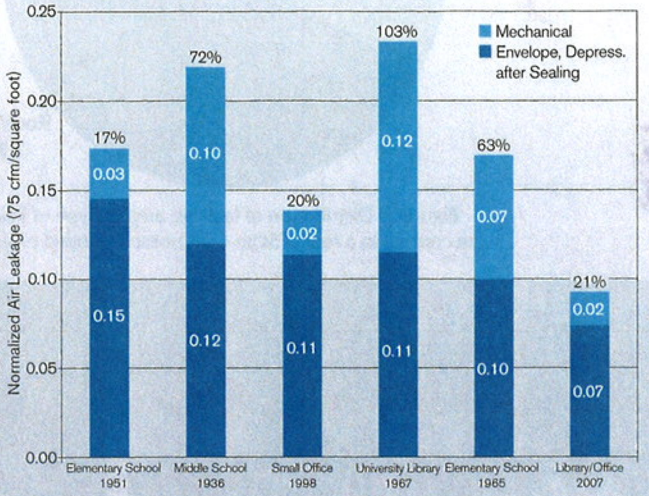

Figure 5: Whole-building leakage tests were conducted, with mechanical penetrations sealed (dark-blue bars) and unsealed. Light-blue bars show additional leakage due to the mechanical systems.

further confirms that an air leakage investigation should prioritize the top of a building.

An example of before-and-after thermal imaging from this project is shown in "Figure 3" (*see page 21*). The initial IR image shows air leakage where walls meet the canopy. A visual inspection found air leakage in the gap between the flutes of the corrugated roof decking and the wall (*see circled area in right image*). Once openings were sealed with two-part foam, hot spots at the wall/roof joint were significantly reduced (*see "Figure 4," page 21*).

Overall, thermal imaging has become a very useful and affordable tool to assist in locating major building air leaks. As building codes increasingly require air barriers and the field measurement of air leakage, the thoughtful use of thermal cameras is rapidly becoming an essential tool for code compliance. It also offers effective, visual feedback to designers and contractors to ensure project success. JNIBS

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[2]*ASTM E1186-03: Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*, (2009). ASTM International, West Conshohocken, Pa. **www.astm.org**.

[3]*IEA ECBCS Annex 46*, (2009). International Energy Agency Energy Conservation in Buildings and Community Systems Programme Annex 46. **www.ecbcs.org/docs/ECBCS_Annex_46_Energy_Process_Assessment_Protocol.pdf**.

[4]Brennan, T.; Anis, W.; Nelson, G.; Olson, C. (2013). "*ASHRAE 1478:* Measuring Air-Tightness of Mid- and High-Rise Non-Residential Buildings." Proceedings of the Thermal Performance of the Exterior Envelopes of Whole Buildings XII International Conference.

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