Air Barrier Performance Testing Considerations

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The Air Barrier Movement:

The air barrier is an important component of a building enclosure system that can improve HVAC system performance, increase occupant comfort, improve smoke/fire control, decrease damage to enclosure components from condensation, and maybe most importantly reduce energy consumption. The air barrier is defined by the Air Barrier Association of America (ABAA) [1] as an assembly to *"control the unintended movement of air into and out of a building enclosure."* By reducing the air infiltration and exfiltration through the exterior enclosure to almost negligible amounts, the air barrier reduces energy consumption by reducing the associated heating and cooling loads and allows the designers to downsize the HVAC system. The reduction in uncontrolled air movement through a building enclosure will also minimize the potential for interstitial condensation development within the envelope cavity by reducing the water vapor carried by airflow and its contact with surfaces below the dew point temperature. In heating climates, the focus is on interior moisture-laden air exfiltration, whereas in humid, cooling climates, the concern is reversed and focuses on exterior moisture-laden air infiltration into air-conditioned structures. Air barriers also improve occupant comfort through noise transmission reduction, along with odor and contaminant control.

The building design and construction industry has recently become more aware of the benefits of air barriers and begun to implement them on new and rehabilitation construction projects. This awareness has even translated into mandates and requirements for air barriers by some state and federal governing agencies above and beyond the somewhat general and non-quantitative air tightness requirements of the International Energy Code (IEC) or ASHRAE Standard 90.1. States such as Massachusetts, Wisconsin, Michigan and Minnesota have incorporated air barrier requirements into their state building codes, but have not implemented quantitative air tightness requirements that are verified by testing. The absence of quantitative testing lends skepticism to any impact the requirements of the IEC, ASHRAE 90.1, and local jurisdictions actually have on the air-tightness of buildings. In contrast, countries such as Ireland and the United Kingdom have included the incorporation, inspection and testing of air barrier systems as a requirement within their building codes for many years.

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When qualitative or quantitative air barrier requirements are implemented on a new or rehabilitation construction project, the air barrier consultant or testing agency is a sub-consulting profession that will join the ranks of the design and/or construction team. An engineer, architect, or consulting firm that is well versed in exterior enclosure systems (water, thermal, air and vapor) may be able to provide a single source for an enclosure commissioning program [2] that includes pre-design objectives, schematic and design development consultation, design and documentation review, site observation quality assurance, and performance testing services that now incorporates the air barrier.

While a number of articles have been published on air barriers and exterior enclosure commissioning [3, 4, 5, and 6 to name a few], the focus of this article is on the considerations for an air barrier performance testing program that should be implemented if the benefits of the air barrier are to be fully realized by the building end user.

Considerations for an Air Barrier Testing Program:

While this list is not all-inclusive and could be added to or amended, it is a basis for the industry to consider and discusses ten important factors when implementing an air barrier performance testing and diagnostic evaluation program.

1. Large Building Experience

The testing firm should possess applicable experience accomplishing air barrier performance testing by fan pressurization methods (ASTM E779-03 [7] and E1827-02 [8]) on large-scale projects, not simply residential "blower door" testing. The testing equipment and level of building systems knowledge required on large scale projects, generally considered to be over 10,000 square feet, is far greater compared to single-family homes for obvious reasons. The testing firm should submit projects of similar size and scope prior to being retained.

2. Adaptability to Variables

An understanding of the complexities involved in testing various building sizes, shapes, and types is necessary for the end results to be a valid and accurate representation of the air tightness metric of the building enclosure. For example, there is a difference between accomplishing air barrier testing on a single-story pre-cast concrete structure with a slab on grade floor and packaged roof-top HVAC units, as compared to testing a multi-story wood framed structure with long corridors, elevator shafts, stairwells, sub-floor crawlspace, and a water-loop heat-pump HVAC system with heat-recovery ventilators; the latter requires a more diligent preparation protocol and contains many additional variables that will affect the end result of the test, possibly indicating a "tighter" or "looser" building enclosure than in actuality. It may not be feasible to test the building as a "single zone" and thus sections, wings, or floors in the building need to be isolated or compartmentalized and results extrapolated. If these variables are not clearly defined within the project specifications, then the consultant or testing agency should be knowledgeable enough to know which questions to ask or provide recommendations and guidance to the owner/design-construction team well in advance of the actual testing.

