BUILDING PERFORMANCE TESTING

By

Karim Allana, PE, RRC, RWC
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Building performance testing is one of the most effective ways of ensuring optimal system performance and reduce risk of premature system failure. This paper will examine performance test methods for various building envelope assemblies and components - including façade elements; windows & curtain wall; air barriers; and waterproofing systems and how industry standards play a role in determining testing procedures. In this paper, I will share the type of equipment, setup needed, and requirements for the various testing methods. Additionally, I will distinguish between methods for “performance testing of assemblies” versus “diagnostic testing” to pinpoint failure mechanism(s). I will also compare and contrast the pros and cons of various types of equipment used for testing including, building negative pressure chambers as opposed to blower door method. Additionally, this paper will explore new technology in waterproofing leak detection: Electronic Leak Detection (ELD). We will review the four types of ELD test methods and equipment including: Electronic Field Vector Mapping, High Voltage Spark, Low Voltage Vertical and Low Voltage Horizontal testing and how they can identify performance issues before they become detrimental.

AAMA, WDMA and ASTM Standards

American Architectural Manufacturers Association (AAMA) was founded to support the common interests of manufacturers of glazing systems like curtain walls, windows and skylights. Similarly, Window and Door Manufacturer’s Association (WDMA), was originally formed to support the door and window industry manufacturers. While AAMA and WDMA are separate organizations, they work together to unify testing standards. Most WDMA standards have been consolidated under AAMA. ASTM International (originally the American Society for Testing Materials) provides testing standards for thousands of items that affect our daily life ranging from toys, construction, aeronautics and many other aspects of our lives. While ASTM prepares standard methods for testing, they do not provide guidance on performance standards or enforce the standards. Organizations like AAMA, WDMA and the Canadian Standards Association (CSA) take some of the testing standards created by ASTM and add performance requirements for windows, storefronts and curtain walls. Furthermore, AAMA/WDMA/CSA 101 created unified performance class and performance grades for rating products, combining performance standards for structural, air and water penetration and certifying products. AAMA also provides voluntary specifications for field testing like AAMA 501, 502 and 503.

When the AAMA test standards were first produced in the 1980's and 1990's, they were written to unify standards and create certification programs to assist manufacturers and provide architects with voluntary specifications for testing fenestration and exterior wall assemblies. AAMA initially excelled at providing consumers, architects, and manufactures with testing requirements and standards which were balanced for all parties.

For example, AAMA 501, 502 and 503, voluntary specifications for field testing of installed storefronts, curtain walls and sloped glazing systems and exterior walls, have changed over time as follows:

According to AAMA, "The AAMA 501-83 publication was the successor publication of the 1968 standard known as NAAMM Standards FC-1 and TM-1-68T originally published by the National Association of Architectural Metal Manufacturers." In 1983, AAMA 501.3-84 states the following in regards to field test pressures:

> 4.2 Laboratory tests are designed to give an indication of how a product will perform when actually installed in the building. However, the installed performance of a product may vary from that which was determined in the laboratory. This field test procedure provides a means for determining the performance of a product as installed.

The stated intent of the field testing was that "…errors in fabrication or installation can be readily discovered and corrections made before the entire project …. is completed."

In 1994, AAMA published a standalone AAMA 503 standard as a "voluntary specification" for field check of products using uniform air pressure - AAMA 503-94. For the first time, AAMA added the following language:

> 4.7 The field water penetration tests shall be conducted at a static test pressure of two-thirds of the specified project water penetration test pressure, but not less than 6.24 psf.

For instance, if a curtain wall is laboratory rated at 12 psf water resistance, AAMA would not allow testing of that same system in the field at more than 8 psf, which is a significant reduction. In effect, under the AAMA guidelines, glazing systems are typically ***sold*** to the building owner on the strength of Laboratory testing but the *warrantable* water resistance rating is actually 1/3 less.

In 2008, AAMA further modified this voluntary specification. The title of the standard was changed to include the words "newly installed". This standard was reduced to being applicable to new installations that are less than "6 months" old as follows:

1.1 These specifications establish the requirements for test specimens, apparatus, sampling, test procedures and test reports to be used in evaluating the performance of newly installed storefronts, curtain walls and sloped glazing systems and their installation during construction, prior to issuance of building occupancy permit, but no later than six months after issuance of the occupancy permit. ("Test Area" hereafter referred to as "specimen".)

The final result of this change is that a newly installed product tested in a laboratory at 12 psf can only be tested in the field at 8 psf. 6 months after installation, the manufacture does not offer a performance rating. If an AAMA-rated product leaks, AAMA now suggests that AAMA 511 protocol be used (which is a leak investigation protocol). AAMA does not recognize that the windows still need to 'perform" to the original published air and water intrusion standard or to even the 1/3 reduced pressure standard.

In my opinion as an engineer, if I design a "beam" to handle 10k load on day 1, I expect it to handle 10k load in 10 years. In my opinion, performance testing of windows at a certified test pressures (or 1/3 reduced pressure) is still the most effective means of checking for window "performance", no different than a beam or any other element of the building that has a published performance standard - particularly for curtain wall, air barrier, and exterior waterproofing systems as they are the most high-risk building systems for litigation.

CURTAIN WALL AND GLAZING TESTING

Prior to bringing curtain wall materials to the jobsite for erection on a building, particularly on large projects, most specifications call for some form of performance testing of the curtain wall system. The performance testing typically includes laboratory mock-up testing where full sized version of the proposed curtain wall system are assembled and installed at a test facility. Tests are conducted to verify actual air infiltration (ASTM E283), static water resistance (ASTM E331), dynamic water resistance (AAMA 501.1), and structural performance (ASTM E330). In California seismic racking, also known as inter-story drift or displacements, is also often evaluated (AAMA 501.4).

Other common types of specified glazing testing include ASTM E90, which evaluates an assembly's STC/OITC performance, and AAMA 1503 which determines the assembly "U" and Condensation Resistance Factor. Both acoustical and thermal performance are dictated by the California Building Code. Note that these two tests are typically conducted on separate, smaller test specimens.

