Lab to Field: From Components to Verified High Performing Buildings

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ABSTRACT HEADING

The building science community has long recognized that reducing air leakage through the building envelope is a cost effective energy conservation strategy. But it took the 2010 requirement by the U.S. Army Corps of Engineers (USACE), and the subsequent incorporation of air leakage standards into the IECC to accelerate the industry discussion, partnerships and innovations. The use of fluid applied sealants and air barriers grew quickly as a result. This paper will compare three common Air & Water Barrier (AWB) systems with data presented from laboratory material evaluations, system performance tests, whole building air leakage measurements, and case studies of real-world field applications. System testing was conducted by Oak Ridge National Lab using their Heat, Air, and Moisture (HAM) penetration chamber to assess the impact of various environmental conditions on wall assemblies of the one of these methodologies. Whole building air leakage testing is also presented to reflect the delivered performance of air barrier options. Real world design and construction case studies are included for the various AWB systems in actual use. The featured projects compare how the different air barrier types are used by design professionals, and are incorporated in various building assembly designs. Further, the wall system case studies review challenges of field placement and transitions to adjacent materials in the context of scaling from laboratory performance to the field..

INTRODUCTION [LEVEL 1 HEAD]

Air leakage is responsible for about 1.1 quads of energy or 6% of the total energy used by commercial buildings in the US (DOE 2014). Consequently, uncontrolled infiltration and exfiltration are among the largest envelope-related contributors to the heating, ventilation, and air conditioning loads in commercial buildings.

Several studies have summarized the air leakage rates of commercial buildings. The work that is most commonly referenced is from Persily (1998) and Emmerich and Persily (2005, 2011, 2014). These publications track the evolution of a database that is being maintained by the National Institute of Standards and Technology (NIST). In their latest publication (Emmerich and Persily 2014) included 387 buildings that were constructed between 1950 and 2010. Figure 1 suggests that smaller buildings appeared to be leakier, although this finding could have been influenced by the fact that the sample size for larger buildings was smaller. Data from Emmerich and Persily (2014) also indicates that buildings in warmer climates appear to be leakier than in colder climates (Figure 2). This could be explained by greater owner vigilance in the north where the effect of air leakage on energy use and the desire for comfort is higher.

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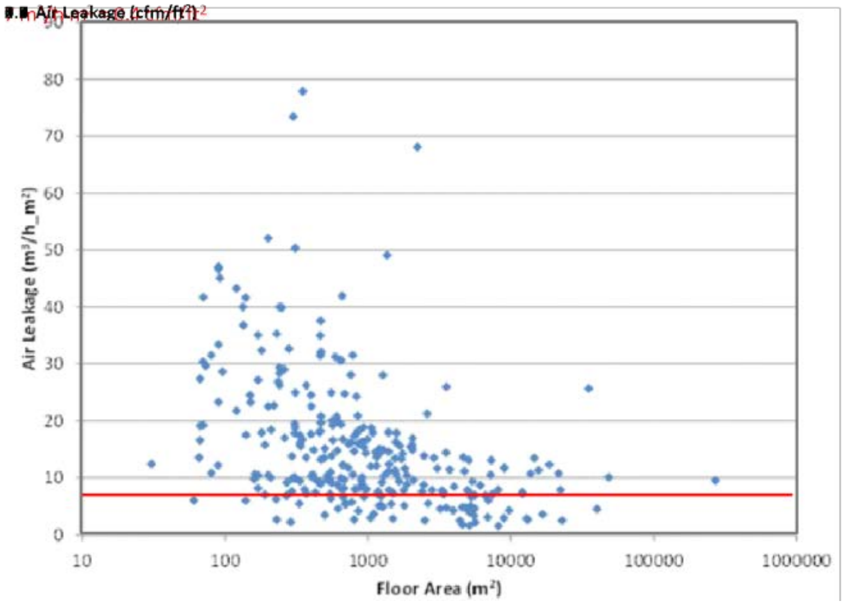


Figure 1. Measured air leakage rate at 0.3 in. of water as a function of floor area (Emmerich and Persily 2014).
Notes: (1) 0.4 cfm/ft² at 0.3 in. of water is one of the options for air barrier compliance under the 2015 IECC. (2) 1 m³/(h·m²) = 0.056 cfm/ft².

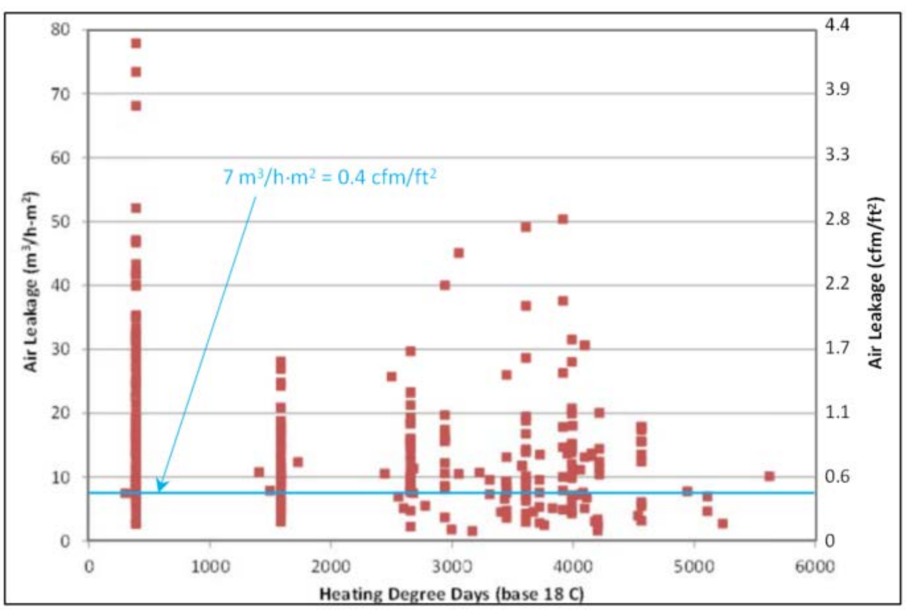


Figure 2. Measured air leakage rate at 0.3 in. of water as a function of heating degree days (Emmerich and Persily 2014).
Notes: (1) 0.4 cfm/ft² at 0.3 in. of water is one of the options for air barrier compliance under the 2015 IECC. (2) 1 m³/(h·m²) = 0.056 cfm/ft².

RDH Building Sciences began a more focused database than that of NIST after Washington State made it mandatory to measure the air leakage rate of new commercial buildings in 2009, although it was not mandatory to achieve a specific air leakage rate. Revisions to the building code require that the contractor documents efforts to decrease the leakage rate if the measured value is greater than what is specified in the 2015 International Energy Conservation Code (IECC) (i.e., 0.4 cfm/ft² at 0.3 in. of water or 2 L/s/m² at 75 Pa) in lieu of a second air leakage test. Among the parameters that Jones et al. evaluated, they included the effect of the air barrier type on air leakage. The air barrier type categories that they used are:

1. Curtain wall/window walls: curtain wall or window wall system that spans from floor to floor.
2. Liquid-applied: exterior sheathing is covered with a liquid-applied membrane.
3. Sheet-applied: exterior sheathing is wrapped with a mechanically-fastened membrane that is taped at the joints or with a self-adhered membrane.
4. Sealed sheathing: joints of the exterior sheathing are sealed, and the exterior sheathing is wrapped with a water-resistive barrier.
5. Storefront glazing: glass panes with aluminum frames.

