High-Performance Buildings:
Integrating the Wall and Roof Air Barriers

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**Abstract**

Controlling unintentional air leakage (infiltration and exfiltration) across building enclosures is a key factor for achieving high-performing buildings. Continuity between air barrier materials and assemblies is essential to controlling air leakage. This presentation will provide practical answers to the question: “What does it take to construct a high-performance building that maintains air barrier continuity across the full enclosure?” Quality assurance and quality control measures, including whole-building air leakage testing and building enclosure commissioning, will be discussed, with examples showing the challenges, equipment, and coordination involved in achieving these measures. Case studies will be presented to highlight project-specific examples.

**Speaker**

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Bill Waterston, RRC, AIA, is a registered architect and a Registered Roof Consultant. He has broad-based architectural experience in both waterproofing and roofing systems, which provides him with a unique perspective for solving building enclosure challenges for new and existing buildings. Waterston provides building enclosure assessments and building commissioning services and performs building enclosure testing of components and completed buildings. He has authored several articles on roofing material choices and roofing practices. Waterston has presented at ABX, RCI, and Construction Specification Institute meetings and symposia.

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INTRODUCTION

Controlling unintentional air leakage (infiltration and exfiltration) across building enclosures is a key factor in achieving high levels of performance in buildings. Continuity between various air barrier materials and assemblies is essential to controlling air leakage. Adhesive compatibility, chemical compatibility, and construction sequence are just some of the factors that need to be considered. Roof-to-wall transitions can present some specific challenges in this regard.

This paper provides a general explanation of air barriers and discuss their performance. We will review various materials, systems, and whole-building requirements and provide definitions and examples of each. The reader will be exposed to examples of air barriers at roof-to-wall transitions that are not continuous. The paper and presentation will also identify important considerations with respect to integrating air barriers between wall and roof assemblies. Additionally, common details and methods will be presented.

AIR BARRIERS DEFINED

Air barriers control air leakage into and out of the building envelope. A further definition of a continuous air barrier would be: the combination of interconnected materials, assemblies, and flexible sealed joints and components of the building envelope that provide airtightness to a specified permeability.

AIR BARRIER CONTINUITY

Continuity is a code requirement for the air barrier. Care should be taken in detailing and construction, whether the building is simple or complex, a few stories or many. To quote from an article in Construction Specifier:

Discontinuity is one of the most common mistakes designers and contractor make. On the drawings, the air barrier should be “traceable” with a finger around the entire envelope, with no discontinuities. One typical problem area involves the membrane installation. The membrane should be installed flat against the substrate without wrinkles or tunnels to control air transfer.

Other locations of concern are the transitions between the wall and roof air barriers, which should overlap each other. However, interference from the roof deck or parapet can make this difficult to achieve. In some cases, the air barrier may need to extend beneath the parapet framing to achieve continuity, or the edge of deck may need to move inward to allow continuity of the barrier behind the wall veneer. If the area is improperly detailed or constructed, severe damage can result, including condensation and damage/corrosion to concealed construction.

An interesting benefit to including an air barrier within a roof assembly was noted in a paper from 2009. The National Research Council of Canada (NRCC) performed research on a variety of fully bonded single-ply roofing assemblies and determined the impact of air intrusion on wind uplift resistance and the benefit of including an air barrier in the roofing assembly. The paper states that air intrusion can significantly alter the wind uplift behavior of the roofing assembly. The research concludes that, “Wind uplift performance is improved on assemblies with (air) barrier[s]. An improvement of about 50% can be measured in the wind uplift rating for the tested assemblies.”

AIR BARRIER PRODUCTS

Air barrier products may take several forms:

- Mechanically attached membranes, also known as house-wraps—usually a polyethylene-fiber or spun-bonded polyolefin, such as Tyvek—generally accepted as moisture and air barriers (ASTM E2178)
- Self-adhered membranes, which are typically also water-resistant and vapor barriers
- Fluid-applied membranes, such as heavy-bodied paints or coatings, including polymeric-based and asphaltic-based materials
- Closed-cell, medium-density, spray-applied polyurethane foam, which typically provides insulation as well
- Some open-cell, spray-applied polyurethane foams that are of high density
- Board stock, which includes 12-mm plywood or oriented strand board (OSB), 25-mm extruded polystyrene, etc., and those with taped seams

AIR BARRIER SYSTEMS

A complete air barrier system is composed of the following hierarchy: Air barrier materials and air barrier accessories are combined into air barrier components; those are combined into air barrier assemblies; and together, they become air barrier systems.