It is critically important that the laboratory test specimen match in every detail with the actual system to be installed in the field. The mock-up should include actual aluminum extrusions, the same glass composition and thickness, same glazing gaskets, same setting blocks, and same associated internal blocking as the installation on the project site. Where internal structural reinforcing is pre-determined through engineering calculations, that same reinforcing must be a part of the mock-up testing. Glazing gaskets are a critical component of system performance, and must be identical to those gaskets that will be used in the actual installation. Internal sealants are another critical element in the overall performance of a curtain wall and must also be identical between the mock-up and the field. It is particularly important that internal seals, which contribute heavily to a successful mock-up, be duplicated in the actual installation. Sealants that are added during lab testing (typically in response to water infiltration) must also be incorporated into the field installation.

If a curtain wall system is new and customized for a specific project, performance testing is intended to validate that the system, as designed, is capable of meeting the project requirements. Laboratory testing of previously untested assemblies represents the minimum standard of care and should be considered mandatory. Even if a selected system is labeled as a "Manufacturers Standard", there is no guarantee that the configuration employed on one project will match a configuration of the second project. Therefore, there is no better of a way to evaluate a proposed system than to perform the laboratory test procedures noted earlier.

At the conclusion of laboratory testing, it is typical for the laboratory personnel to dismantle, inspect, and record the condition of the curtain wall system. This can be important if a part that was previously concealed shows signs of failure or near-failure. The glass is inspected to make sure that no contact was made between the glass edges, the most vulnerable part of the glass, and the internal surface of the frame. Edge spalling or cracking would be a sign that something had gone wrong, even though the test specimen may have passed.

The Laboratory concludes testing with a full report noting structural deflection at 100% of Design Load and again at 150% of Design Load, the presence or absence of water infiltration, the rate of air infiltration, and the overall condition of the test specimen curtain wall at the conclusion of the testing. This forms a permanent record and serves as a guideline for the actual installation in the field.

FORENSIC INVESTIGATION THROUGH CURTAIN WALL FIELD TESTING

We have seen how Laboratory testing of curtain walls establish a baseline for field installation by physically verifying how a given system is likely to perform on a building during its "service" years. However, the level of care and concern for detail that typically occurs with mock-up testing is not always duplicated in the field-erected product. Water infiltration is usually the first sign of trouble, but we have seen instances where other types of failures have manifested including:

- Structural failures with parts like trim pieces that become disengaged from the wall and create an immediate hazard below.
- Excessive differential movement between the curtain wall and adjoining substrates.
- Glass failures including failure (fogging) of insulating glass, PIB migration, and corrosion of low "E" coatings.
- Painted coatings that exhibit signs of blistering, cracking, and excessive fading.
- Laminated glass with bubbles between the interlayer and one or more lites of glass.

That being said, the most prevalent form of failure in window systems by far is water intrusion. There are several standards for field evaluation of water leakage. The primary standard is ASTM E1105 (also known as "chamber testing") the "Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference". This standard dictates that a water spray rack with an array of nozzles delivers water at a calibrated rate of 5.0 gallons per square foot (of specimen) per hour.

Figure 1 - 453 Unit Apartment Complex

Chambers are usually constructed of wood 2 x 4's and heavy duty clear plastic. A chamber just larger than the test specimen is typically constructed on the interior side of the specimen and mounted to the interior wall surface where the window is located. It is important to make sure that no part of the wood chamber is touching the window or curtain wall framing. The chamber needs to be as airtight as possible, so it is sealed to the adjoining substrate with tape.

Figure 2 - 1,300 Unit New Construction Apartment Complex

Creating the proper differential pressure is accomplished with controllable blowers, vacuums, or other such devices. In order to measure the pressure being created, we typically use a digital manometer that must be accurate to ± 2% or ± 0.01” of water column.

Figure 3 - Mock-Up Testing Of Glazing System with Manometer

An alternate method of creating differential pressure for testing purposes involves the use of a door frame mounted blower door. This method has many advantages over the traditional framed chamber because the room itself (or even the entire unit of an apartment) becomes the chamber and the differential pressure is provided by a large fan that is in turn controlled by a digital manometer. With this approach you can quickly set up and remove the test equipment and you can perform multiple tests on different specimens without a separate setup. The manometer is programmed with the target test pressure and it maintains that pressure by automatically adjusting fan speed.

There is another standard that is often mentioned in accordance with ASTM E1105 when doing field water testing - AAMA 503. AAMA, as its name (American Architectural Manufacturers Association) implies, is an industry representative of the various window and curtain wall manufacturers. This becomes important because determining the "right" amount of differential pressure a specimen is subjected to often determines if the specimen passes or fails.

There is no prescriptive formula within ASTM E1105 for determining how much pressure to apply to a given specimen. AAMA 503, titled "Voluntary Specification for Field Testing of Newly Installed Storefronts, Curtain Walls and Sloped Glazing Systems", attempts to fill that void by dictating that *field test pressures* are to be reduced from *Laboratory test pressures* by 1/3.

Figure 4 – Water Spray Testing

Both ASTM and AAMA define water leakage as penetration of water beyond a plane parallel to the innermost projection of the framing system but not including applied trims like sheet rock receptors. ASTM does not specify how much water must penetrate, but presumably their definition would include any water. AAMA allows for up to 0.5 ounces of water to accumulate on an interior horizontal plane and still pass the water infiltration testing. The underlying logic of both ASTM and AAMA is that water must be "managed" and that water infiltration is by definition "unmanaged".

For curtain walls, the test duration is 15 minutes while maintaining both pressure and water spray for the entire test duration. Documenting leaks during the test cycle is typically accomplished by viewing the specimen through the plastic that encloses the chamber. A distinct advantage of the blower door method is that visibility is unobstructed since there is no separate chamber involved. A window professional will evaluate the type of leaks that occurred, their intensity and the amount of time it took to see the leak in trying to determine the actual cause of the leak. For instance, leaks that occur around the specimen perimeter are often, but not always, the result of a breach in the exterior perimeter sealant. Other causes could include flashing failures or unsealed perimeter fasteners.