3. Building Enclosure Knowledge

Extensive knowledge, background and experience in all facets of building envelope enclosure systems is necessary so the air barrier system does not unintentionally adversely affect other enclosure requirements such as water vapor transmission. This includes all types of roofing (steep slope and low slope), exterior wall types (mass reservoir, barrier, water managed, rain screen), cladding or façade types and materials, fenestrations (doors and windows), curtain walls, flashing mechanisms, sealants, expansion joints, insulation, and all other component parts and systems forming the exterior floor, wall, or roof assemblies. A building enclosure consulting firm or architectural/engineering firm that can also accomplish building performance testing would be preferred over a company that just provides testing services. The former would minimize the potential for corrective measures to remedy air leakage, such as sealing an exterior joint or transition that may adversely affect the performance of other building systems. For example, if the joint or transition is a drainage or weep mechanism for the façade's water management system, it could result in serious concerns with the façade's inability to properly direct water out and away from the structure if inadvertently sealed for air tightness.

4. HVAC System Knowledge

An understanding of the building's HVAC components and systems is vital so they can be taken into consideration and properly prepared prior to any performance testing, specifically the ventilation and air distribution systems. Should such systems be included in the test (as-is), should they be isolated from the test, or are they relevant (all components within the building enclosure)? The HVAC system preparation parameters may not be incorporated in the air barrier testing specifications as commonly referenced test standards allow for flexibility. Isolation of air-distribution systems and "intentional" holes in the enclosure will provide a more accurate air-tightness measurement of the building enclosure, but at the expense of significant time and effort to seal all those openings in the enclosure or within the building. The testing agency's knowledge of mechanical system air distribution networks could also allow expedient preparation if only certain components of the HVAC air distribution system require isolation. For example, it would save time if only the outdoor air intake on RTUs were sealed rather than every supply and return register within the test zone. Exhaust fan registers may not need to be isolated if only a depressurization test is required by the project documents as the (non-motorized) damper should close during the test, effectively isolating it from the enclosure.

5. Building Preparatory Tasks

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Building preparation generally includes accurate building take-offs to determine fan capacity requirements, isolation of HVAC components and temporary system disabling, plumbing traps filled, fenestrations locked, and many additional tasks that may or may not be outlined in the project specifications or testing protocols. Frequently, air barrier project requirements or testing protocols are absent of such specific tasks, thus buildings are prepared differently and the results are not repeatable and cannot be compared between different buildings. The testing program must clearly identify all preparatory tasks to achieve repeatable and comparable tests in addition to eliminating conflicting preparatory opinions by on-site witnesses, immediately prior to testing.

6. Fan Capacity

If the air barrier test program specifies on-site pressurization (not an off-site mock-up), the specifications should include a requirement for adequately sized, rated, and calibrated equipment with up-to-date calibration records. Of course, the larger the building, the more cubic feet per minute (cfm) of air that will be required from the fan(s) to pressurize or depressurize the structure to the target value, say 50-75 Pascals. Adequate fan capacity should be calculated prior to arriving on-site based on the air tightness requirements that are normalized by some building metric, such as envelope area or volume. For example, if the air tightness requirement is 0.25 $cfm/ft2_{envelope}$ @ 75-Pa, envelope takeoffs can be accomplished and multiplied by 0.25 to determine the capacity required if the building is to achieve its target pressure differential.

Utilizing a building's HVAC supply air fans may be necessary for large buildings where traditional portable fans may not be practical. The use of the HVAC system for air-tightness testing involves a variety of additional considerations including accurate supply air flow measurement techniques, proper damper positioning, and, of course, the cooperation from the mechanical designer-of-record and facility manager. The report by Bahnfleth [9] provides for many considerations in large building air-tightness testing using the HVAC system.

