Air Barrier Assembly Testing to Replicate Real World Conditions

Craig Boucher[1]

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[1] Craig Boucher - Technical Service Manager; WR Grace 62 Whittemore Ave. Cambridge, MA 02140 USA

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Abstract

Air barrier assemblies in exterior walls can improve the energy efficiency of a building, and limit or prevent uncontrolled air leakage into and out of a building to reduce moisture damage and organic growth in exterior walls. Air barrier assemblies must perform in real world conditions to achieve their intended benefits. Simple air leakage tests of materials, such as ASTM E 2178, provide very little information about an air barrier assembly's ability to resist air passage in real life field conditions.

However, the ASTM E 2357 test standard described, together with typical test results for several types of air barrier assemblies shows what can be achieved when they are exposed to simulated real world conditions. Roof and foundation assembly tie-ins to the exterior wall air barrier, application of the air barrier onto a typical substrate, penetrations, a window opening and seams in the air barrier assembly are real world conditions included in the ASTM E 2357 Standard. The standard also exposes air barrier assembly to positive and negative air pressures to simulate wind, stack and fan pressures that occur in real buildings.

The work will indicate why, in the author's opinion, ASTM E 2357 is currently the best laboratory standard available to simulate real word air barrier assembly exposure conditions and can provide evidence that the air barrier assemblies will work as intended in the field. A case study of how the test is run will be provided with additional information about going beyond the ASTM E 2357 test requirements and bringing the air barrier assemblies to failure.

[1] Craig Boucher - Technical Service Manager; WR Grace 62 Whittemore Ave. Cambridge, MA 02140 USA

Introduction

Buildings are structures that provide shelter for humans and the goods we choose to shelter. Controlling the interior conditions of these structures in an energy efficient manner has become of primary importance in recent times. Optimization of heating and cooling systems through judicious design involving insulation and air barrier systems, while at the same time providing a healthy indoor environment for the occupants, is becoming a major goal of building design teams. This cannot be achieved well unless uncontrolled air leakage is minimized. This paper will demonstrate how some systems can provide a high degree of control on air leakage.

The Benefits of Air Barriers

Quite simply, an air barrier assembly in a building is intended to prevent or limit the uncontrolled air leakage into and out of a building through the building enclosure. The air barrier assembly should be continuous across all six sides (roof, all four exterior walls and foundation/basement) of a building to perform as intended. The benefits of using an air barrier assembly include energy efficiency, moisture degradation prevention and organic growth prevention to reduce indoor air quality issues.

Preventing or limiting uncontrolled air leakage is a critical factor in creating energy efficient and healthy buildings. Preventing air leakage can account for saving significant heating and cooling costs, according to a report from the National Institute of Standards and Technology (Emmerich et al. 2005).

Air Leakage Test of Materials

The typical method of evaluating a materials ability to act as an air barrier has been to test the material for air permeance. The primary material used in the air barrier assembly is often called the air barrier material.

The air barrier material may be a peel and stick sheet, sprayed foam insulation, liquid applied coating, mechanically attached sheet, board stock or another technology that limits or prevents air passage through it. The air barrier material provides the air barrier for the majority of the air barrier assembly. Air barrier components, such as sealants, foams or tapes are used to seal the air barrier materials together or to other air barrier materials (i.e. windows and doors) to form the air barrier assembly. Air barrier assemblies such as the roof air barrier assembly, exterior wall air barrier assembly and below grade foundation air barrier assembly need to be joined together to form the air barrier system for the building. For the purposes of this paper we are focused mainly on the air barrier assembly for the exterior wall, which includes the opaque face of the exterior wall, windows, penetrations through the wall and tie-ins to the roof and foundation.

Air barrier materials are relatively easy to test for air permeance. American Society for Testing and Materials (ASTM): ASTM E 2178 *Standard Test Method for Air Permeance of Building Materials* is the most common, current test method to determine air permeance of a material. Basically, the test requires a 1-meter by 1-meter section of the material to be subjected to a pressure differential across the material and the air permeance is calculated. Air permeance is calculated by dividing the measured air leakage rate by the cross sectional area of the material tested and the pressure difference exerted onto the material.

Figure 1 provides a sketch of the testing apparatus used to run the ASTM E 2178 test. A sealed, five sided box is used with an opening on the sixth side of the box. A 1-meter by 1-meter sample of a material is clamped to the top of the box. The air leakage rate and air permeance of the material at a pressure differential of 75 Pa (1.566 pounds per square foot) is typically reported in product data sheets. The pressure differential 75 Pa is equivalent to a 25 mile per hour wind load.