Finding a leak is only half of the story. The ultimate goal of field testing should be to isolate the source of leakage and to provide a long-term solution to remedy the leak.

AIR BARRIER TESTING

Air barriers requirements are slowly finding their way into many building and energy codes. The majority of energy codes nationally use the 2012 or 2015 IECC as a model code, both of which have quantitative air barrier requirements. See Figure A at the end of the paper for current state requirements. In addition to Code requirements, ASHRAE, GSA, USACE and Passive House, along with many sustainability and "net zero" initiatives, require air barriers, usually more stringent air leakage requirements than the Code. With such widespread code adoption, it is now the design professionals' duty to design and specify air barriers such that can be tested, diagnosed, and repaired to meet the quantitative or qualitative requirements outlined. Specifying the proper standards can be challenging, and simply citing the ASTM standard in the Code does not provide the full amount of scope needed to accomplish the air barrier requirements.

QUALITATIVE VS. QUANTITATIVE

Most early standards outlined qualitative requirements, such as *seal airtight*. These types of references did not provide a measurable way of determining if the Code or Standard's intent was met. Most current requirements are quantitative. They outline a maximum air leakage rate or a maximum amount of Air Exchanges per Hour (ACH). The transition from qualitative to quantitative requirements put additional pressure on the design and construction teams since making repairs to the air barrier is not always possible without considerable cost.

SPECIFYING

Air barriers are specified as products, assemblies, and systems to mirror the IECC code. The product and assembly specification requirements [Material (ASTM E2178) and Assembly (ASTM E2357)] are geared toward verifying, through quantitative measures, a material's ability to limit air leakage itself and when joined with its immediate transitional elements. Testing for compliance at the material and assembly level is conducted in a lab environment and by individual manufacturers. Not all materials and assemblies are required to have published ASTM E2178 or ASTM E2357 results. Most Codes, when requiring air barriers, offer materials and assemblies that are approved as air barriers without needed testing verification. When specifying air barriers, it is important that the specifier confirm that the product meet or exceed the air leakage requirements outlined.

Figure 5 - Air Barrier Test with Blower Door

Specification requirements for verifying Code compliance or for verifying whole building air leakage rates, is completed through two ASTM standards that supplement each other. The specifier will use either ASTM E779 or ASTM E1827 to outline the testing method and supplement that with ASTM E1186 for diagnostics requirements. Diagnostics are not required by Code should the testing determine that the air leakage rate falls below the Code requirement. However, it may be the Client's/Owners desire to have the testing firm provide diagnostics in order to provide the most air tight building possible.

TESTING CONSTRUCTION OF AIR BARRIERS

Whole building air barrier testing requires a large amount of planning and coordination between the testing firm, the general contractor, and their subcontractors. It is in the project's best interest to have had mock-ups and in-progress field observations completed to verify the air barrier design intent can be accomplished with as-built conditions. As construction progress nears completion, the options for repairing or supplementing the air barrier are more invasive and costly. The easy solution would be to test the air barrier early in construction. Unfortunately, the air barrier assembly isn't complete until the storefronts, hollow metal doors, fire barrier sealants and other typically late-in-the-schedule items are completed.

Moving these activities up in the schedule is not impossible, but it does take additional efforts on behalf of the construction team to accomplish. Mock-up testing can be useful, but it rarely mimics the challenges that a full whole building test has to overcome. The best process for ensuring that a building meets the performance requirements of a whole building air barrier test is still a good design understanding of the air barrier assemblies as well as in field construction observation.

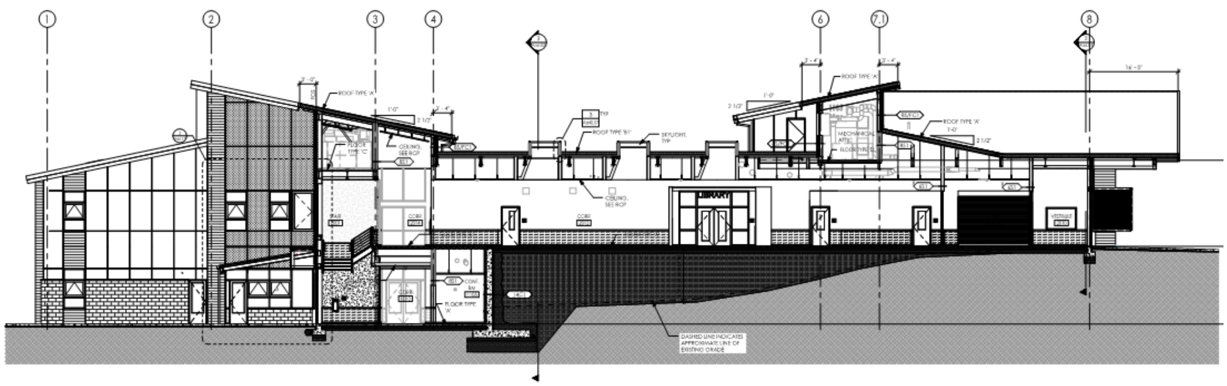

Figure 6 - Complicated Structure for Air Barrier Testing

The complexity of testing of an entire building's air barrier is based on the size and complexity of the building itself. The testing agency will need to visit the project site to establish pre-testing and testing protocols. This type of test requires several weeks of pre-planning and coordination in order to run smoothly.

A short list of pre-testing coordination items includes the following:

- *Who is verifying the air barrier is complete?* The entire air barrier shall be complete the day of testing.
- *Who is providing the air barrier preparation services?* The avenues of planned air flow (mechanical systems, louvers with damper, air intake and makeup, fireplaces, microwaves, plumbing, etc.) need to either be filled or masked shut so that they are not influencing the test results. This preparation can occur from the interior or from the exterior or both.
- *Who is confirming that fenestration is shut?* The windows, doors, skylights, garage entry doors, roof hatches, and any other operable fenestration needs to be shut during the test. This is commonly confirmed by the testing agency immediately before the test.
- *Who is confirm that doors are open throughout the building?* Each door opening should be open fully so as to allow pressurization and/or depressurization to occur as evenly and thoroughly as possible.
- *Who is confirming power availability and access?* The testing equipment can cause many types of electrical breakers to pop during testing. Verifying a workable power source is necessary prior to testing.