Results on Figure 3 from this limited dataset indicate that a leakage rate of 0.4 cfm/ft^2 is achievable irrespective of the air barrier type employed. Furthermore, buildings with a sheet-applied air barrier had the largest variance in air leakage rate, although these numbers should be used with caution because the sample size is small and because the sheet-applied category includes two types of membranes, mechanically-fastened and self-adhered, which use very different installation procedures.

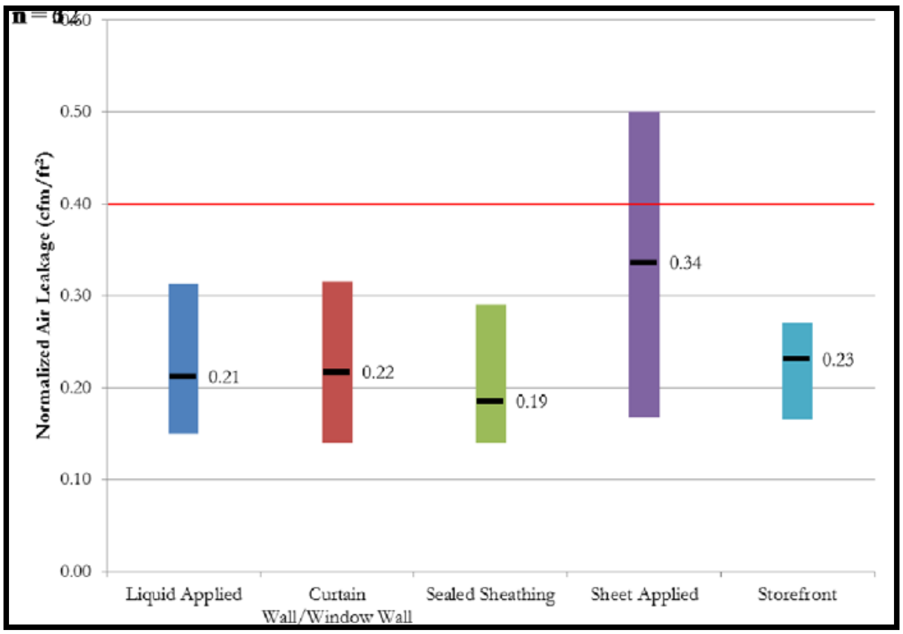


Figure 3. Measured air leakage rates at 0.3 in. of water from buildings with different air barrier types (Jones et al. 2014). Colored bars show the minimum and maximum air leakage rates, and the black line indicates the average value.

A few years after Washington State started mandating air leakage tests, the US Army Corp of Engineers (USACE) issued an Air Leakage Test Protocol for Building Envelopes (USACE 2012). According to this document, buildings that are tested per this protocol need to achieve an air leakage rate that is lower than 0.25 cfm/ft^2 at 0.3 in. of water. Zhivov et al. (2014) published information about 285 new and renovated buildings that were tested per the USACE protocol. The buildings included barracks; medical, training and childcare centers; offices; and miscellaneous facilities. The number of floors of these buildings varied between 1 and 8. Moreover, their floor areas ranged from 13,000 to 371,000 ft^2. Zhivov et al. reported the air leakage rate from 122 of the buildings that complied with USACE's airtightness requirement; the authors stated that compliance was achieved with minimal increase in material cost. RDH Building Science (2015) summarized in Figure 4 some of the data that were collected by Zhivov et al. Figure 4 indicates that most of the buildings reached airtightness levels that spanned from 0.04 to 0.26 cfm/ft^2 at 0.3 in. of water (0.2 to 1.3 L/s·m^2 at 75 Pa).

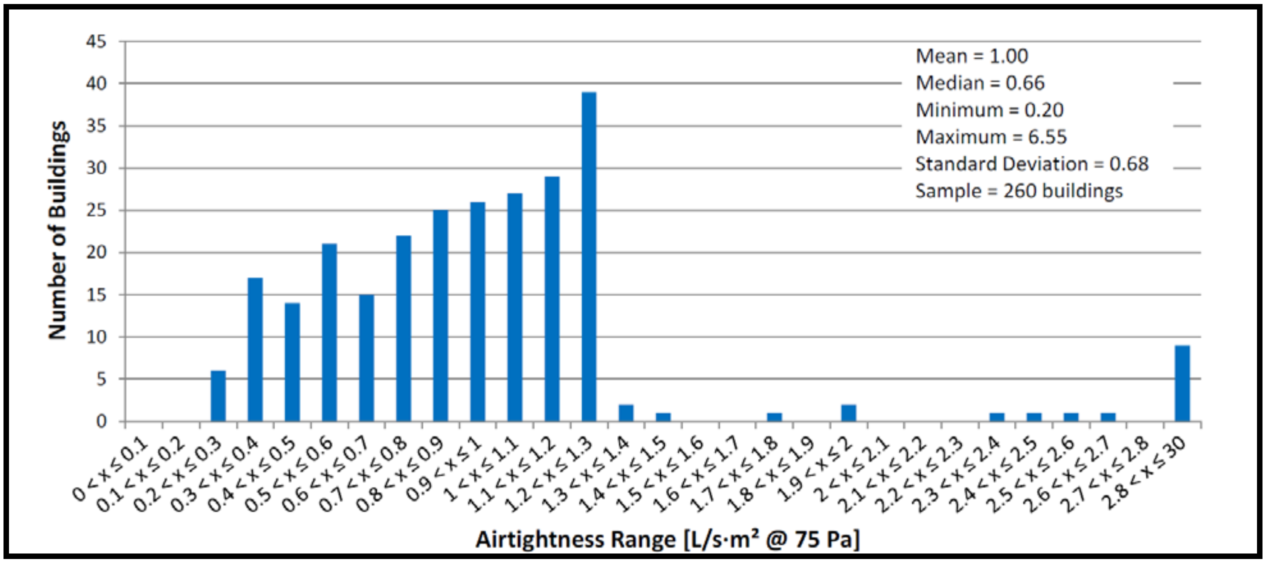


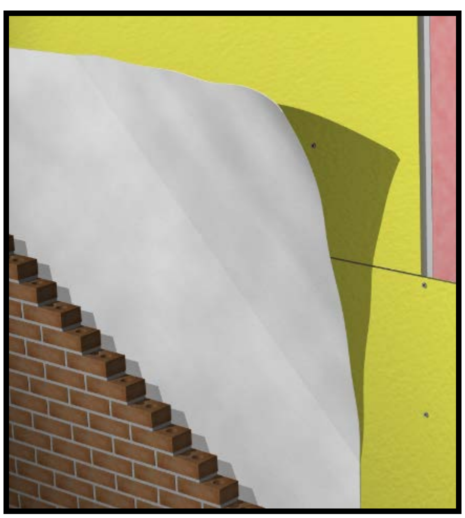
Figure 4. Measured air leakage rates at 0.3 in. of water (75 Pa) from buildings that were evaluated per the USACE Air Leakage Test Protocol (RDH Building Science 2015). Note that the USACE airtightness requirement is 0.25 cfm/ft^2 at 0.3 in. of water (1.25 L/s·m^2 at 75 Pa).