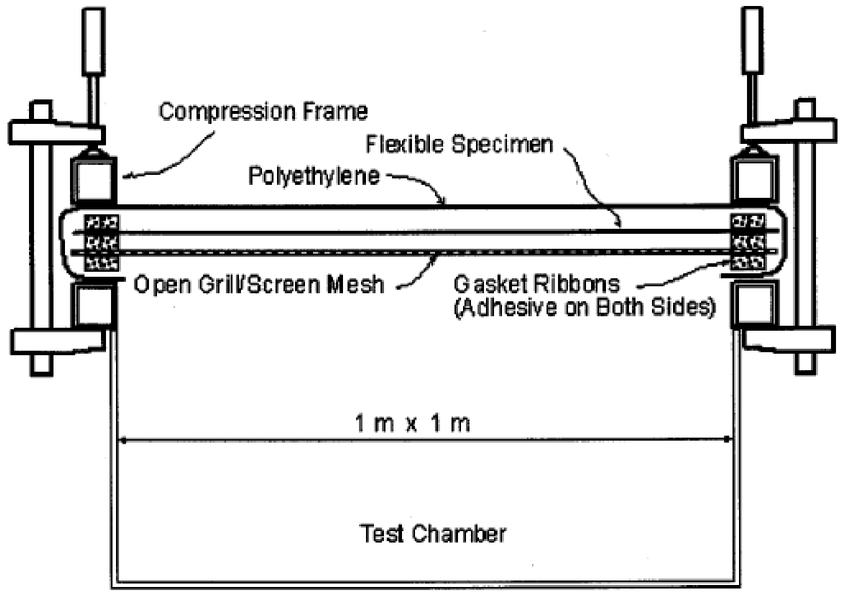

Figure 1: ASTM E 2178 Test Apparatus (with polyethylene sheet used to measure the extraneous air leakage of the test chamber)

The ASTM E 2178 test method is straight forward, fairly easy to do and a good method to evaluate the ability of a material to resist air passage. However, it does not provide much useful information about how a material will perform on a real building in real life environments. Materials are tested without seams, without penetrations and without tie-ins to other materials that make up the air barrier assembly. The test method basically confirms whether or not the 1-meter by 1-meter material has holes in it.

Since the ASTM E 2178 test method does not provide much information about the in situ performance of an air barrier *material* and absolutely no information about the in situ performance of an air barrier *assembly*, we get back to the questions posed earlier; How do you know that a particular air barrier assembly will effectively prevent air leakage? How can you validate the performance of products in the context of a typical application, under real world conditions?

A Test Method for an Air Barrier Assembly

The answer lies in the ASTM E 2357 *Standard Test Method for Determining Air Leakage of Air Barrier Assemblies*. Developed by ASTM in collaboration with architects and engineers and other interested parties, ASTM E 2357 provides a uniform methodology for testing and measuring the leakage rate of air barrier assemblies as they are typically used in building enclosures, under realistic wind load cycles.

Prior to ASTM E 2357, one could only evaluate performance for individual pieces of the air barrier assembly - the primary air barrier material alone, the flashing alone or the sealing materials alone. This “piece by piece” approach does not provide a holistic evaluation of real world performance, where the interaction among pieces - and the interaction of pieces and wall elements, such as windows and other penetrations - is key to the assembly’s ability to maintain a continuous air barrier. ASTM E 2357 overcomes these limitations by enabling a uniform method of evaluating and comparing entire air barrier assemblies.

The first such objective, uniform method available, ASTM E 2357 has been adopted by the Air Barrier Association of America (ABAA) as a key element of its acceptance criteria.

“ASTM E 2357 is the only test method that gives the user any information on the performance of an installed air barrier assembly. Every building contains multiple air barrier materials. It is only when a material is selected and combined into an assembly does it actually perform the function of an air barrier,” said Laverne Dalgleish, Executive Director of the ABAA. *“ASTM E 2357 determines the air leakage rate after being conditioned under real world loads, which provides the user with a precise air leakage rate and confidence that it will provide this performance when installed. Data from ASTM E 2357 is critical to every design professional.”*

ASTM E 2357 defines a specimen wall assembly and test protocols for evaluating air barrier assembly performance. The specimen is a realistic, 8 foot-by-8 foot wall mock-up, complete with typical wall penetrations as well as roof and concrete foundation interfaces (see **Figure 2**). The air barrier assembly to be tested is applied to the wall, complete with flashing and sealing materials applied around all penetrations and at air barrier joints in specified locations on the wall. The wall specimen is then mounted in a well-sealed test chamber with an air supply that allows application and measurement of both positive and negative air pressure differentials across the wall structure.