- *Who is monitoring mechanical and electrical equipment?* Some equipment needs to be shut down during testing so as to not be impacted by the preparation measures. For instance, a unit whole house fan that runs without the ability to intake due to plastic preparation will burn out.

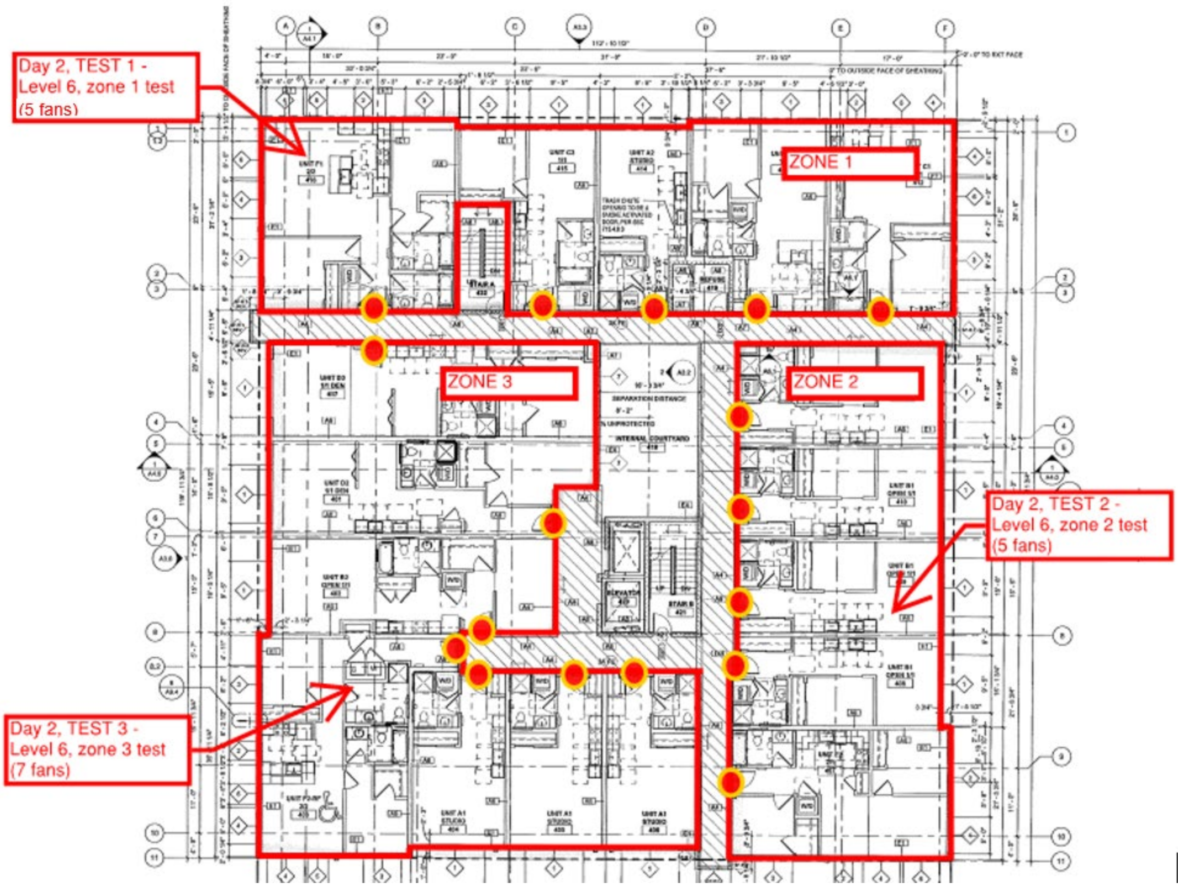

Figure 7 - Zoned Testing Due to No Internal Corridors

The height of a building, due to stack pressure, may prevent the building from being tested in a single phase. The compartmentation of a building (no common corridors or staircase) may also prevent the building from being tested in a single phase.

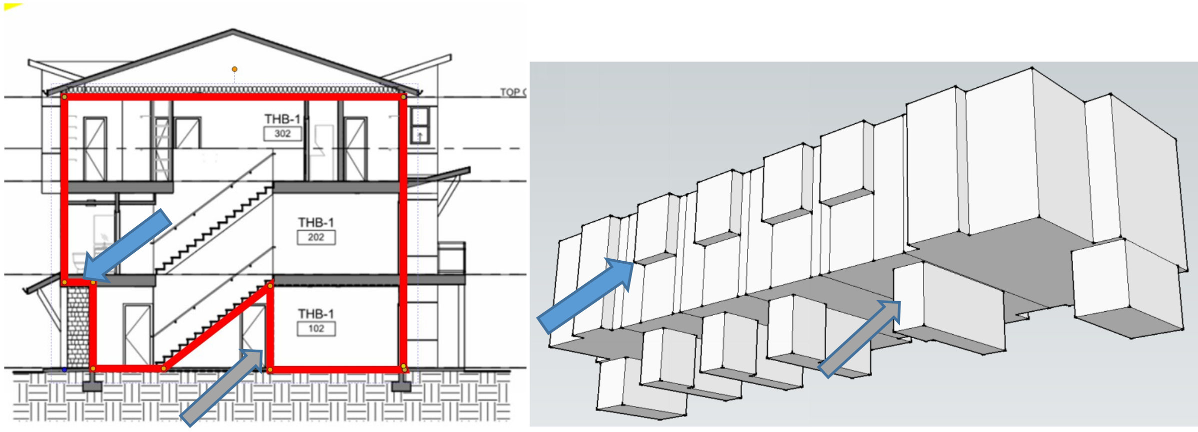

Figure 8 - Effective Leakage Area Identification

Whole building air barrier testing is primarily outlined via ASTM E779 (pressurization via several methods) and ASTM E1827 (Pressurization via blower door). These methods require that the testing agency or Architect identify and quantify the square footage of the "Effective Leakage Area." The effective leakage area represents the square footage of the air barrier surface and it is across this surface that the test is measuring the rate of flow of unintended air leakage. If the effective leakage area is either misidentified or mis-quantified, the results will be significantly skewed.