7. Equipment Flexibility

The party administering the tests should have the equipment capability that allows for flexibility in the testing regimen due to differing building geometries and sizes, and possible sectional isolation and extrapolation. Pressure equalization must be achieved at all points within a building within 10%, or 2.5Pa, depending on the test protocol and professional judgment of the testing parties. Utilization of long pressure taps, sometimes in excess of 200-feet, both inside and outside, are necessary to verify that a uniform pressure differential is achieved within the test zone, especially when windy conditions exist (in excess of 10-mph). The exterior pressure taps can be connected to a manifold to average the exterior pressure readings if localized wind-induced pressures will affect the baseline building pressures and subsequent pressure readings in the judgment of the testing agency. Pressure loss within the taps/tubing is not generally considered, assuming the tubing is free of small pin holes, kinks or rain water.

In some cases a single high-capacity fan (trailer mounted), three-fan or even a six-fan assembly in one centralized location will provide the adequate capacity to achieve the desired pressure differential at all points within the structure. This generally applies to buildings with open floor plans such as warehouses or some open office spaces. On the other hand, complex building geometries will require multiple fan assemblies located in strategic locations within the building and operated simultaneously to achieve the desired pressure differential at all points monitored within the building. If the testing entity is not prepared with equipment flexible enough to make such adaptations, it will result in a non-uniform pressure differential distribution within the building and thus questionable test results.

In addition, the flexibility of testing equipment becomes more valuable if more specific tests are warranted while on-site. For example, measuring air leakage through fenestrations may be necessary (ASTM E783-93 [10]) to segregate and determine specific building air leakage rates at specific components of the structure if it is suspected they are large contributing sources to the overall building leakage.

8. Diagnostic Experience

Diagnostic evaluation of the air barrier performance (ASTM E1186-03 [13]) should be included in any air barrier performance testing program. These diagnostics are most commonly accomplished utilizing infrared thermography and/or smoke tracer and generation devices. The program should employ certified and experienced infrared thermographers that are able to accurately diagnose specific areas of air leakage for targeted retroactive air sealing. Infrared cameras have become relatively inexpensive to purchase over the last decade so many companies now possess an infrared camera; however, the knowledge of operation and accurate diagnoses may be suspect. Even certified infrared thermographers may not have the experience necessary with building systems to render effective evaluation during diagnostic testing of a building's air barrier. For example, is the infrared image confirming air loss or is it potentially an infrared reflection from an adjacent substrate or material, solar loading, or radiation? A mis-diagnosis of air leakage could result in wasted resources in retroactive air tightening and as described in #3, could adversely affect the performance of the building enclosure.

Infrared cameras should be capable of achieving the required resolution, and should also have updated calibration with records. Lastly, air temperature differentials are required between the interior and exterior during diagnostic testing for effective infrared imaging and air leakage detection. Hence, the time of day for the diagnostic testing and manipulation of the building's heating or cooling systems may need to be considered. Baseline infrared imaging should always be accomplished before pressurization and diagnostic testing is accomplished with the infrared camera. Infrared and digital images captured should be documented on building elevation, floor and roof plans should a review of their location on the building be desired at a later date.

9. Mock-Up Consideration

The air barrier system may be tested in a mock-up scenario (ASTM E2357-05 [14]), on or off-site, prior to commencement of construction. Some buildings are too large and complex to reasonably achieve a uniform pressure differential across the entire building envelope by the testing equipment available today. Use of the building's HVAC system to achieve pressure differentials, while possible, introduces uncertainty and requires exceptional knowledge of building control systems by the testing agency or mechanical designer of record. In these circumstances, it is generally beneficial to construct an off-site mock up of a typical wall assembly that includes most or all of the relevant components so the standards of construction can be established and challenging interfaces are not simply "worked out", untested, in the field. The testing of mock-up wall assemblies should not necessarily be limited to only large buildings, but should be considered for smaller or complex buildings as well. If mock-ups are utilized, testing can be performed not only on the air barrier system, but also the thermal barrier, water penetration barrier, structural dynamics, and other metrics as required by the Owner or project specifications. Certainly discovering that an air barrier system does not meet the required design performance criteria after completion of the building could be a costly lesson, further increasing the benefit of mock-up or intermittent performance tests whether on or off-site. It has been estimated that the cost to repair a failed air barrier could be greater than 50 times the cost of installing it correctly the first time [15].