Air barrier materials – Building materials that are designed and constructed to provide the principal plane of airtightness through an environmental separator, which has an air permeance rate no greater than 0.02 L/(s·m²) at a pressure difference of 75 Pa when tested in accordance with ASTM E2178. Air barrier materials meet the requirements of the CAN/ULC S741 Air Barrier Material Specification. The air barrier materials are typically the “big” pieces of material used in an air barrier assembly.

Air barrier accessories – Products designated to maintain airtightness between air barrier materials, assemblies, and components, to fasten them to the structure of the building, or both (e.g., sealants, tapes, backer rods, transition membranes, nails/washers, ties, clips, staples, strapping, primers), and which have an air permeance rate no greater than 0.02 L/(s·m²) at a pressure difference of 75 Pa when tested in accordance with ASTM E2178. Air barrier components are used to connect and seal air barrier materials and/or air barrier assemblies together.
Air barrier components – Pre-manufactured elements, such as windows, doors, and service elements that are installed in the environmental separator and sealed by air barrier accessories and that have an air leakage rate no greater than 0.20 L/(s•m²) at a pressure difference of 75 Pa when tested in accordance with ASTM E2357.

Air barrier assemblies – Combinations of air barrier materials and air barrier accessories that are designated and designed within the environmental separator to act as continuous barriers to the movement of air through the environmental separator and that have an air leakage rate no greater than 0.20 L/(s•m²) at a pressure difference of 75 Pa when tested in accordance with ASTM E2357.

Air barrier systems – Combinations of air barrier assemblies and air barrier components, connected by air barrier accessories, that are designed to provide a continuous barrier to the movement of air through an environmental separator, which has an air leakage rate no greater than 2.00 L/(s•m²) at a pressure difference of 75 Pa when tested in accordance with ASTM E779 or CAN/CGSB 149.10 or CAN/CGSB 149.15.

MARKETPLACE CHALLENGES

As designers, consultants, manufacturers, and installers, we have many challenges in today’s construction environment, including design complexity, increasing material and system options, varying project delivery, contracting and procurement methods, and both national and local code performance requirements.

REQUIREMENTS

The U.S. Army Corps of Engineers (USACE) set a requirement (ECB 29-2009) that all new buildings and buildings undergoing major renovation shall pass an air leakage test where the results are less than or equal to 0.25 CFM per square foot of exterior envelope at 0.3 inch of water gage (75 Pa) pressure difference.

Since the introduction of air barrier requirements and maximum allowable air leakage rate in 2009, more than 250 newly constructed and renovated buildings have been tested to meet or significantly exceed these requirements. Some of them were proven to have an air leakage rate between 0.005 and 0.25 CFM per square foot at a pressure difference of 75 Pa during the first test. This experience has proven that when buildings are designed and constructed with attention to details, US Army requirement to air tightness can be met with minimal cost increase (primarily for development of architectural details and testing).

Since this was published in 2011, it is expected that the USACE continues to experience similar results.

Within ASHRAE Standard 189.1 - 2014, Standard for the Design of High Performance Green Buildings, there is a requirement that the air barrier be continuous and the completed building air leakage rate of the building envelope must be less than or equal to 0.25 cubic feet per minute per square foot of envelope area (0.25 CFM/75 ft²).

Mandatory requirements of ASHRAE 90.1 - 2016, Section 5.4.3, Air Leakage, include:

- Continuous air barrier design
- Continuous air barrier installation
- Testing, acceptable materials, assemblies
- Penetration and doors
- Loading-dock weather seals
- Vestibules

In Section 5.4.3.1.1, Continuous Air Barrier Design, requirements are:

- Air barrier components of each building envelope assembly clearly identified or noted on construction documents
- Joints, interconnections, and penetrations of continuous air barrier components detailed or noted
- Continuous air barrier shall extend over all surfaces of the building envelope
- Continuous air barrier shall be designed to resist positive and negative pressures from driving forces

In Section 5.4.3.1.2, Continuous Air Barrier Installation, they are:

- Joints around fenestration and door frames
- Junctions between walls and floors, between walls at building corners, and between walls and roofs or ceilings
- Penetrations through the continuous air barrier in building envelope roofs, walls, and floors
- Joints, seams, connections between planes, and other changes in continuous air barrier materials