Method Options

There are several material/assembly methods available in the marketplace for achieving a code compliant air and water barrier (AWB). These methods and materials can be grouped into four categories.

Method 1: Sheet-Applied

Sheet applied air barriers are thin films or fabrics that are mechanically attached to the exterior wall with seams that are taped or sealed in such a way as to achieve air barrier qualities. The sheets themselves must also be an AWB. For this paper, the investigation of sheet applied AWBs were not included.



Method 2: Self-adhered

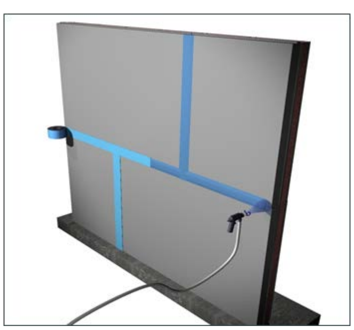
Self adhered membranes are plastic films with thick layers of butyl or asphalt adhesives which allow them to self adhere to a smooth substrate, overlap at seams, and, to some extent, self-heal when penetrated. Often referred to as "peal-and-stick" products, these are typically applied in full coverage.

Method 3: Fluid applied

Fluid applied membranes are viscous, high solids content liquids which are applied at a given thickness to a prepared substrate and allowed to cure/dry into a flexible, solid material which is a barrier to water and air penetration. These are also typically applied to fully cover the substrate.

Method 4: Joint-treated boards

Many sheathing board materials that are applied over a stud system are inherent air and water barriers. Such sheathing boards include water resistant gypsum boards and most foam plastic insulation boards. An air and water barrier layer can be created by sealing the joints between sheathing boards and thus extending the air water barrier across the entire opaque vertical envelope.



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LABORATORY TESTING

Per 2015 International Building Code (IBC) and International Energy Conservation Code (IECC), materials that qualify as air barriers must comply with:

- Material only: ASTM E2178: Standard Test Method for Air Permeance of Building Materials
- Wall Assembly: ASTM E283 Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen
- or ASTM E2357. Standard Test Method for Determining Air Leakage of Air Barrier Assemblies

Those that meet water barrier requirements pass ASTM E331: Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference

Most commercially available air barriers used today also comply with water barrier requirements. In fact as summarized in Table 1, it is difficult to determine what air or water barrier material would perform best considering they all comply with the code requirements by material and assembly pass/fail criteria.

Table 1: Summary of Commercially Air and Water Barrier Materials

Test Methods	**Air and Water Barrier Types**			
	Sheet Applied	**Self-Adhered**	**Fluid Applied**	**Joint Treated**
ASTM E2178	$\leq$0.02 l/s-m^2	$\leq$0.02 l/s-m^2	$\leq$0.02 l/s-m^2	$\leq$0.02 l/s-m^2
ASTM E283	PASS	PASS	PASS	PASS
ASTM E331	PASS	PASS	PASS	PASS
ASTM E2357	PASS	PASS	PASS	PASS

In order to gain more in-depth understanding of the robustness of the barrier system options, Oakridge National Lab (ORNL) designed a series of laboratory evaluations above and beyond code requirements through humidity and temperature cycling to assess the long term performance. Only the joint-treated board method is represented in the detailed testing conducted by ORNL. The joint treatments used are 1) flashing tape, which is representative of Self-Adhered technology, and 2) liquid flashing, similar to many Fluid Applied products in principle. The authors feel that this can efficiently highlight some of the laboratory limitations in the different materials assessed.

The series of laboratory evaluations conducted at ORNL evaluates the performance of an air and water barrier assembly beyond the code minimums, but is still based on industry test standards from the American Society for Testing and Materials (ASTM) International, and the American Architectural Manufacturers Association (AAMA). The AWB method tested in this series was exclusively joint sealed XPS Insulation boards. The performed tests were:

- ASTM E283-04: Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen
- ASTM E331-00: Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference
- ASTM E1424-91: Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen
- ASTM E2357-05: Standard Test Method for Determining Air Leakage of Air Barrier Assemblies
- AAMA 501.5-07: Test Method for Thermal Cycling of Exterior Walls

As indicated in Figure 5, these tests were arranged to examine air and water penetration through an air and water barrier assembly before and after it was aged through pressure and thermal cycles. Figure 5 also describes the passing criteria that were followed throughout these tests.

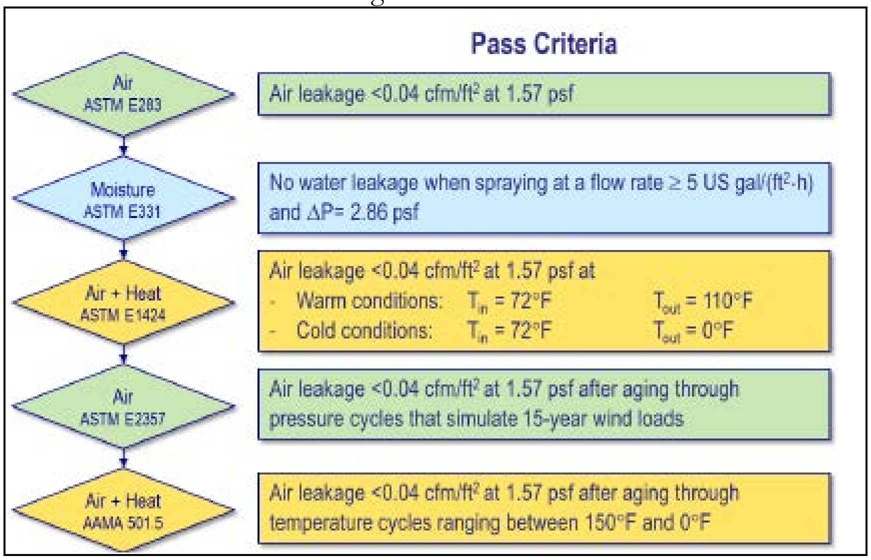

Figure 5. Tests conducted to evaluate the air and water tightness of air and water barrier assemblies.

<u>Equipment</u>

Tests were conducted in the Heat, Air and Moisture (HAM) penetration chamber shown in Figure 6. The chamber is composed of an indoor room, an outdoor room and a test frame; all three components are thermally isolated from the lab space with R30 insulation, which facilitates controlling the temperature within the chamber. The indoor room and the test frames are movable so walls that are up to about 8'-0" wide by 10'-0" tall can be built outside the chamber. Table 1 lists the parameter ranges that the chamber is capable of regulating. Both the indoor and outdoor rooms have patch panels within them so sensors can be installed on either side of the test wall to monitor temperature and relative humidity at various locations without penetrating the air- and water-resistive barriers. ASTM and AAMA tests were executed through LabView codes that regulated the parameters listed in Table 1.