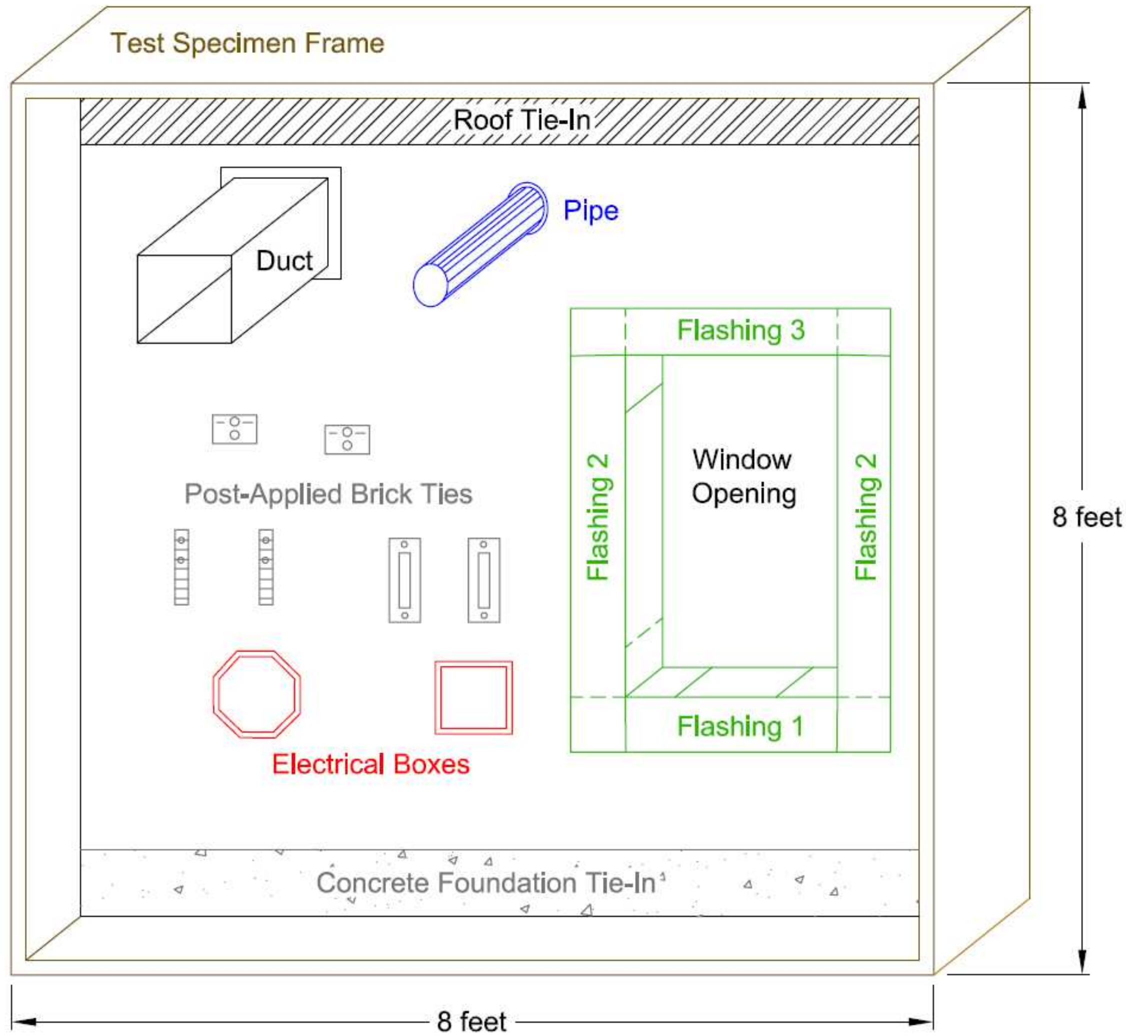

Figure 2: Diagram of specimen wall for testing air barrier assembly performance, as specified in ASTM E 2357.

