HOW LEAKY IS YOUR BUILDING? CASE STUDIES OF TWO WHOLE-BUILDING AIR LEAKAGE TESTS

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ABSTRACT

Air leakage testing is used to qualitatively identify or quantitatively measure air leakage through the building enclosure. The testing process involves pressurizing a space (e.g., a room in an apartment complex, building floor, whole building, etc.) with blower door fans to create a pressure differential across the building enclosure. For qualitative tests, tracer smoke or an IR camera are some of the available diagnostic tools used to detect air leakage paths through the envelope. Quantitative tests require experimental measurement of air leakage through the envelope; the results are used to refine energy models for retrofit projects, improve mechanical system operation or reduce system size, or demonstrate compliance with energy codes or project specifications for new construction.

The need for quantitative testing continues to increase as energy code requirements for airtightness become stricter and designers include airtightness targets for specialty high humidity buildings such as pools and museums. The 2012 International Energy Conservation Code (IECC) is the first ICC code to require a dedicated air barrier for the building enclosure; the 2012 IECC allows whole building air leakage testing to demonstrate air barrier compliance. Although only four states have currently adopted the 2012 IECC, states including New York and Washington State amended their state energy codes to specify maximum whole building air leakage rates and allow or require whole building air leakage testing to demonstrate energy code compliance.

This paper will briefly summarize building code requirements and industry standards and provide quantitative air testing case studies of a new art museum and an existing high-rise residential tower to illustrate air testing execution and results. This paper will also demonstrate how air leakage testing can be used as a diagnostic and forensic tool.

KEYWORDS

Quantitative air testing, whole-building air testing, commercial air testing, 2012 IECC

1. INTRODUCTION

Code officials and industry agencies in the United States are realizing the need for tighter building air barriers, and building codes are becoming stricter with respect to air barrier requirements in buildings. Continuous air barriers limit uncontrolled air leakage through building enclosures, thereby reducing building energy consumption, allowing more-precise control of building interior conditions, and preventing premature failure of building enclosure cladding systems in humidified buildings.

The 2012 International Code Council (ICC) codes, some state building codes, and several government agencies are beginning to require quantitative field testing to measure the air leakage rate in whole-buildings to demonstrate compliance with predefined target air leakage rates. Building codes recognize that it is not possible to determine the whole-building air leakage rate analytically or through computer simulation due to building complexity, the wide range of air barrier materials, vast differences in air barrier installation workmanship and quality, and a general lack of data for commercial building airtightness. Quantitative air test results are not only used to demonstrate compliance with energy codes or project specifications for new construction but also to refine energy models for retrofit projects, improve mechanical system operation, and reduce system size. Due to the high cost and disruption associated with repairing air barrier breaches postconstruction, air leakage testing is a useful and efficient diagnostic tool to identify and repair locations of air barrier breaches during construction.

2. PROBLEMS WITH DISCONTINUOUS AIR BARRIERS

In general, the air barrier system consists of a combination of materials joined in an airtight manner to restrict air infiltration or exfiltration through the building enclosure. An air barrier must be able to resist pressure differentials without tearing or displacement. Because air barriers are often membranes or, in some instances, sheet goods, they must be well attached to a solid substrate to be able to resist the pressure drop across them. To be effective, these systems must be continuous at walls, roofs, penetrations, and transitions between systems to prevent the uncontrolled passage of air. The term “uncontrolled air” is used because the air barrier materials, assemblies, and system allow a small amount of air to pass through each component as defined by the industry standards or building codes. Most problems arise when breaches, voids, and other defects allow large quantities of air to bypass the air barrier. These defects often occur at penetrations (e.g., structural steel or conduit penetrations through the air barrier material) or at cladding intersections and transitions.

Air barriers that contain voids can have several consequences depending on climate and building pressurization. Primarily, heat/cooling loss through air barrier breaches results in poor mechanical system performance requiring additional energy to condition a building. As a result, building owners incur additional operating costs and potentially require systems to be replaced.

Uncontrolled air infiltration through the building enclosure can also allow environmental allergens/pollutants and other airborne particulates to contaminate interior air. In heating climates for all building types, uncontrolled air exfiltration can exacerbate icicle formation or ice dams at roof eaves (Photo 1) and increase the risk of condensation in wall assemblies and associated deterioration of cladding assemblies. This risk is greatest in specialty high-humidity buildings such as natatoriums or museums because of the high interior air dew point temperatures.

Photo 1: Severe icicle and ice dam formation at metal roof eave (arrow).

In cooling climates, exterior warm/moist air infiltration can cause condensation on interior surfaces and biological/mold growth within the building enclosure.