Table 1. Parameters that can be controlled in the heat, air and moisture penetration chamber.

Parameter	Indoor Room	Outdoor Room
Temperature (°F)	32 to 90	0 to 115
Relative humidity (%)	10 to 90	10 to 90
Pressure (psf)	± 2.1	± 31.3
Infrared radiation (W/ft²)	NA	0 to 100
Rain water flow rate (gal/min)	NA	0 to 7.9
Rain water temperature (°F)	NA	40 to 95

The chamber setup has been calibrated to measure a minimum airflow rate (Qchamber min) of 1.4 cfm (0.66 L/s) following the procedure described in ASTM E283-04. Airflow measurements that are presented in this report are standardized to 70 F (21.1 C) and 29.92 in. Hg (101.3 kPa).


Figure 6. Environmental chamber that evaluates heat, air and moisture penetration.

Test Wall

Figure 7 illustrates the material layout. The test wall was divided into two sections so that a liquid applied board joint sealant and flashing tape board joint sealant could be simultaneously exposed to the same conditions while installed over polyisocyanurate insulation boards to seal gaps between boards and around penetrations. The two sections were built so air would not leak between them. Moreover, plywood covers, which were sealed with a self-adhered membrane, were built for each of the sections so air leakage through each wall could be measured separately.

Gaps around PVC pipes, electrical outlets and steel ducts were close to ¼" wide, and joints between polyisocyanurate insulation boards were ~1/8" wide. All the joints and gaps were sealed with either the liquid applied board joint sealant or the flashing tape board joint sealant and as illustrated in Figures 8 through 10. A supporting material was not used underneath either board joint flashing method.

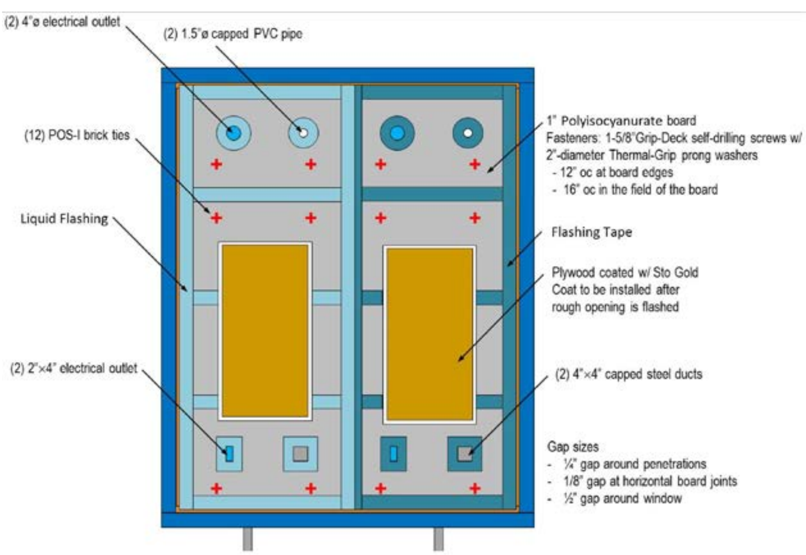

Figure 7. Material layout in test wall.

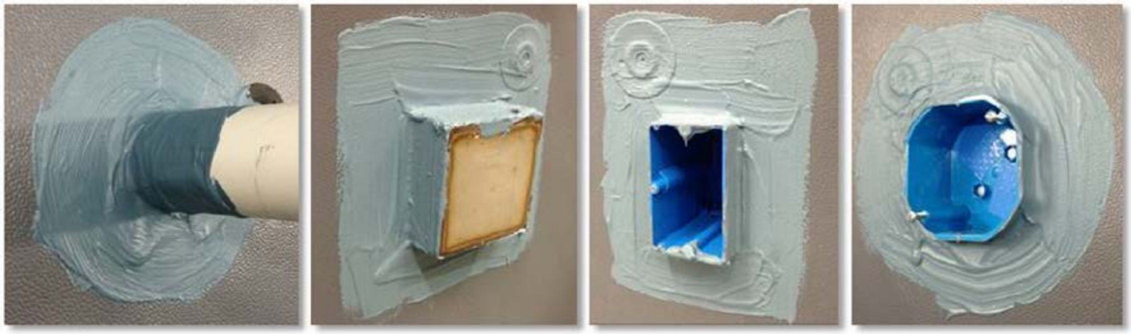

Figure 8. Gaps around penetrations that were sealed with liquid flashing.

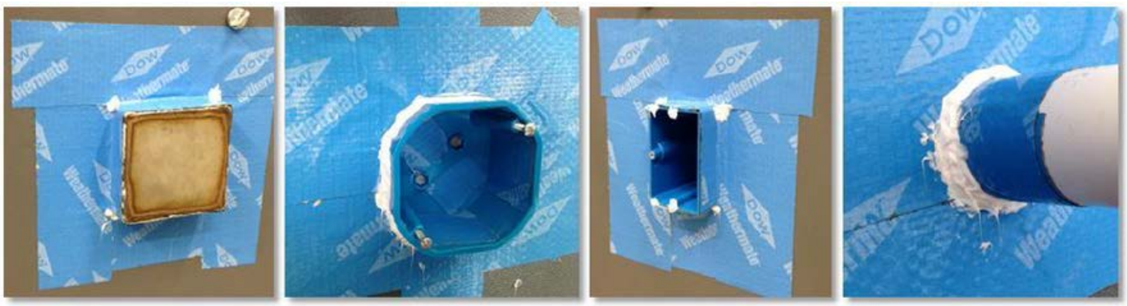

Figure 9. Gaps around penetrations that were sealed with flashing tape and sealant.

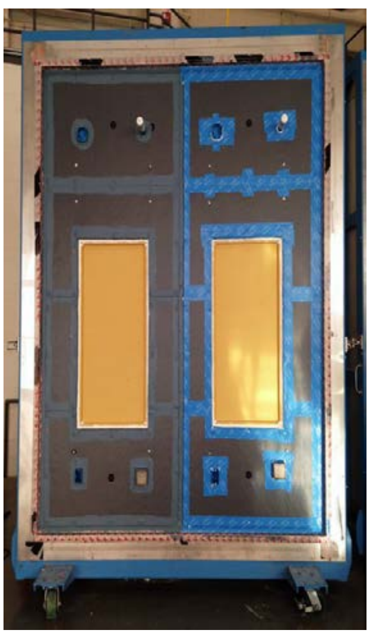

Figure 10. Completed test wall. Board joints and gaps on the left section of the wall were sealed with a liquid flashing, and on the right side were sealed with flashing tape.

Laboratory Test Results

ASTM E 283 - 04

This test method is a laboratory procedure for determining the air leakage rate of air barrier assemblies under pressure differentials of 0.52, 1.04, 1.57, 2.09, 3.13, 5.22 and 6.27 psf (25, 50, 75, 100, 150, 250 and 300 Pa).