Once the effective leakage area is identified and quantified, the testing agency determines the location and amount of blower door fans required to conduct testing.

AIR LEAKAGE DIAGNOSTICS - ASTM E1186 (DIAGNOSTICS)

The recommended diagnostic procedures during a whole building air barrier test are outlined in ASTM E1186. The standard includes seven procedures. In our experience however, two of the procedures are the most logistically feasible and suitable for widespread use; infrared scanning and a smoke pencil.

- Infrared Scanning Pros: Broad strokes review, cover more surface area
- Infrared Scanning Cons: Requires temp delta between interior and exterior, thermal bridges and different material thermal emissivities may create false readings, equipment training required.

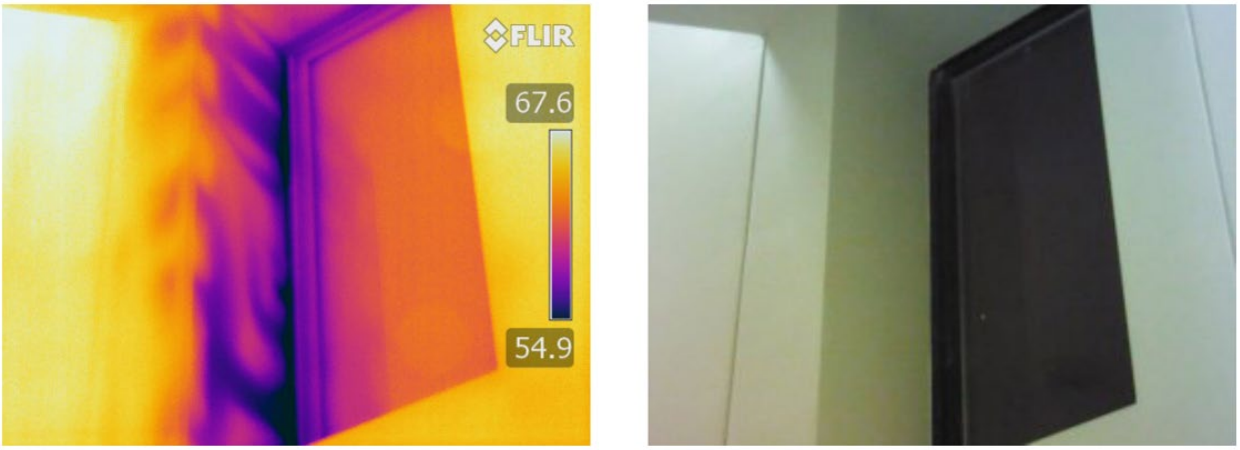

Figure 9 - Thermal Camera Showing Depressurization

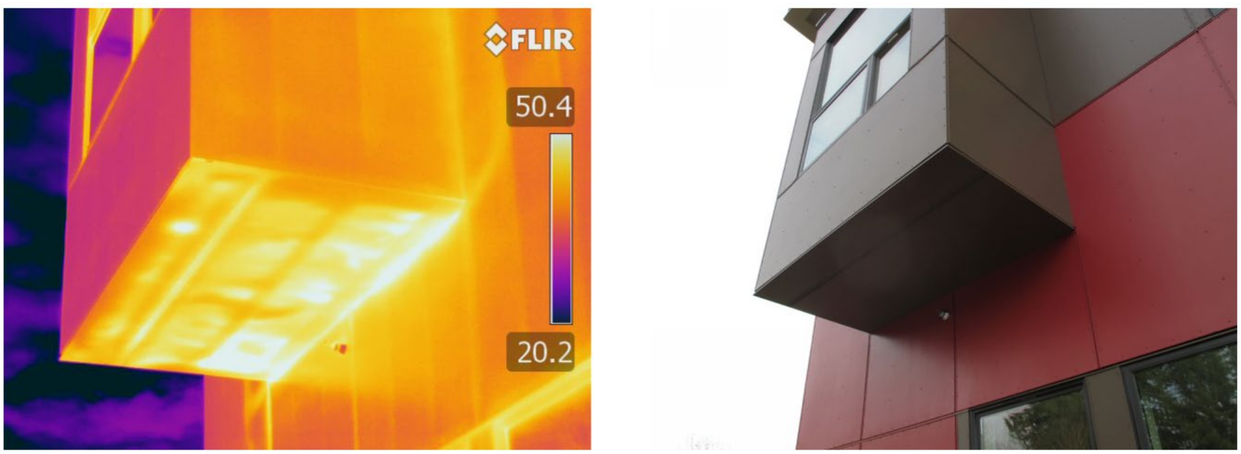

Figure 10 - Thermal Camera Showing Positive Pressurization

- Smoke Pencil Pros: Pinpoints air leakage (test shown in figure below).
- Smoke Pencil Cons: Difficult to do on exterior conditions, smoke needs to be within 4 inches of air leakage location (so surveying out of reach transitions is not possible).