3. AIRTIGHTNESS INDUSTRY STANDARDS

Various standards or organizations provide guidelines for air barrier design and performance. Several building codes, including the 2012 IECC, incorporate air barrier installation and performance standards. The 2012 IECC is the first code published by the ICC that requires a continuous air barrier in commercial buildings, except for buildings in Climate Zones 1 through 3. The 2012 IECC allows designers several options to demonstrate air barrier compliance, one of which is to measure the air leakage rate through the building enclosure postconstruction (maximum whole-building air leakage rate of 0.40 cubic feet per minute (CFM) per square foot (sq ft) at 75 Pa (0.30 in. water) when tested per ASTM E779 – Standard Test Method for Determining Air Leakage Rate by Fan Pressurization). As a point of reference, 75 Pa (0.30 in. water) is the air leakage test pressure for a fenestration unit rated Commercial (CW) per the American Architectural Manufacturers Association (AAMA) Standard 101 – North American Fenestration Standard – Voluntary Performance Specification for Windows, Skylights, and Doors.

Many states are adopting air barrier provisions either explicitly or via the IECC. Washington is the first state to require whole-building air leakage testing prior to building occupancy. The target air leakage rate through the enclosure is 0.40 cfm/sq ft at 75 Pa (0.30 in. water). However, Washington State only requires that the air leakage rate be reported for information purposes, and passing the test is not required to obtain a certificate of occupancy.

The following industry organizations publish standards for building airtightness performance levels, summarized below:

- U.S. Army Corps of Engineers (USACE) requires that all buildings be field tested and demonstrate a maximum air leakage rate of 0.25 CFM/sq ft at 75 Pa (0.30 in. water) pressure differential, which is stricter than the 2012 IECC. Recent USACE studies show that both small and large buildings are meeting or exceeding the 0.25 cfm/sq ft airtightness requirement.
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 90.1-2010) requires continuous air barriers for most commercial buildings but does not require field testing to demonstrate compliance.
- The U.S. General Services Administration (GSA 2010 P100 standard) allows a field test to demonstrate a maximum whole building air leakage rate of 0.40 cfm/sq ft at 75 Pa (0.30 in. water) pressure differential.
- Air Barrier Association of American (ABAA) established a guideline of 0.40 cfm/sq ft at 75 Pa (0.30 in. water) for new commercial buildings with continuous air barriers but does not require field testing to demonstrate compliance.

4. TEST METHODS

Performing whole-building air infiltration testing can help verify the performance of air barrier installations as well as locating defects in the system. For new construction, it is prudent to perform testing before the air barrier system is concealed by cladding materials or interior finishes so that defects can be identified and repaired more easily. Removing cladding postconstruction to locate and repair air barrier discontinuities is often costly and disruptive to the building occupants.

Field testing requires that the building be positively or negatively pressurized using blower door fans or manipulating the HVAC system to force air to leak through any air barrier discontinuities in the building enclosure. Various quantitative and qualitative techniques are available to identify air leakage paths, including infrared (IR) thermography and tracer smoke. These tests should be discussed with the project team early in the design process and required by the project specifications so that they are scheduled at the appropriate time during construction.

Qualitative Air Infiltration Testing. ASTM E1186 – Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems – describes various qualitative methods to locate air barrier discontinuities. One such practice is to pressurize or depressurize the building or individual spaces by using fans (Photo 2) or by manipulating the HVAC system, and then using a tracer smoke source over the interior or exterior surfaces of the building enclosure. Qualitative testing is generally performed prior to the quantitative testing to identify and repair air barrier breaches prior to measuring the air leakage rate.

Photo 2: Test setup for blower door test with calibrated fans.

Placing the tracer smoke source at the building interior and pressurizing the building or space to locate air exfiltration sites reduces the influence of wind or stack effect. In this case, tracer smoke will be drawn from the building interior through any breaches in the air barrier and be identifiable at the building exterior (Photo 3).

Photo 3: Tracer smoke exfiltration at roof eave (arrow).

Although it is possible for some projects to depressurize the building and locate the source of tracer smoke on the building exterior, this method may be difficult because of the influence of wind and the risk that the tracer smoke will rapidly dissipate before it is drawn into the building interior through the air leakage site.

IR Thermography. IR thermography (per ASTM E1186) is another useful and efficient qualitative method to locate discontinuities in the air barrier. The purpose of the IR scans is to identify locations of elevated heat loss through the building enclosure. Air infiltration or exfiltration through the building enclosure modifies temperatures of wall components in the region of air leakage pathways, given an interior and exterior temperature difference; IR scanning equipment can be used to detect local surface temperature differences (Photo 4).