In both wall sections the infiltration and exfiltration flow rates at all the prescribed pressure differentials were less than Qchamber min. This indicates that both wall sections had leakage rates that were < 0.038 cfm/ft^2 at 1.57 psf (0.19 L/(s-m^2) at 75 Pa) and meet the 0.04 cfm/ft^2 at 1.57 psf (0.2 L/(s-m^2) at 75 Pa) maximum requirement for air barrier assemblies.

ASTM E 331 - 00
This test method evaluates the resistance of water barrier assemblies to water penetration while they are sprayed with > 5 US gal/(ft^2-h) of water and subjected to a constant pressure of 2.86 psf (137 Pa).

Polyisocyanurate Insulation with liquid flashing: Water leakage through the test wall section did not occur during the test.

Polyisocyanurate Insulation with flashing tape: The ASTM E331 test compliance required more installation rework at penetrations due to inconsistent installation of the flashing tape. Around the outlet boxes and penetrations, the leading edge of the flashing needed additional spot sealant before passing the test.

ASTM E 1424 - 91
This laboratory procedure examines how the air leakage through an air barrier assembly varies with temperature. Infiltration and exfiltration rates are measured at 0.56, 1.57 and 6.27 psf (27, 75 and 300 Pa) after the test wall has been conditioned at each of the following two temperature modes. Note that the test was conducted twice because each wall section had to be evaluated independently.

	Warm Mode	**Cold Mode**
Indoor temperature	72°F ± 3°F (22°C ± 2°C)	72°F ± 3°F (22°C ± 2°C)
Outdoor temperature	110°F ± 3°F (43°C ± 2°C)	0°F ± 3°F (-17°C ± 2°C)

After steady-state temperatures had been reached, all the infiltration and exfiltration airflow rates that were measured at the prescribed pressures were less than Qchamber min. Therefore, the wall sections had leakage rates of < 0.038 cfm/ft^2 at 1.57 psf (0.19 L/(s-m^2) at 75 Pa), which meet the 0.04 cfm/ft^2 at 1.57 psf (0.2 L/(s-m^2) at 75 Pa) maximum requirement for air barrier assemblies in both the warm and cold modes.

ASTM E 2357 - 05
This test method measures the air leakage rate of air barrier assemblies per ASTM E 283 before and after the test specimen is aged through sustained and cyclic pressures. Additionally, the deflection of the test wall is recorded when it is exposed to gust loads of 25.1 psf (1200 Pa).

The infiltration and exfiltration airflow rates after the wall sections were aged through pressure cycles were lower than Qchamber min. Consequently, the wall sections had leakage rates of < 0.038 cfm/ft^2 at 1.57 psf (0.19 L/(s-m^2) at 75 Pa) and complied with the 0.04 cfm/ft^2 at 1.57 psf (0.2 L/(s-m^2) at 75 Pa) maximum requirement for air barrier assemblies.

AAMA 501-07
This test method is a laboratory procedure to evaluate the effects of thermal cycling on airflow through an air barrier assembly. Measurements are gathered before and after the test specimen is subjected to three temperature cycles. Outdoor temperatures are varied between ~150 °F (65.6 °C) and 0 °F (-17.8 °C) after remaining for two hours at

these setpoints, while the indoor temperature is set to 75 °F (23.9 °C). Both hot air and infrared lamps are used to reach the outdoor temperature setpoints.

For each of the wall sections, leakage rates before and after the thermal cycling were lower than Qchamber min. Thus, the wall sections had leakage rates < 0.038 cfm/ft^2 at 1.57 psf (0.19 L/(s-m^2) at 75 Pa) and met the requirement for air barrier assemblies of flow rates less than 0.04 cfm/ft^2 at 1.57 psf (0.2 L/(s-m^2) at 75 Pa).

Laboratory Conclusions

Laboratory evaluations were performed on a test wall that was assembled per Table 2 and Figure 3. The objective was to conduct a side-by-side assessment of the performance of liquid flashing and flashing tape over polyisocyanurate Insulation boards with ~¼"-wide gaps around penetrations. A supporting material was not provided underneath the liquid flashing or the flashing tape. The test wall was divided into two separate sections that did not allow for air to flow between them. Results from the laboratory evaluations indicate that both test walls passed the airtightness criteria described in Figure 1; that is, their air leakage rates were lower than 0.04 cfm/ft^2 at 1.57 psf (0.2 L/(s-m^2) at 75 Pa). However, differences were encountered during the water penetration tests. It was more difficult to get a perfect water seal with the flashing tape than liquid flashing in one pass. The leakage path was difficult to see without deconstruction, although water tight seals were achievable with both flashing tape with sealant and liquid flashing in the lab. This difference that was observed between the liquid flashing and the flashing tape walls could be explained by the fact that a liquid flashing is easier to install over uneven surfaces and curved gaps.

Field Case Studies

It has been noted that "common mistakes and failures of the air barrier systems are not a result of the material or small defects, but rather occur at junctions, transitions and interfaces.[1]" The authors agree with this statement; therefore it might be asked what can be learned from case studies of actual installations. The benefit of this examination comes from understanding what aspects of each AWB method can lead to more frequent "transition" defects. In other words, which building or design conditions are best suited for each type of AWB? The following examples illustrate some of the "real world" challenges of achieving performance goals for each system.

1. "Impact of Air Leakage on the building Envelope: Myths and Facts about airtightness" Construction Specifier, February 2011

Method 1: Sheet Applied
Sheet applied methods and products were not selected to be part of this investigation.

Method 2: Self-Adhered

Case Study 2-A: Gordon Foods [11-135]

Highlights: A self adhered AWB with primer was tested for water penetration at the fasteners. Its installation revealed some improper seaming and some difficulties with transitions to adjacent precast panels and roofing.

Figure 2A-1 Partial view of Corporate Headquarters

Building Description:
This is a 380,000 Sq. ft. corporate headquarters (Figure 2A-1). The wall system consists of a steel structural frame with steel stud wall-framing and precast wall panels. The air and water barrier at the steel stud walls is provided by a self-adhered membrane. The wall system is behind a metal cladding rain screen system.

Construction Challenges (The Issues):
(1) The self-adhered membrane (also referred to as a "peel and stick") was applied to a fiberglass faced exterior gypsum sheathing board which had been primed with an adhesive. As with any air and water barrier, the system must maintain integrity when penetrated by fasteners. In the case of this product, that is accomplished through "self-gasketing." To test this characteristic, a sample board with a fastener attached was subjected to a water stream with an AAMA 501.2 test nozzle for one hour (Figure 2A-2). There was no detectable water penetration through the system.