GENERAL DESIGN OF THE BUILDING ENCLOSURE

Let’s step back and look at the various functions of the building enclosure. The building enclosure must:

- Control rain penetration
- Control airflow
- Control vapor flow
- Control heat flow
- Control light, solar, and other radiation
- Control noise
- Control fire
- Be durable
- Provide strength and rigidity
- Be aesthetically pleasing
- Be economical
- Require little or no maintenance

For the purposes of this paper, we are only discussing controlling airflow. Issues with air leakage include the following:

- Life safety: fire and smoke containment, frozen sprinkler pipes
- Durability: condensation, corrosion, decay, and biological growth
- Roof membrane uplift forces
- Occupant comfort and health: indoor air quality, temperature control, noise, moisture, odor transmission
- Elevator and manual or automatic door operation
- Insect and pest control
- Operating costs: energy consumption, maintenance

AIR LEAKAGE

For air leakage to occur, there must be a pathway or opening and a driving force or difference in pressure. The pathway can be an orifice, a channel, or diffuse or microscopic openings that allow airflow directly through a material. Leakage paths in buildings are from exterior to interior, as well as interior to interior, and include shafts, stairs, elevators, and duct work. The direction of flow is always from high pressure to low. Differential pressure can come from wind, stack effect, or be mechanically driven.
WHOLE-BUILDING AIR LEAKAGE TESTING

Whole-building air leakage testing is generally performed following the test method described in ASTM E779, Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. This test method is intended to quantify the airtightness of a building envelope. This test method consists of mechanical pressurization or depressurization of a building and measurements of the resulting airflow rates at given indoor-outdoor static pressure differences. From the relationship between the airflow rates and pressure differences, the air leakage characteristics of a building envelope are determined.

Generally, fans are installed in door openings, and relative pressure differences are measured between indoor and outdoor conditions. The amount of airflow is measured. These tests are performed during mild temperatures and low-wind conditions to minimize the impact of those external factors.

To perform whole-building air leakage testing, the building must be essentially completely constructed. If the building does not meet the performance requirements, repairs to the air barrier are difficult or impossible without deconstructing building envelope components. Testing of components, portions of the building, or individual systems, such as curtainwall assemblies or opaque wall systems before the cladding is installed, is recommended while the building is under construction. This will help determine the air leakage rates of components to confirm the materials and installation are in alignment with the whole-building leakage criteria. By performing testing early, remediation efforts can more easily be performed. Air leakage testing of the whole building can then be performed as a confirmation that the building enclosure systems meet the overall requirements.

In an effort to determine average whole-building air leakage rates for more modern buildings in the United States, ASHRAE developed a research project, designated ASHRAE 1478 - RP. Sixteen mid- and high-rise commercial buildings constructed since 2000 were tested from 2010 to 2012 for airtightness as a research project for ASHRAE. The enclosure of each was tested to determine its overall air leakage compared to other buildings in the group and previous investigations and compared to design standards. The International Energy Conservation Code (IECC) 2012 (0.40 CFM75/ft²), U.S. Army Corps of Engineers (USACE) (0.25 cfm75/ft²), and ASHRAE Standard 189.1, Design of High Performance Green Buildings (0.25 CFM75/ft²), were used as benchmarks. Each of the standards relies on the same testing procedures; only the maximum allowable air leakage values vary.

Three-quarters of the buildings met the IECC requirement of 0.40 cfm75/ft². Of the sixteen, six were designed with an enclosure consultant and quality assurance program. All buildings with such special attention paid to airtightness met the USACE 0.25 CFM75/ft² standard.4

PROJECT EXAMPLE – EXAMPLE 1

The reality in some projects is interesting and instructive. The following section and detail depict a roof-to-wall intersection at a scupper (Figure 1). The details and shop drawing development illustrate the limited information provided by the construction documents and the interpretation of the design in the shop drawings. The constructability of the air barrier and the sequencing of construction are not addressed well in the curtainwall contractor’s drawings.

The detail was further modified in the shop drawing process (Figure 2). Some of

Figure 1 – Section provided in the documents of roof edge and curtainwall intersection.

Figure 2 – Detail provided for the scupper within the drawings.
Figure 3 – Detail by curtainwall contractor.

the work required for a fully integrated air barrier was indicated to be performed “by others.”

This shop drawing detail did not consider the sequencing of the roofing installation and the fastening of the curtainwall supports (Figure 3).