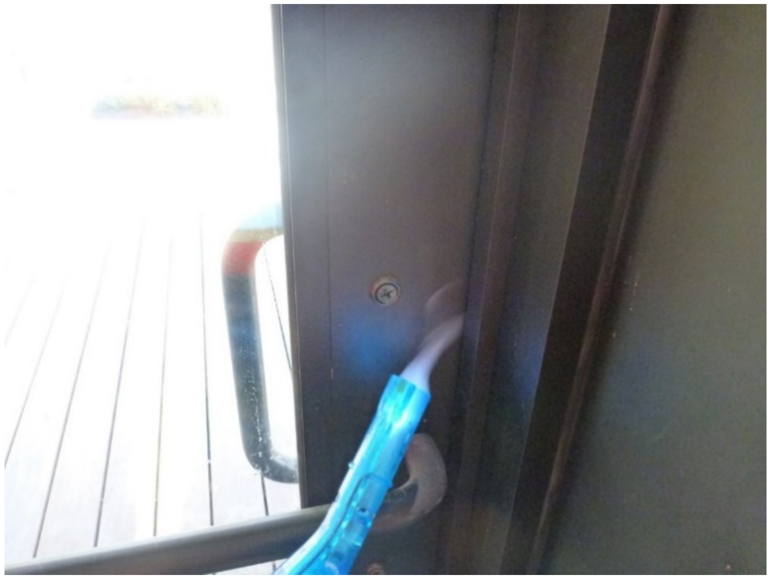

Figure 11 – Building Air Leakage Testing

THE USE OF ELD FOR MEMBRANE PERFORMANCE AND DIAGNOSTIC TESTING

In Electronic Leak Detection (ELD) testing of waterproofing membranes, the protocol between performance testing and diagnostic testing requires a complete understanding of the assembly design as related to the basic principles of ELD testing protocols. To perform ELD testing properly and to assure accurate test results, the designer must take into consideration that ELD testing is only as accurate as the design assembly and the technician operating the equipment.

BASIC PRINCIPLES OF ELECTRONIC LEAK DETECTION (ELD) CIRCUITRY

The basic physics principal of ELD testing is that if a breach exists within the ELD test area, an electrical path is created by establishing the maximum voltage potential between the waterproofing membrane and the roof substrate.

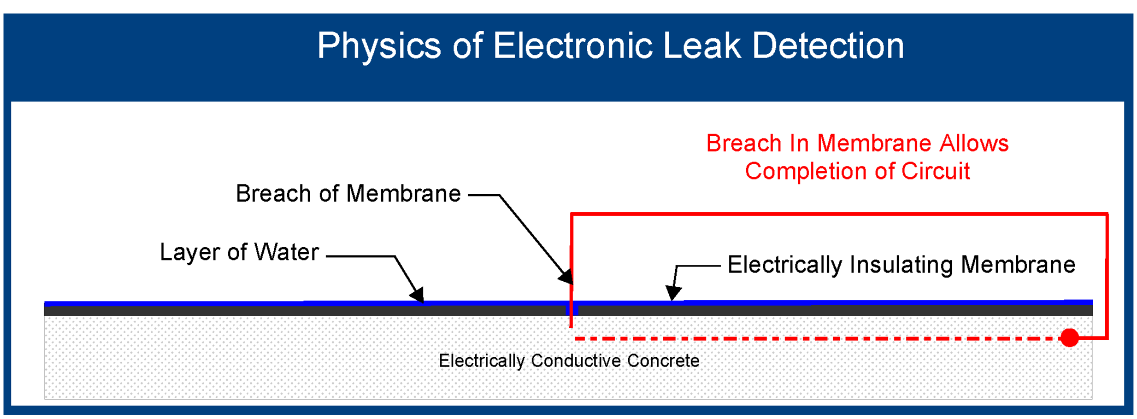

Figure 12 - Typical Diagram of Electrical Path Creating a Circuit

WHY USE ELD?

When properly designed, ELD has replaced other types of leak testing (with the exception of flood testing) such as impedance scanning, infrared and nuclear. Of the four types of survey methods used to identify leaks, ELD is the only one that provides a leak locations.

ASTM TESTING GUIDELINES AND TEST SELECTION CRITERIA

Standard procedures for using electrical conductance measurements as a method of locating leaks in waterproofing membranes is outlined in ASTM D7877-14 - "Electronic Methods for Detecting and Locating Leaks in Waterproof Membranes". Within this document four types of ELD procedure methods are depicted:

1: Low Voltage Membrane Electric Field Vector Mapping (EFVM)

2: Low Voltage Horizontal Membrane Scanning Platform

3: Low Voltage Vertical Membrane Surface Scanning

4: High Voltage Membrane Testing

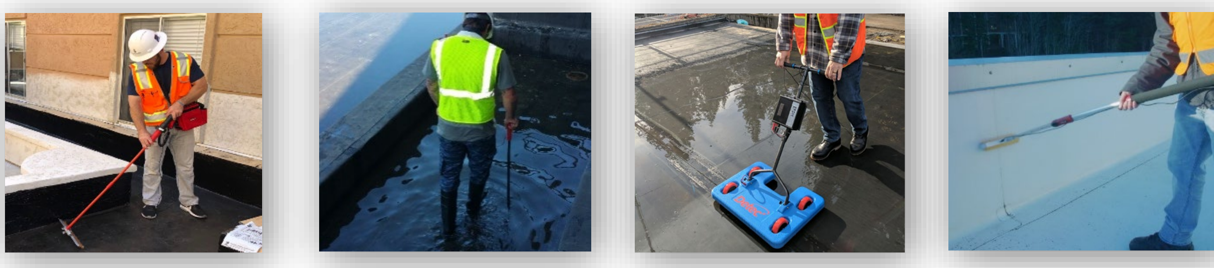

Figure 13 - Four Types of ELD Equipment

Of the four types of circuitry specified in new construction, the low voltage ELD testing is the most prevalent. Although ELD testing has gained popularity over the last few years, the circuitry has not progressed until recently with development of the scanning platform.

HIGH VOLTAGE TESTING

High voltage testing is always performed on a dry membrane surface utilizing high voltage. The voltage is adjustable and is calibrated to the thickness of the membrane tested.

The high voltage test process consists of a lead wire connected from the portable current generator to the grounded medium or substrate. An electrode brush made with conductive metal bristles, usually copper, is then swept over the membrane surface. An electric spark is created that arcs from the brush through the breach contacting the grounded medium thus creating an electrical path.