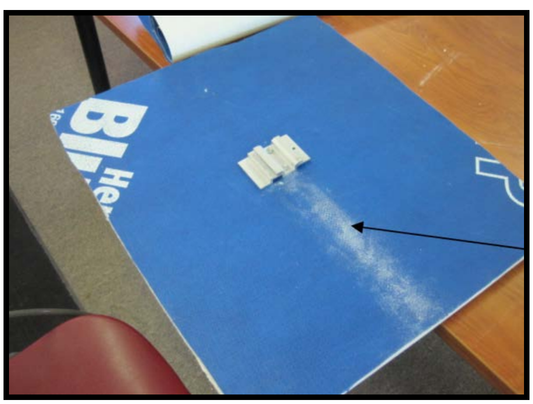

Figure 2A-2 Typical metal panel mounting clip installed on the AWB test board

(2) The manufacturer's instructions call for the membrane to be "shingled". That is, sheets that are higher in elevation should always end with their bottom edges overlapping to the exterior of the sheet below. This helps the water running down the barrier to shed to the exterior. If this instruction is not followed, even microscopic delaminations between the sheets can catch and hold liquid water as it runs down. During onsite inspections, the installation exhibited a number of "fish-mouth" gaps at horizontals [Figure 2A-3]

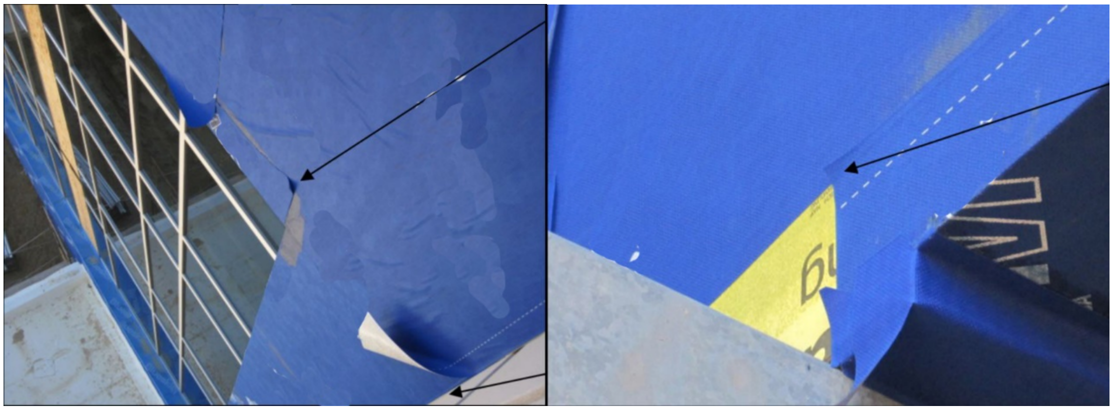

Figure 2A-3 Installations with improper shingling

(3) As with many air and water barriers, the transition to a different system was shown to be a weak point. In this case, the installers failed to follow manufacturer's recommendations for the transition from the AWB material to the adjacent precast [Figure 2A-4] The builder cut the AWB to just touch the precast panel and then proposed sealing the AWB to the precast with a "fillet" sealant shape [figure 2A-5, left]. This type of sealant joint would likely fail in an unacceptably short period.

Figure 2A-4 View of junction between Blue Skin and precast concrete

In Figure 2A-5 a metal panel rainscreen system meets a fully adhered roof membrane. The AWB behind the metal panels is cut just to the top of the sheathing. Another section had to be stripped in, extended across the rough substrates, and married to the roofing membrane. This is a case where a self-adhered membrane is best suited compared to the other categories of AWB considered by the authors.


Figure 2A-5 Metal panel rainscreen meet a roof

Building Performance

This project was scanned with an IR camera. The scan was generally unremarkable except where it revealed heat flux anomalies at beam penetrations adjacent to an expansion joint. The project was not whole-building pressure tested. There have been no maintenance requests regarding the AWB.

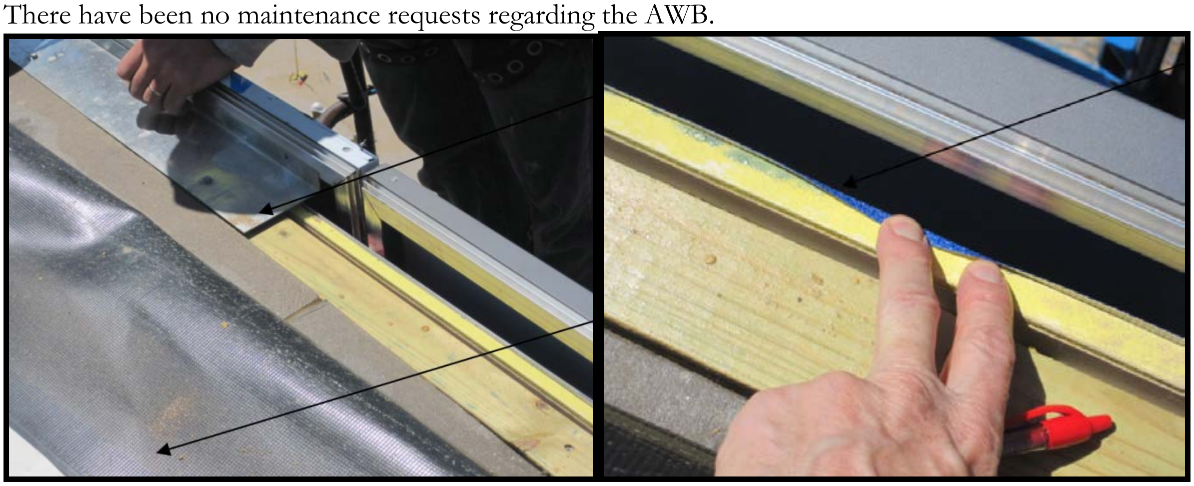
Figure 2A-7 Close up of roof-panel junction shows the irregular substrates that the self-adhered AWB must span to marry to the roof system

Case Study 2-B - Ionia [15-061]:

Highlight: A self-adhered AWB product had difficulties navigating the complex geometries of this building and had to be augmented with spray foam at beam penetrations and window offsets to accomplish a continuous air barrier. Also, there was difficulty properly flashing the AWB at a window to direct water from behind rain-screen panels out of the building. This area failed repeated water tests.

Construction Challenges:
The AWB system consisted of a self-adhered sheet air barrier that did not require the use of a primer. The physical nature of the product was shown to be thicker and less malleable than other sheet products, which created difficult installation around complex geometry. In the case of this particular building, the structural steel penetrated the exterior sheathing and supported cantilevered canopies. The AWB product simply was unable to navigate the geometry, leaving larger portions of the sheathing exposed with no AWB [See Figure 2B-1].

Figure 2B-1: Example of Complex geometry where self adhered AWB was unable to be applied

Similarly, the ribbon windows for the building were inset from the face of the AWB and tightly snug to various overhangs at the head conditions. Due to this, distinct head, sill, and jamb conditions did not compliment the AWB product that was selected for the project and continuity of the systems was not easily accomplished [See Figure 2B-2].

	
Figure 2B-2: Distinct geometry limited the ability of the AWB to mate with the glazing systems	Figure 2B-3: Spray foam was used in place of the sheet applied AWB in areas where the product could not be applied.

Solutions:
In instances where the AWB was not able to navigate complex geometry, exterior spray foam was improvised to bridge the gaps in the AWB and fill sections where the AWB simply could not be installed. The option offered here utilized readily available materials that were already on site to improve the air, water, and thermal performance of these difficult locations [See figure 2B-3].