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10. Bias Potential Consideration should be given to the potential for bias if the testing agency is the same as the air barrier designer and the quality assurance or oversight entity. In a perfect world, the test results should be uniform and repeatable, or at least within 10%, between any qualified testing agency and any calibrated equipment. However, if the air barrier system fails to meet the project requirement, the costs of repair and re-testing will be borne by some entity. If that entity is also the one performing the testing, the possibility of bias is real and should be acknowledged.

Conclusion:

Without a quantifiable air barrier performance testing requirement, the actual benefits of an air barrier system may not be realized by the building end user. Efforts are continual to incorporate such quantitative requirements into the IEC, ASHRAE 90.1, and local jurisdictions but to date only a limited number of entities are requiring performance testing of the air barrier system.

The considerations within this paper should assist in avoiding mistakes and non-repeatable data that may result in costly expenditures after the fact. Using the old adage “a chain is only as strong as its weakest link,” if the considerations above are not implemented into the decision-making process for the testing program, accurate diagnostic evaluations and repeatable performance results for the air barrier assembly may not be achieved and the overall goal of an air-tight building may be compromised.

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References:

[1] ABAA – Air Barrier Association of America, 1600 Boston-Providence Hwy, Walpole, MA, 02081, phone 866-956-5888, website www.airbarrier.org
[2] NIBS – National Institute of Building Sciences, 1090 Vermont Avenue, N.W., Suite 700, Washington D.C., 2005, phone 202-289-7800, website www.nibs.org, NIBS Guideline 3-2006, Exterior Enclosure Technical Requirements For the Commissioning Process, Copyright 2004-2006
[3] The Impact of Airtightness On System Design, Wagdy A.Y. Anis, AIA, ASHRAE Journal, December 2001
[4] Commissioning the Air Barrier System, Wagdy Anis, AIA, ASHRAE Journal, March 2005
[5] Commissioning Airtight Building Enclosures: The Importance of the Pre-Construction Phase Commissioning Process, Kevin D. Knight and Bryan J. Boyle of Retro-Specs Consultants Ltd, Journal of Building Enclosure Design, Winter 2007
[6] NIBS Guideline 3: Exterior Enclosure Technical Requirements for the Commissioning Process, Wagdy Anis, LEED AP, AIA, Journal of Building Enclosure Design, Winter 2008
[7] ASTM - American Society of Testing and Materials, ASTM E 779-03, Standard Test Method for Determining Air Leakage Rate by Fan Pressurization, originally approved in 1981, previous edition approved in 199 and current edition approved and published in 2003.
[8] ASTM - American Society of Testing and Materials, ASTM E 1827-1996 (Reapproved 2002), Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door, originally approved 1996, published 1997 and reapproved 2002.
[9] Protocol for Field Testing of Tall Buildings to Determine Envelope Air Leakage Rate (935-RP), William P. Bahnfleth, Ph.D., P.E., Grenville K. Yuill, Ph.D., and Brian W. Lee, Department of Architectural Engineering at the Pennsylvania State University, prepared for ASHRAE, July 1998
[10] American Society of Testing and Materials, ASTM E 783-93, Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors, originally published 1981, previous edition 1991, current edition approved and published 1993.
[11] ASTM - American Society of Testing and Materials, ASTM E 1105-96, Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Difference, originally published 1986, previous edition 1993, current edition approved and published 1996.
[12] ASTM - American Society of Testing and Materials, ASTM C 1060-90 (Reapproved 2003), Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings, originally published 1986, previous edition 1997, current edition approved and published 2003.
[13] ASTM - American Society of Testing and Materials, ASTM E 1186-03, Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems, originally approved 1998, current edition approved and published 2003.
[14] ASTM - American Society of Testing and Materials, ASTM E 2357-05, Standard Test Method for Determining Air Leakage of Air Barrier Assemblies, current edition approved and published 2005.
[15] A New Protocol for the Inspection and Testing of Building Envelope Air Barrier System, Knight K.D., Boyle, B.J. and Phillips, B.G., Performance of Exterior Building Walls, ASTM STP 1442, P.G. Johnson, Ed., ASTM International, West Conshohocken, PA, 2003.