The air barrier assembly is penetrated by realistic types of penetrations, required by the ASTM E 2357 Standard, exposing the potential weak points of the air barrier assembly. The PVC pipe, galvanized rectangular HVAC duct, and electrical box penetrations require the air barrier assembly to seal to these materials. The penetrations are familiar and found on real world job sites, which is a practical test for the air barrier assembly. The window opening requires the air barrier assembly to flash the window opening and subsequently seal against a wooden buck that is used to simulate a window. Again this window opening and window/air barrier interface is a realistic building condition that will be evaluated for air leakage during the test. The last penetration type is the post-applied brick ties. Fastening post-applied brick ties through a previously applied air barrier assembly is a common occurrence in building construction. The air barrier assembly may be capable of receiving the brick ties while maintaining an airtight seal or additional sealing may be required. Incorporating post-applied brick ties into the test allows for a standardized test method to evaluate what is required at the post-applied brick ties to maintain a continuous air barrier assembly.

Earlier the concept of an air barrier system on the whole building was discussed. The air barrier system consisted of several air barrier assemblies (wall, roof and foundation) sealed together to form the air barrier system for the whole building. ASTM E 2357 incorporates the roof and foundation tie-ins to the air barrier assembly on the wall. Ensuring an airtight interface between the air barrier assemblies is essential to ensure an air barrier system on the entire building is achieved.

Test Procedure

Once the air barrier assembly specimen is secured in the test frame and chamber, the wall specimen is subjected a wind load schedule. The wind loads are applied as both positive and negative loads during three distinct loading stages (see **Figure 3**):

- Sustained Load – 600 Pa (12.5 psf), equivalent to a 70 mph wind speed for 1 hour
- 2000 Cyclic Loads – 800 Pa (16.7 psf), equivalent to a 81 mph wind speed for 3 seconds each
- Wind Gusts – 1200 Pa (25 psf), equivalent to a 99 mph wind speed for 3 seconds

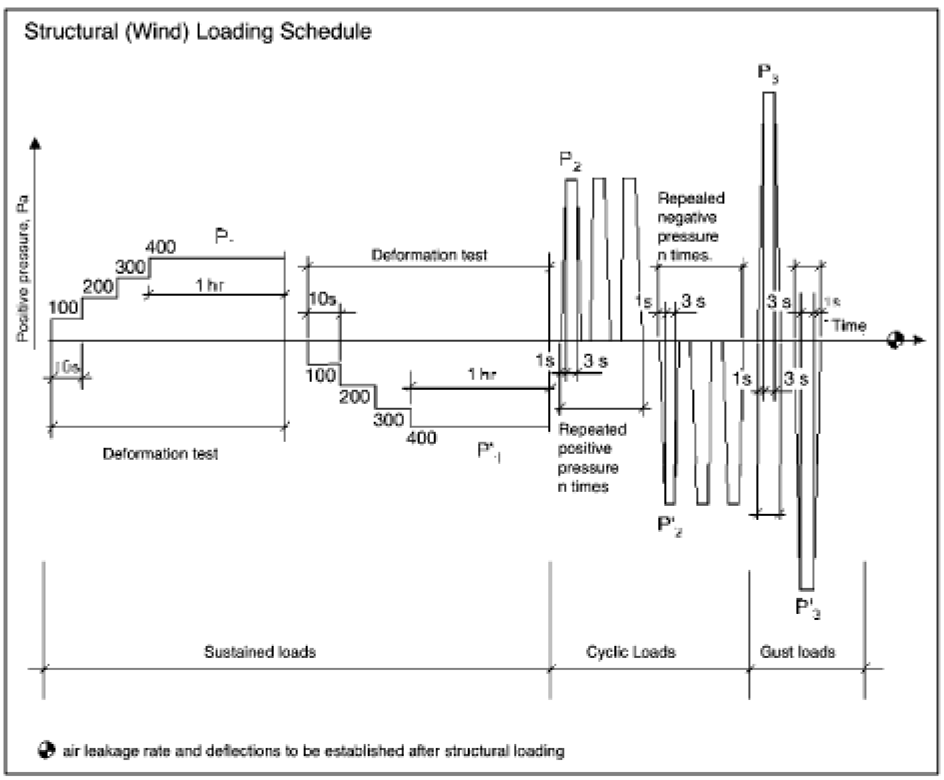

Figure 3: Chart of ASTM E 2357 Wind Loading Schedule illustrating positive and negative sustained, cyclic and gust loads to which the air barrier assembly is subjected during testing.

Following all three wind loading stages, the air leakage rate, or *air permeance*, is measured at a reference pressure of 75 Pa (air permeance is also measured at 25 Pa, 50 Pa, 100 Pa, 150 Pa, 250 Pa, and 300 Pa). Air permeance is expressed in units of cfm/ft^2 or L/s*m^2. Upon completion of the air permeance measurements, air barrier assembly deflection is measured.