At window locations, each distinct window condition required a custom shop fabricated piece of sheet metal to provide a backing surface to bridge the gap between the AWB and the glazing system [See figure 2B-4]. This option was shown to be time consuming, labor intensive, and often ineffective in its attempts to complete the air and water barrier. It is worth noting that the construction schedule had be reconfigured to account for this, which delayed cladding install.

Figure 2B-4: To bridge the gap between systems, custom pieces of sheet metal had to be installed to provide a surface for the AWB to span the gap.

Building Performance:
The glazing systems were tested for water penetration using the AAMA 501.2 standard and it was discovered that the AWB connection to the glazing systems demonstrated water leakage after repeated testing and rework. The primary issue appeared to result from the complications presented the glazing systems lying out-of-plane of the AWB, and the improvised field options to make these systems meet. Because of this, the open channel aluminum mullions of the window systems served to collect water and direct it into the building rather than appropriately flash the water outward.
It is worth noting that due to increased project delays due to water intrusion, ownership opted to forego whole-building air leakage testing and instead allocated the air barrier testing fee to further water penetration testing.

<u>Method 3: Fluid-Applied</u>

Case Study 3-A: Ping Tom Park [12-157]
A fluid applied AWB is used for the steel stud portions of this project. The application thickness didn't meet spec and the product had to be reapplied. The building performed satisfactorily on a blower door test.

Figure 3A-1 View of the completed community recreation center.
Construction Challenges:

Building Performance:
The entire building was pressure tested using a blower door in accordance with ASTM E-779-10




Fluid-applied Air and Water Barriers-Summary:
Challenge: Human error in application can result in pin holes
Challenge: Does not span dissimilar materials well
Advantage: Can conform to complex geometries.

Method 4: Joint-treated boards

Case Study 4-A: Spectrum Muskegon [16-115]

Highlights: A liquid applied, joint-treated polyisocyanurate insulation board system was the AWB and was applied directly to the steel studs. It was backed up with spray foam applied between the studs. While the project experienced minimal issues with the AWB itself, a field-improvised solution to close the cavity behind masonry at windows had to be used. The building performed well in whole-building blower door test.

Building Description:
A 31,000 sq. ft. (2,878 M^2) single-story medical facility utilized a steel structural frame and steel stud wall-framing. The thermal, moisture, water, and air barrier are all offered by proprietary panel system using glass-fiber-reinforced polyisocyanurate foam panels faced with an embossed thermoset-coated aluminum. The joints were treated with a tape and, in some areas, reinforced with a fluid-applied joint seal. The joint-treated boards were used behind both cladding systems: metal panels or brick veneer. Spray foam was installed between the steel studs on the interior side of the boards and acted as a second line of defense. There was a flat roof of EPDM which made for a simple tie-in between wall and roof systems.

Figure 4A-1 AWB before metal panels are applied. Note the scarring of the surface from masons pressure washing of the brick.

The punched window openings were located in the brick-clad portions of the wall. In the design, the plane of the glass is offset 2-½" (51 mm) toward the exterior from the face of the AWB board. The storefront mullion design (a "C" shape) required any seals to occur either at the exterior or interior end of the mullion. The moist, untempered air in the cavity behind the brick is then left directly exposed to the interior of the mullion. The result is that there is no second line of defense for the AWB nor any thermal barrier at the window mullion. [Figure 4A-2, left]. The joint-treated board system did not offer a method of spanning or otherwise sealing the offset.

This condition was identified in the field by the enclosure commissioning agent who proposed a solution to close the cavity, create a surface to receive the primary silicone seal, and marry the window mullion to the AWB [Figure 4A-2, right].

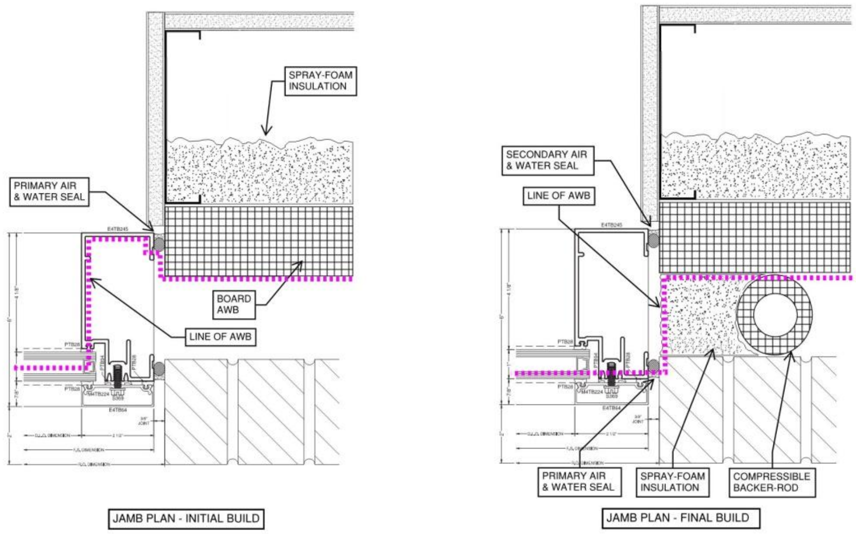

Figure 4A-2 Plan sections of window jamb

Spray foam is applied in the cavity between the AWB Board and the brick at the window jamb. A tubular flexible rubber pipe insulation is used as a backer against which to place the foam. The primary seal (silicone caulk) is placed between the spray foam and the window mullion.

Figure 4A-3 View of window sill and jamb after placement of foam cavity-closer

Building Performance

The building was tested for air-tightness with a whole-building blower door test in accordance with ASTM E779-10. The test demonstrated a whole-building leakage rate of 0.124 CFM/SF of enclosure at 75 Pascals. The blower door was tested in both the positive and negative directions using a multi-point test, which yielded similar results regardless of pressurization direction. Infrared scanning was performed during blower door testing which demonstrated little leakage around the windows. Another transition condition, the exterior wall sill plate and the concrete foundation exhibited the most leakage.

Case Study 4-B: Spectrum Ada [16-211] Two Story Medical Facility

Highlights: The Contractor experienced problems with the tape-sealed joints of the polyisocyanurate insulation board AWB and switched to fluid-sealed joints. The windows were residential grade and came with a nailing flange. Thus, they avoided the Issue presented in the previous case study. There were some challenges in maintaining the integrity of the air barrier, particularly at the wall-to-attic interface. Because the ventilated attic relied on the gypsum board ceiling for the air barrier at the horizontal plane, contractors struggled to navigate the steel structure effectively so that the horizontal air barrier connected with the vertical air barrier.

Building Description:
25,000 Sq. ft. two-story medical facility with steel structural frame and steel stud wall-framing. Local requirements for a traditional look resulted in a residential-style sloped roof supported by metal trusses. The AWB is a board system screwed directly to the steel studs forming the thermal, moisture, water, and air barrier both behind the brick and the metal panels. Initially, the joints between boards were taped but after some problems with application of the tape the builder switched to a liquid-applied joint seal.