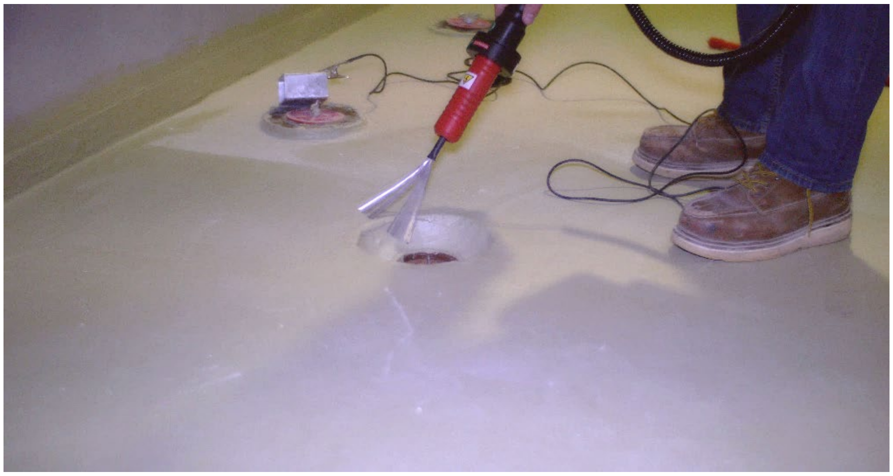

Figure 14 - High Voltage ELD Testing of Shower Pan

- High Voltage Pros: Does not require water to provide the top electrical plate. Can test both vertical and horizontal membranes.

- High Voltage Cons: The testing is highly dependent on the technician to assure proper voltage settings are correct. If improper voltage setting of the equipment are set too low, then inaccurate results will apply. If the voltage is too high, then the membrane could easily be damaged during testing. The membrane must be completely dry.

ELECTRIC FIELD VETOR MAPPING (EFVM™)

The Electric Field Vector Mapping™ method implements an electric potential gradient across the wetted membrane surface to be tested and utilizes a voltmeter and probes to locate possible membrane leaks. A conductor cable loop "trace wire" is installed around the perimeter of the area to be tested. A pulse generator is connected to the loop cable and the building ground or conductive substrate.

Figure 15 - Electronic Leak Detection Test Method EFVM™

- EFVM™ Cons: EFVM™ has more limitations than the platform scanning. For instance, one of the main limitations is the claim that the trace wire can be left in place on the membrane below the overburden and that the same procedures as testing without overburden could be followed in identifying the location of a leak.

Unfortunately, some specifiers do not understand EFVM™ and basic electrical circuitry enough to know that there are variables in this type of testing that affect the results. This embellishment is also connected to the EFVM™ standard test methods on exposed membranes. Some specifiers are unaware that EFVM™ does not test beyond the trace wire. This means that some projects that have EFVM™ testing do not include penetrations, drains, and/or vertical tie-in areas or for that matter any vertical surface such as parapet walls, below grade walls, etc.

VERTICAL LOW-VOLTAGE ELD SCANNING

The vertical test method utilizes the same principles and circuitry as horizontal testing on vertical surfaces with the added benefit of inducing water onto the membrane. In lieu of wetting the membrane surface the moistened sensor is connected through a wire to the receiver. This test procedure also includes isolating and testing of penetration details, corners, walls, membrane seams, down turns and drain tie-ins.

Figure 16 - ELD Low Voltage Vertical Scanning

HORIZONTAL LOW-VOLTAGE ELD SCANNING WITH PLATFORM

The dual sweep circuitry scanning platform utilizes two sets of metal sweeps which make constant electrical contact with the wetted waterproofing membrane surface. The positive terminal of the generator is attached to the building electrical ground or the conductive substrate and the negative terminal connects to the two sets of sweeps. The outer sweep function is to both provide a reading of potentials beaches but also to block the inner sweep that is connected via audio. When the platform crosses over a breach an alarm will sound.

Figure 17 - ELD Low Voltage Horizontal Scanning with Platform

- Horizontal Platform Scanning Pros: Isolates the area to be tested and is beneficial for diagnostic testing.
- Horizontal Platform Scanning Cons: Membrane to be tested will get wet.

ELD PERFORMANCE TESTING

Performance testing of newly installed waterproofing membrane systems or what is more commonly referred to as "integrity testing," has moved from industry standard flood testing to a more accurate method consisting of ELD testing.

Often overlooked in the design phase is the grounding medium being specified directly below the waterproofing membrane. ASTM D7877-14 "Standard Guide for Electronic Methods for Detecting and Locating Leaks in Waterproof Membranes" not only provides the complete considerations of design for ELD testing but clearly depicts the grounding medium be placed *directly below* the membrane to be tested.

ELD DIAGNOSTIC TESTING

ELD can also be utilized in diagnostic testing to determine the point of watery entry into a waterproofing membrane. When properly designed, ELD testing has replaced other types of leak location methods such as flood testing, infrared and nuclear impedance scanning.

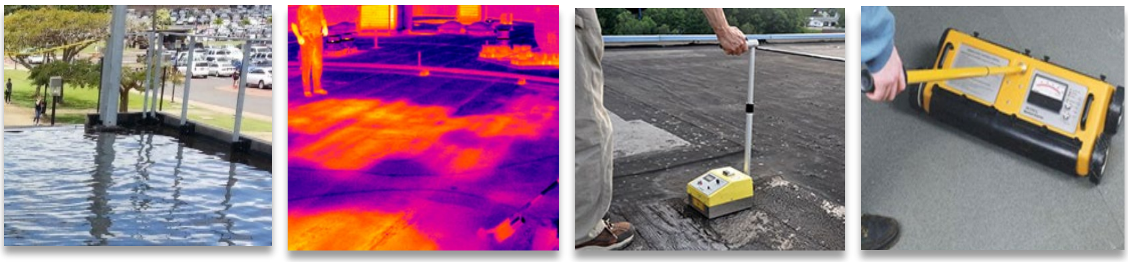

Figure 18 - Four Types of Leak Detection Survey Methods

Of the four types of survey methods used for identify leaks in diagnostic testing, none of them provide the location of the leak entry, only ELD pinpoints the location of leak. As with performance testing, the design of the assembly as related to the ELD protocols directly dictates the accuracy of the test results.

When requesting ELD testing to determine a location of a pre-existing leak it also becomes equally as important to have the correct technician performing and operating the ELD equipment. The technician must contain a very high level of understanding of the physics of ELD, as well as an understanding of waterproofing assemblies and manufacture’s system assemblies.