Positive and negative pressure differentials are consistent with real world exposures of an air barrier assembly. Positive and negative pressures will be applied onto an air barrier assembly from various sources such as stack pressure, wind pressure and fan pressure over the life of a building. Stack, wind and fan pressure are detailed in **Figure 4**. Stack pressure is the difference in pressure between the bottom and top (or any intermediate height) of a column or air. In the heating season warm air could rise up a building causing a suction pressure at the base of the building and as the air tries to exit the building at the top a pushing force could be exerted on the air barrier assembly. Wind pressure also provides positive and negative pressures on an air barrier assembly. On the windward side of a building, where wind directly impacts onto a building, a positive pressure is applied onto an air barrier assembly. As wind moves around a building, suctions forces are exerted on the leeward side of a building resulting in a negative pressure on an air barrier assembly. Fan pressure is the pressure exerted by the HVAC or fans in a building that push air down into a room and out to the exterior walls of a building. Fan pressure can exert a negative pressure on an air barrier assembly. The ASTM E 2357 test method incorporates positive and negative pressures onto an air barrier assembly simulating real world exposures.

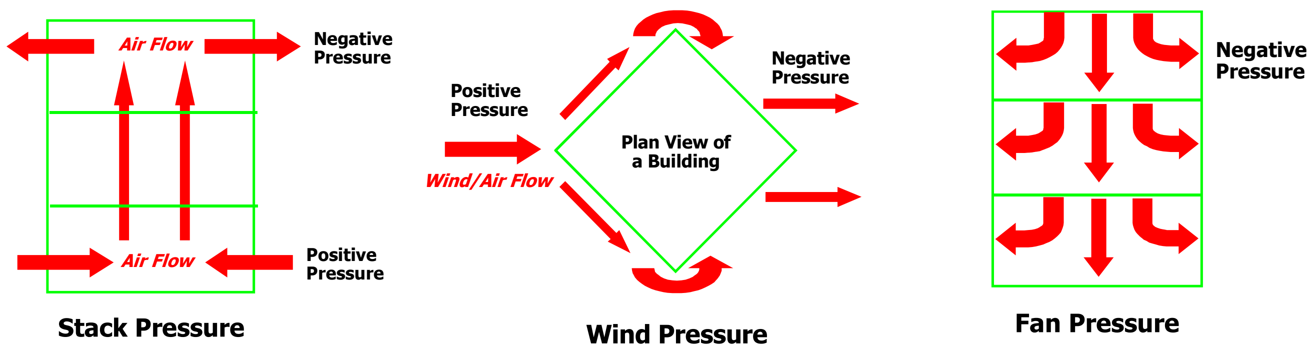

Figure 4: Stack Pressure, Wind Pressure and Fan Pressure – Positive and Negative pressures applied onto the air barrier assembly

These positive and negative pressures could tear open weak points in an air barrier assembly. ASTM E 2357 exposes the air barrier assembly to positive and negative pressure loading prior to testing the air barrier assembly for air leakage to account for these real world conditions.

In summary, the ASTM E 2357 test method incorporates a real world mock-up of an air barrier assembly complete with typical penetrations and tie-ins. The mock-up is exposed to positive and negative pressures to simulate real world conditions to put stress on any weak points that may yield an air leak in the assembly. After the air barrier assembly is subjected to the pulling and pushing forces of the test, the assembly is measured for air leakage. The ASTM E 2357 test method provides the best source of laboratory data of an air barrier assembly's ability to perform as intended on real world buildings. ASTM E 2357 can be used to confirm that the different materials used in the air barrier assembly are compatible to each other in achieving the desired goal.

Case Study

The following section discuses applications of the ASTM E 2357 test method being used to evaluate air barrier assemblies. The air barrier assemblies were installed in accordance with the manufacturer's instructions and details.

To ensure objectivity, two independent laboratories Intertek and Architectural Testing (ATI) conducted the case study testing at their facilities in April of 2007 and November 2009. Eight wall specimens were constructed according to the ASTM E 2357 specifications, with four different air barrier assemblies applied to each set of two walls. A fully adhered vapor impermeable peel and stick sheet membrane, a fully adhered vapor permeable sheet membrane, a synthetic, spray-applied vapor impermeable membrane and a spray-applied, vapor permeable, membrane were evaluated. Fully adhered membranes were used to flash the window openings on all wall specimens and sealant was used in areas such as annular space around the duct, pipe and electrical box penetrations to complete the air barrier assembly.