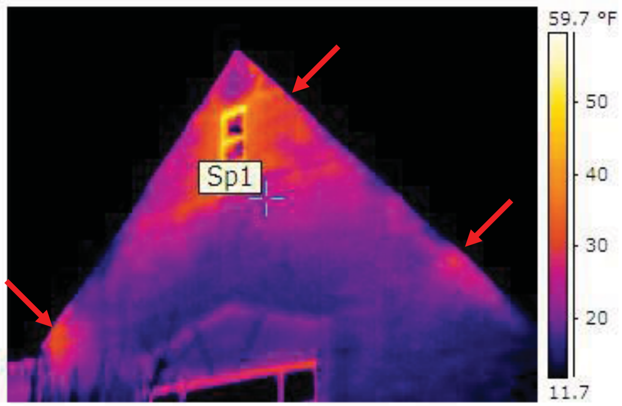

Photo 4: Infrared image of exterior wall taken during the winter in a heating climate. Orange/yellow regions indicate locations of elevated heat loss (arrows).

The conditions most conducive to accurate IR scans are low winds with a large temperature difference (at least 20°F) between the interior and exterior air temperatures. Additionally, IR scans should be performed before sunrise or after sunset to maximize the temperature difference between the interior and exterior as well as to avoid false readings due to solar exposure. Depending on the building pressurization, the IR scans can be conducted from the building interior or exterior. Using fans or the HVAC system to pressurize or depressurize the building during the IR scan can exacerbate air leakage through discontinuities in the air barrier, making it easier to identify air barrier breaches on an IR image.

Quantitative Air Infiltration Testing. Blower door testing per ASTM E779 is intended to characterize the airtightness of the building enclosure. The test results can be used to compare the airtightness of the subject building to similar buildings or against criteria set by industry standards or governing building codes. The tests are conducted using calibrated fans (Photo 2) to pressurize and depressurize the building under controlled conditions.

The ASTM E779 test procedure typically requires a range of induced pressure differences (pressurization and depressurization) from 10 Pa to 60 Pa. The measured air leakage flow rates (cubic feet per minute) are typically normalized by the building surface area (walls, roof, and floor) and calculated as the average of the pressurization and depressurization at 75 Pa (0.30 in. water) pressure difference using the air flow equations provided in ASTM E779.

Should the initial results of the ASTM E779 test exceed the air leakage rates required by the project specifications, various qualitative testing methods such as tracer smoke and IR testing are available to help identify breaches in the air barrier system.

5. AIR LEAKAGE TEST PLANNING

Quantitative whole-building air leakage testing is a labor and equipment-intensive process. In the authors' experience, the most successful tests are planned at least one month in advance to allow sufficient time to develop and fully vet the project specific testing procedure and coordinate with facilities personnel. The following highlights some, but not all, considerations for air leakage test preparation and execution:

- **Initial Planning** – Review the construction documents, if available, to assist with estimating the air leakage rate and required field equipment (i.e., blower door fans); the estimated air leakage rate depends on the presence and continuity of an air barrier. Performing a field visit to verify as-built conditions will reduce unanticipated conditions identified during the test.
- **Coordinate with Owner** – Test results are most accurate when interior and exterior temperatures are similar (to reduce the influence of stack pressure). Scheduling air leakage testing while the building is unoccupied will reduce interruptions during the test. Deactivation of the mechanical and combustion systems, smoke/fire alarms, and security systems is necessary during the test, particularly when using tracer smoke to identify locations of air leakage.
- **Test Execution** – Use automated software to control blower door fans to pressurize and depressurize the building, record real-time pressure and air flow data, improve the test accuracy, and reduce the test duration. Interior and exterior temperature, relative humidity and barometric pressure affect air density and leakage results. These air density corrections must be performed prior to analyzing the results.

6. CASE STUDIES

The authors' firm has performed many air leakage tests on commercial and residential buildings, including a new art museum and an existing high-rise residential building.

6.1 New Art Museum in Northeast U.S.

Air barrier breaches can result in severe consequences (e.g., condensation and concealed deterioration) in high-humidity specialty buildings such as museums in cold climates. The authors' firm performed air leakage testing of a new two-story art museum located in the northeast U.S. to measure the air leakage rate and identify deficiencies in the air barrier system. The exterior wall systems consist of glass curtain wall, terra-cotta, and precast concrete panels over exterior gypsum sheathing and steel stud framing. The exterior wall and roof assemblies include a self-adhering sheet membrane to function as a combined vapor retarder and air barrier. Although the project specifications required an air leakage test to measure the building airtightness, they did not specify a maximum allowable air leakage rate. For comparison purposes, the governing building code allowed a maximum air leakage rate of 0.40 cfm/sq ft at 75 Pa (0.30 in. water) pressure difference.