Figure 4B-X: Connection of vertical polyisocyanurate insulation to horizontal gypsum board in the attic. Note the various structural components interrupting the connection of the two materials.

Construction Challenges (The Issue):

The flashing tape did not hold to the polyisocyanurate insulation at the panel joints. A decision was made mid-construction to switch to a liquid applied product at the joint panels.

The polyisocyanurate insulation joint sealing system can be easily damaged during construction

The wall-to-attic connection of the air barrier was simply not constructible. This resulted in field improvised options along the entire perimeter to span the gap between the polyisocyanurate insulation joint sealing system and the gypsum board to the attic.

Options:

Continuous repair to damaged system

Where feasible, a field applied spray foam was installed to span from the polyisocyanurate insulation joint sealing system to the horizontal gypsum board to cover the gaps between the insulation, cold formed framing, gypsum board, and the rolled structural steel.

Building Performance:

The air tightness of the building was below expectations. The building was tested for air-tightness with a whole-building blower door test in accordance with ASTM E779-10. The test demonstrated a whole-building leakage rate of 0.633 CFM/SF of enclosure at 75 Pascals. The blower door was tested in both the positive and negative directions using a multi-point test, which yielded similar results regardless of pressurization direction.

Infrared scanning was performed during blower door testing which demonstrated the majority of the air leakage from the top plate of exterior walls into the framing cavity. This condition appears to be directly linked to challenges of connecting the air barrier at the wall to attic interface.

While the overall air tightness of the building was below expectations, it did not appear to be a direct result of the polyisocyanurate insulation product and the joint sealing method, but rather the way in which the product was detailed to connect to the air barrier in the attic. Wall-to-roof connections are notoriously tricky, but in this case, the wall-to-attic air barrier was shown to be nearly impossible to construct in an air-tight manner as designed. Such difficult areas need to be identified in the design phase.

Field Test Results

ORNL: Homeland Security Training Center at the College of DuPage Case Study

The Homeland Security Training Center (HTC) at the College of DuPage was constructed with a board joint sealing method using polyisocyanurate boards and liquid flashing joint sealant as the AWB for the opaque walls (Figure 4). The completed building has 40,000 ft2 of floor area. The air leakage rate was tested via the blower door technique as outlined in ASTM E779-10.

Figure 4. Liquid flashing sprayed over board joints and a window rough opening.

Results of blower door testing indicate that the HTC has an average air leakage of 0.15 cfm/ft2 at 1.57 psf, which is 63% lower than the 0.4 cfm at 1.57 psf specified in the 2015 IECC. The data indicate that the airtightness level of the HTC is 45% lower than the average value of 0.28 cfm/ft2 at 1.57 psf from 79 commercial buildings with air barriers, and 83% less than the average value of 0.86 cfm/ft2 at 1.57 psf from 290 buildings without air barriers.

Table 2. Comparison of air leakage rates from the Homeland Security Training Center at the College of DuPage and from a database compiled by the National Institute of Standards and Technology (NIST).

NIST database	**Sample size**	**Air leakage (cfm/ft2) at 1.57 psfa**	**Air Leakage of HTC = 0.15 cfm/ft2 at 1.57 psf**
Buildings w/ air barrier	79	0.28	45% lower
Buildings w/o air barrier[a]	290	0.86	83% lower

All buildings	387	0.72	79% lower

a. These are buildings that were not specified as having an air barrier, but some could have had one in place.

A simulation model was created to estimate the energy savings due to the airtightness achieved at the HTC. The DOE's whole building energy simulation software EnergyPlusTM ver 8.3 (DOE 2016a) was used in this task. The building geometry was obtained from the architectural drawings that included the dimensions, floor plans, and construction material layouts. The HVAC system in the HTC consists of water cooled chilled water for cooling and boilers for heating. Internal loads, lighting, HVAC set point temperatures and efficiency, and their respective schedules were primarily based on information from the architectural drawings; assumptions that are commonly made for typical office buildings based on DOE prototype buildings (DOE 2016b) were used as inputs for missing information.

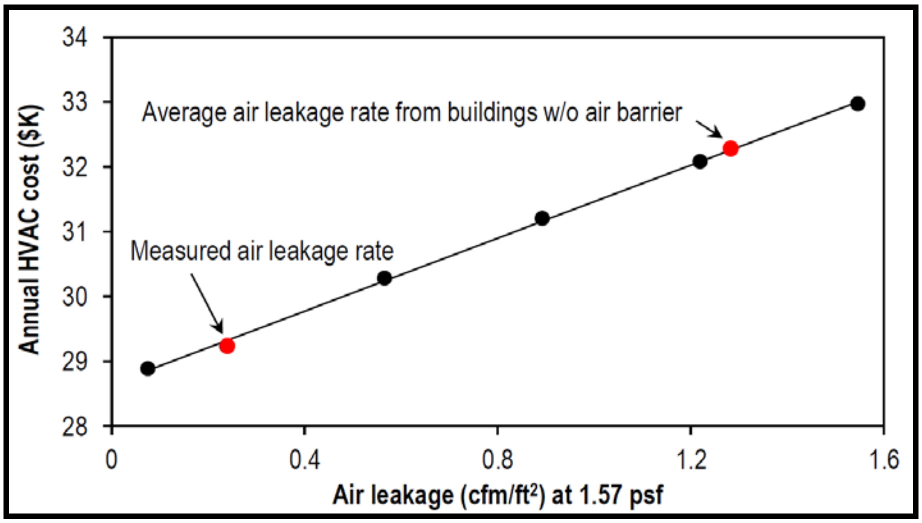

Figure 11. Simulation results of the annual HVAC energy cost for the Homeland Security Training Center as a function of air leakage rate through the above grade walls and roof.

Conclusions

As summarized in Table 3 below, each of the commonly used air and water barriers have distinct advantages and challenges. It may be beneficial for the designer to consider whether the building features, such as a lot of curve surfaces or plane changes, make it difficult to balance form with function unless the right choice of air and water barrier is selected up front.

METHOD	ADVANTAGES	CHALLENGES
1) Sheet Applied	• Quick installation	• Susceptible to wind damage when unprotected: Intermittent fastening allows wind billowing • Must marry to another material to turn into openings

2) Self-adhered	• Total bond to substrate • Can span across substrate gaps	• Difficulty negotiating complex geometries
3) Fluid applied	• Total bond to substrate • Easier to install over uneven surfaces • Can conform to complex geometries	• Labor intensive relative to other systems for large flat areas •
4) Joint-treated boards	• Quick Installation • AWB & substrate are multi-purpose; often serving as sheathing, thermal barrier, and vapor barrier	• Difficulty negotiating complex geometries and changes of plane.

ACKNOWLEDGMENTS

The authors wish to thank the constructive discussions and support from Gary Parsons, Senior Research Fellow, DowDuPont Safety and Construction, and Jay Johnson, Principal Studio Director from Legat Architects, who provided access and support for the whole building enclosure test at College of DuPage.

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