The base wall specimens were constructed of glass faced gypsum sheathing fastened to 6 in. wide steel studs. **Figure 5** shows the base wall prior to application of the air barrier assembly. The galvanized steel HVAC duct and PVC penetrations can be seen at the top left of the wall specimen. The electrical boxes are in the lower left of the wall specimen and the window opening framed with steel studs is to the right of the specimen. At the bottom of the specimen is a concrete curb to simulate the top of the foundation wall with an open joint between the top of the concrete foundation curb and bottom of the gypsum sheathing. A steel angle is fastened to the top of the wall to simulate the transition of the exterior wall to a roof. The open gap between the angle and the wall assembly must be addressed by the air barrier assembly to prevent air leakage through the joint.

Figure 5: Photograph of wall specimens tested by Intertek. Each wall specimen was constructed according to ASTM E 2357 specifications.

The PVC pipe, HVAC duct and electrical box penetrations were sealed with a sealant. **Figure 6** shows photos of the two methods of sealing the penetrations used for the case study. For the two spray-applied membranes the penetrations were sealed prior to application of the spray-applied membranes. For the peel and stick membrane the penetrations were sealed after application of the peel and stick membrane and the sealant overlapped onto the surface of the peel and stick membrane.

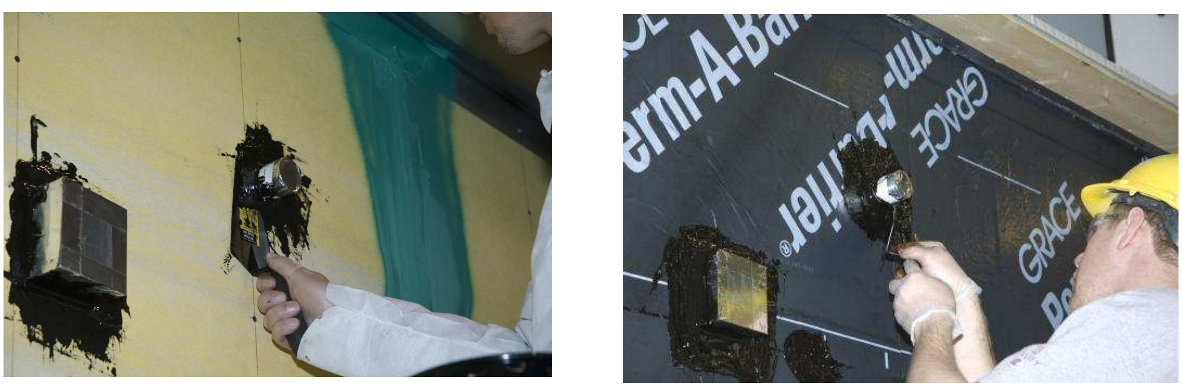

Figure 6: Application of sealant at PVC pipe and HVAC duct penetrations.

The joints in the gypsum sheathing were kept within the guidelines of ASTM E 2357 with a small gap between the gypsum sheathing boards. Steel fasteners were used to secure the gypsum sheathing boards to the steel studs. The joints in the gypsum sheathing were treated per the air barrier assembly manufacturer's standard instructions as shown in **Figure 7**. In this photo we see the spray-applied vapor impermeable membrane applied over the gypsum sheathing joints. The same fluid applied air barrier material that was used on the field of the sheathing was used at the sheathing joints. The membrane air barriers were simply installed over the sheathing joints with no additional joint treatment.

Figure 7: Treatment of gypsum sheathing joints per air barrier assembly.

The next step in the installation was to flash the window openings. A fully adhered flashing membrane was used to flash the windows as shown in **Figure 8.** The flashing membrane was installed into the steel stud framed opening onto the steel studs and then overlapped onto the surface of the gypsum sheathing. The sill of the window was flashed first, followed by the two vertical jambs and then finally the window head was flashed. The window opening was flashed in this manner to simulate real world construction practices and provide water-shedding overlaps of the flashing membrane. Fully adhered membranes were also used at the roof tie-in and foundation wall tie-in to simulate fully adhered roofing membranes and fully adhered foundation waterproofing membranes.

Figure 8: Flashing windows with a fully adhered membrane.