SUITABILITY OF ROOF SYSTEMS FOR ELD TESTING

The first design intent is to determine and specify the grounding return path substrate or material directly below the waterproofing membrane. Typically, this is concrete for such assemblies as fluid applied rubber over concrete for plaza and podium decks, planters and foundations.

For assemblies or systems that do not have a conductive substrate directly below the membrane then such materials as a conductive compound can be specified to be applied to the cover board, plywood or other suitable substrate including vertical surfaces.

Figure 19 - Primer Being Applied

LESSONS LEARNED

1. Learn how to specify building envelope testing including, glazing and curtain wall testing; façade testing; and electronic leak detection for waterproofing and roofing systems.
2. Learn about the differences in AAMA and ASTM testing methods.
3. Diagnosing air and water leakage through assemblies.
4. Learn the pros and cons of the four types of Electronic Leak Detection (ELD) and test techniques.

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
AK	2012	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2012	R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 3 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)
AL	2016 Alabama State Commercial Energy Code	C	2013 ASHRAE 90.1	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2015 Alabama Residential Energy Code	R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
AR	2011 Arkansas State Energy Code	C	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
		R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
AZ	2012	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2012	R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 3 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
CA	Title 24	C	2016 Building Energy Efficiency Standards	Qualitative		
		R				
CO	2008	C	2003 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2003 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
CT	2016	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 3 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)
DE	2014	C	ASHRAE 90.1-2010	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2014	R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 3 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)
DC		C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per	Blower Door @ 33.5 psf (50 Pa)

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
					hour in all climate zones	
FL	2015	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2012	R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 3 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)
GA	2012 GA State Amendments to the IECC	C	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
		R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
HI	2015	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2015	R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
IA	2012	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2012	R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 4 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
ID	2015	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
IL	Illinois Specific Amendments	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
IN	2010 Indiana Energy Conservation Code	C	ASHRAE 90.1-2007	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
KS	None	C	ASHRAE 90.1-2007	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
KY	2013 Kentucky Building code	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
LA	2011	C	ASHRAE 90.1-2007	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2015	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
MA	2017	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
	2017	R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
MD	2015	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2015	R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
ME	2010	C	ASHRAE 90.1-2007	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2010	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
MI	2017	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2016	R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
MN	2015	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2015	R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 3 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)
MO	None	C	ASHRAE 90.1-2007	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	None	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
MS	2013	C	ASHRAE 90.1-2010	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	None	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
MT	2014	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2014	R	2012 IECC	Quantitative	<4 air changes per hour	Blower Door @ 33.5 psf (50 Pa)
NC	2012 NC Energy Conservation Code	C	2009 IECC	Quantitative	<5 ACH or .50 cfm/sqft	ASTM E779-03
	2012	R	2009 IECC	Quantitative	<5 ACH or .50 cfm/sqft	ASTM E779-03
ND	2014	C	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
	2014	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
NE	2011	C	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
	2011	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
NH	2010	C	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
	2010	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
NJ	2015	C	ASHRAE 90.1-2013	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2015	R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
NM	2012	C	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
	2012	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
NV	2012	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2012	R	2012 IECC	Quantitative	Shall not exceed leakage 5 air changes per hour in climate zones 1-2, 3 air changes per hour in climate zones 3-8	Blower Door @ 33.5 psf (50 Pa)
NY	2016	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2016	R	2015 IECC with amendments	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
OH	2017	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2013	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
OK	2011	C	2006 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
	2016	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
OR	2014 Oregon Energy Efficiency Specialty Code	C	2009 IECC	Quantitative	.40 cfm / sqft	ASTM E779 or Equivalent
	2017 Oregon Residential Specialty Code	R	2015 International Residential Code	Qualitative	All Openings shall be sealed in a manner approved by the building official	N/A
PA	2009	C	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
	2009	R	2009 IECC	Qualitative	Air Leakage <7 Air changes per hour	Blower Door @ 33.5 psf (50 Pa)
RI	2013	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2013	R	2012 IECC with amendments	Quantitative	Post Construction test leakage <8cfm/100 sqftRough-in test leage <6 cfm/100sqft	ASTM E779 or Equivalent
SC	2013	C	2009 IECC	Quantitative	.40 cfm / sqft	ASTM E779 or Equivalent
	2013	R	2009 IECC	Quantitative	.40 cfm / sqft	ASTM E779 or Equivalent
SD	None	C	None			
	2011	R	2006 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
TN	2016	C	2012 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2017	R	2009 IECC with Amendments	None		

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
TX	2015 IECC	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2015 IECC with Amendments	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
UT	2016	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2016	R	2015 IECC with amendments	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
VA	2014	C	2012 IECC with amendments	Quantitative	Shall not exceed leakage 5 air changes per hour	Blower Door @ 33.5 psf (50 Pa)
	2014	R	2012 IECC with amendments	Quantitative	Shall not exceed leakage 5 air changes per hour	Blower Door @ 33.5 psf (50 Pa)
VT	2015	C	2015 CBES	Quantitative	.50 cfm/sqft @50 Pa	ASTM E779 or Equivalent
		R	2015 RBES	Quantitative	Shall not exceed leakage 3 air changes per hour	Blower Door @ 33.5 psf (50 Pa)
WA	2015 WA ST Energy Code	C	2015 IECC with Amendments	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
		R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
WI	2017	C	2015 IECC with Amendments	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2016	R	2009 IECC with Amendments	Quantitative	.40 cfm / sqft	ASTM E779 or Equivalent
WV	2013	C	ASHRAE 90.1-2007	Quantitative	.40 cfm / sqft	ASTM E779 or Equivalent

FIGURE 20 - CODE REQUIREMENTS FOR AIR BARRIERS BY STATE

State	Applicable Energy Code and State	Commercial/Residential	Model Code	Air Barrier? Qualitative vs Quantitative	Air Leakage Requirement, if any	Air Barrier Testing requirement?
	2013	R	2009 IECC	Quantitative	.40 cfm / sqft	ASTM E779 or Equivalent
WY	2015 IBC	C	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent
	2015 IBC	R	2015 IECC	Quantitative	.40 cfm/sqft	ASTM E779 or Equivalent