Test Preparation and Execution

The contractor installed a majority of the air barrier and exterior cladding systems prior to the authors' arrival on site. However, several curtain wall openings and HVAC construction openings were incomplete due to fabrication delays. The accelerated construction schedule did not allow postponement of the field test until the contractor installed the remaining HVAC and curtain wall components. Therefore, the construction team in-filled these construction openings with 2x4 stud walls covered with polyethylene sheets (Photo 5) to create a temporary air seal for the test.

Photo 5: Construction opening with a temporary stud wall wrapped with polyethylene sheet to create an air seal during the test.

Photo 6: Tracer smoke exfiltration (arrow) at a transition between cladding systems (precast concrete to terra-cotta) and waterproofing membranes (below-grade waterproofing to wall AVB membrane).

Test Results

Using two blower door fans, the authors measured air leakage rates for the positive and negative air tests of 0.10 cfm/sq ft and 0.12 cfm/sq ft, respectively, at 75 Pa pressure difference. These test results indicate that the enclosure airtightness exceeds typical expectations for new construction and the governing building code requirements.

Despite the low air leakage rates, smoke testing also identified several air barrier breaches at complex cladding intersections or transition details. Tracer smoke testing identified air leakage at gaps in the above-grade to below-grade waterproofing transition (Photo 6) and the spandrel beam penetration through the air barrier (Photo 7). The contractor immediately repaired these air barrier deficiencies before completing cladding installation.

Photo 7: Unsealed beam penetration through air barrier at masonry wall (arrow).

6.1. 1960s Residential Tower in Northeast U.S.

The authors' firm performed air leakage testing of an existing brick, limestone, and concrete-clad building constructed in the early 1960s. The residential tower, located in northeast U.S., exceeds fifteen stories and consists of a concrete-framed structure with reinforced concrete-masonry-unit (CMU) backup and cast-in-place concrete at exterior walls. The exterior walls contain a minimal amount of rigid insulation. Steel-framed (nonthermally broken) windows with fixed and operable sash and monolithic glazing are set into masonry openings; the operable sash lack contemporary weatherstripping to reduce air infiltration. Occupants report excessive air leakage through the existing operable sash during the winter; the building consumes approximately 20% of the total heating plant capacity during winter. As such, the building owner is considering replacing the existing windows with more airtight and thermally efficient insulating glass units combined with other building enclosure or mechanical system upgrades to reduce energy use. The air leakage testing is part of a study to evaluate the potential impact upgrading the building enclosure or mechanical systems will have on reducing energy consumption.

Test Preparation and Coordination

The high-rise tower required substantial more preparation time for test set-up and execution than the previous case study. This is primarily due to the building height and the need to install blower door frames in existing window openings at intermediate floors to provide a uniform pressure differential on the building enclosure for the full building height. This test required custom-built frames to retain the blower door fans in the existing window openings (Photo 8).

Photo 8: Custom-built blower door frame installed in a window opening.

Test preparation included propping over 500 interior doors to equalize pressure distribution throughout the building, filling drain p-traps to minimize the risk of sewer gas migration during testing, and air sealing areaways at grade, louvers, chimney and other roof penetrations, and hallways connected to adjacent buildings (Photo 9). It took six personnel working in parallel two days to prepare the building for the quantitative testing.

Photo 9: Various envelope penetrations sealed with tape and polyethylene sheet.

Test Results

Using eight blower door fans, the authors' measured air leakage rates for the positive and negative pressurization tests are 0.78 and 0.68 cfm/sq ft, respectively, at 75 Pa pressure differential. The existing building envelope is significantly leakier than contemporary industry standards; these results will be used as inputs in a whole-building energy model to better predict building energy use with various enclosure/mechanical system modifications. The tracer smoke testing effectively identified the operable window sash as a major contributor to overall building air leakage (Photo 10).

Photo 10: Tracer smoke exfiltration (arrow) at the operable window sash.

7. CONCLUSIONS

Continuous air barriers will help reduce building operating costs and minimize carbon footprint in the face of rising energy costs and an increased demand for high-performance buildings. Design professionals should be aware that code requirements for air leakage rates are becoming stricter, and this trend is likely to increase significantly as more states adopt the 2012 IECC. Quality-control methods built into the design and construction schedule including whole-building blower door tests can be implemented to identify issues early during construction when correction is more-easily achieved than after building occupancy.