The spray-applied membranes used in the case study were applied both over or onto the fully adhered membrane and under or receiving the fully adhered membrane. Both methods were evaluated to measure air tightness of the fluid-applied membranes applied both onto and under the fully adhered membranes. The capability of the fluid-applied membranes to adhere to the plastic film on top of the fully adhered membranes and act as an air barrier was one of the objectives of the case study. The results of the test will be discussed in detail, but it is important to note that both methods of installation performed very well as part of the air barrier assembly.

Once the air barrier was fully installed onto the base wall specimens, the post-applied brick ties were installed. **Figure 9** shows examples of the completed air barrier assemblies with the post-applied brick ties fastened through the primary air barrier material. Three different types of brick-ties were used, all of which were fastened to the steel studs with steel fasteners. The positive and negative pressure loads were applied onto the air barrier assembly in accordance with ASTM E 2357 requirements. During the wind loading, witnesses in the test facility noted the air barrier assembly and wall specimen pulsing or deflecting slightly as the pressures were applied onto the wall. After the pressure loading the air barrier assembly was measured for air leakage to calculate the air permeance.

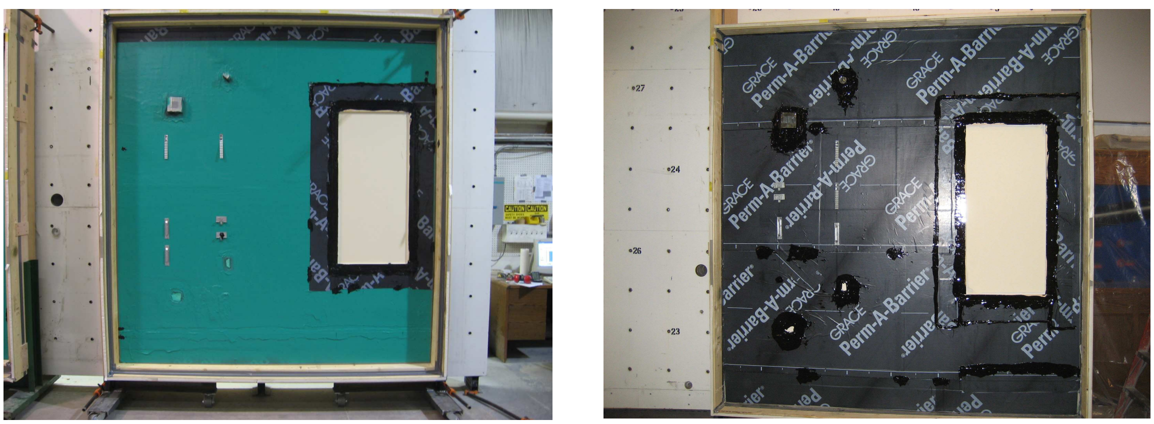

Figure 9: Full scale mock-ups of the installed air barrier assemblies complete with PVC pipe HVAC duct and electrical box penetrations sealed, windows flashed, tie-ins to roof and foundation and post-applied brick ties.

Results

After being subjected to the ASTM E 2357 standard wind load schedule, air permeance for all eight of the wall specimens was measured to be less than 0.0008 cfm/ft^2 (0.004 L/s*m^2). This represents air leakage rates below the detectable limit of the laboratory test equipment for all four air barrier assemblies tested. As a barometer, the Air Barrier Association of America (ABAA) uses an air permeance of 0.04 cfm/ft^2 (0.2 L/s*m^2) as their acceptance criteria for an air barrier assembly. **Tables 1 through 8** provide the results data.

Table 1: Opaque Wall: Fully Adhered Vapor Impermeable Peel and Stick Sheet Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	<0.004	<0.004	<0.004	<0.004
50	<0.004	<0.004	<0.004	<0.004
75	<0.004	<0.004	<0.004	<0.004
100	<0.004	<0.004	<0.004	<0.004
150	<0.004	<0.004	<0.004	<0.004
250	<0.004	<0.004	<0.004	<0.004
300	<0.004	<0.004	<0.004	<0.004

Table 2: Penetrated Wall: Fully Adhered Vapor Impermeable Peel and Stick Sheet Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	<0.004	<0.004	<0.004	<0.004
50	<0.004	<0.004	<0.004	<0.004
75	<0.004	<0.004	<0.004	<0.004
100	<0.004	<0.004	<0.004	<0.004
150	<0.004	<0.004	<0.004	<0.004
250	<0.004	<0.004	<0.004	<0.004
300	<0.004	<0.004	<0.004	<0.004

Table 3: Opaque Wall: Fully Adhered Vapor Permeable Sheet Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	0.001	0.001	0.001	0.001
50	0.001	0.001	0.001	0.001
75	0.001	0.001	0.001	0.001
100	0.001	0.001	0.001	0.001
150	0.001	0.001	0.001	0.001
250	0.001	0.001	0.001	0.001
300	0.001	0.001	0.001	0.001

Table 4: Penetrated Wall: Fully Adhered Vapor Permeable Sheet Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	0.001	0.001	<0.001	0.001
50	0.001	0.001	0.001	0.002
75	0.002	0.001	0.001	0.004
100	0.002	0.001	0.001	0.003
150	0.002	0.001	<0.001	0.001
250	0.001	0.001	<0.001	0.001
300	0.001	<0.001	<0.001	0.002

Table 5: Opaque Wall: Synthetic, Spray-Applied Vapor Impermeable Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	<0.004	<0.004	<0.004	<0.004
50	<0.004	<0.004	<0.004	<0.004
75	<0.004	<0.004	<0.004	<0.004
100	<0.004	<0.004	<0.004	<0.004
150	<0.004	<0.004	<0.004	<0.004
250	<0.004	<0.004	<0.004	<0.004
300	<0.004	<0.004	<0.004	<0.004

Table 6: Penetrated Wall: Synthetic, Spray-Applied Vapor Impermeable Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	<0.004	<0.004	<0.004	<0.004
50	<0.004	<0.004	<0.004	<0.004
75	<0.004	<0.004	<0.004	<0.004
100	<0.004	<0.004	<0.004	<0.004
150	<0.004	<0.004	<0.004	<0.004
250	<0.004	<0.004	<0.004	<0.004
300	<0.004	<0.004	<0.004	<0.004

Table 7: Opaque Wall: Spray-Applied, Vapor Permeable, Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	<0.004	<0.004	<0.004	<0.004
50	<0.004	<0.004	<0.004	<0.004
75	<0.004	<0.004	<0.004	<0.004
100	<0.004	<0.004	<0.004	<0.004
150	<0.004	<0.004	<0.004	<0.004
250	<0.004	<0.004	<0.004	<0.004
300	<0.004	<0.004	<0.004	<0.004

Table 8: Penetrated Wall: Spray-Applied, Vapor Permeable, Membrane

Test Pressure (Pa)	Infiltration Pre-Conditioning (L/s*m^2)	Exfiltration Pre-Conditioning (L/s*m^2)	Infiltration Post-Conditioning (L/s*m^2)	Exfiltration Post-Conditioning (L/s*m^2)
25	<0.004	<0.004	<0.004	<0.004
50	<0.004	<0.004	<0.004	<0.004
75	<0.004	<0.004	<0.004	<0.004
100	<0.004	<0.004	<0.004	<0.004
150	<0.004	<0.004	<0.004	<0.004
250	<0.004	<0.004	<0.004	<0.004
300	<0.004	<0.004	<0.004	<0.004

The results indicated that the positive and negative pressures did not force open any openings in the air barrier assemblies tested. The air barrier assemblies functioned as intended to prevent air passage.

After the testing was completed on the four air barrier assemblies it was decided to further evaluate the assemblies to determine their limitations. The air barrier assemblies were subjected to a maximum suction or negative force equivalent to 168 mph wind gusts (for comparison, the highest wind gusts recorded during Hurricane Katrina were approximately 150 mph) before allowing air leakage through the assembly. That translates into a negative air pressure of 72 psf (3445 Pa) before leaking.

Conclusion

Air barrier assemblies are touted as being beneficial for buildings in terms of energy efficiency, prevention of moisture degradation issues and reduction of indoor air quality issues due to organic growth. Testing a small sample of an air barrier material alone does not provide enough information to make an informed decision about the real world performance of air barrier assemblies.   The ASTM E 2357 test method takes real world conditions into account such as seams in the air barriers, penetrations of the assembly, tie-ins to windows, roofs and foundations and most importantly positive and negative pressures that the air barrier assembly will be exposed to in buildings. ASTM E 2357 is a standardized test method that provides evidence that air barrier assemblies will work as intended on buildings. The testing also confirms that the components of the air barrier assembly are compatible with each other and work together to achieve the goal of the air barrier assembly. The recommendation of this paper is to require and/or specify air barrier assemblies that have been tested in accordance with ASTM E 2357.

References

Emmerich, S.J., T.P. McDowell, and W. Anis. 2005. “Investigation of the impact of commercial building envelope airtightness on HVAC energy use,” NISTIR 7238.