Other cases are caught after construction and then need to be modified, such as this example of exhaust ducts located on the roof plan, without adequate distance between penetrations and intake and exhaust (Figure 4 and Figure 5). This was a roofing issue and an air barrier issue, because at this point, both terminated at the same point. Ultimately, the stacks were reconfigured to create a greater separation between intake and exhaust airflow.

SPECIFYING AIR BARRIERS AND QUALITY ASSURANCE

When specifying air barriers, each of the following must be addressed:

- Performance
- Warranty
- Submittals
- Quality assurance
- Products
- Execution
- Field quality control

All of these are included in the technical sections for the products, but it is also advised to include a Division 01 specification that outlines the coordination necessary between the application of air barriers and the systems and products that they attach to, overlap, or otherwise interact with. Within the Division 01 specification, the performance testing for the completed work, mock-ups required, and those shop drawings that include transitions—i.e., between wall and roof air barrier system—must all be defined.

When specifying air barrier submittals, require product data, test reports, product certificates, shop drawings, and installer qualifications. This documentation is required in order to ensure that the product or products submitted meet the performance requirements. Review of these documents will assist with proper sequencing, confirm proper coordination, ensure compatibility, identify manufacturers’ requirements, and confirm that the installer is qualified for the installation. Many times, installers resist the detailing of the integration of their system with adjacent systems. However, it should be required
that the shop drawings be coordinated and that details indicate the continuity of the air barrier to ensure proper integration and understanding of sequencing.

When specifying the products, the air barriers should be strong enough to resist building pressures and be suitable for the climate (i.e., high-temperature-resistant). This also applies to auxiliary and accessory materials. Indicate the location on the drawings of the air barrier in relation to other materials, and review the constructability of the assembly in which it will be installed. In your product review and comparison between products, assure that materials are available and that there are skilled and trained installers in the location of the project.

Compatibility of products within the assembly and adjacent materials is vitally important. We often see materials intended to bond to silicone sealant or silicone sheet. Nothing bonds well to silicone except silicone. So the order of construction and the selection of sealants and mechanical attachment are all important in order to ensure that materials intended to be bonded together stay attached.

Quality assurance steps to specify include the third-party assessment and testing of the air barrier by trained inspectors. One group that trains installers and inspectors is the Air Barrier Association of America (ABAA). Full-scale mock-ups at an offsite laboratory, as well as on-site mock-ups, can be used to illustrate and review details and conditions found in the overall project. This allows the installing contractor the opportunity to review the assembly, sequencing, coordination, and constructability of the various components. Pre-installation meetings are important to include not only the installing contractors for the air barrier, but include the contractors installing the neighboring or overlying components. Insist on a meeting where the wall air barrier contractor and the roofing contractor, as well as the waterproofing contractor, discuss edge conditions and the overlapping of materials, the potential time delays between the installation of materials, and other coordination issues to ensure a continuous air barrier.

When the product and systems are being installed, specify that the contractor examine the substrate assembly and adjacent materials, the surface preparation for the air barrier, and the treatment of joints between the products. Specify flashing materials and their support. Specify transition materials such as silicone sheets to bridge the gap between window assemblies and roofing or walls.
Include specifications for the repair of damage or deficient air barriers and substrate conditions. Stress continuity and the coordination with other trades.

Field quality control can take the form of inspections by ABAA inspectors, field tests to determine if penetrations or ties are sealed and airtight, partial system testing, and other specific tests such as adhesion tests for the membranes. Remember not to rely on whole-building air leakage testing as quality control, because it requires that the building be essentially complete before any testing can be performed. Rely on testing of materials, systems, and joints between systems to be air and watertight. Test as you build, rather than testing after it’s all built because by then, it may be too late to go back and fix something broken.

**WHOLE-BUILDING AIR LEAKAGE TESTING**

Whole-building air leakage testing can be performed using ASTM E779-10, Determining Airtightness of Buildings’ Air Leakage Rate by Single-Zone Air Pressurization or the U.S. Army Corps of Engineers’ Air Leakage Test Protocol for Building Envelopes, 2012. All of these test methods collect data to determine the building airtightness. It should be noted that whole-building testing is not a simple or inexpensive undertaking. This testing can be disruptive and will require a coordinated effort by a variety of personnel. It should include those familiar with the operation of the heating and cooling of the building, the ventilation and exhaust stacks, and the stair and elevator operations.

**REVIEWING AIR BARRIER DESIGNS OR DRAWING AIR BARRIERS**

When reviewing or designing air barriers, take the time to look at the building overall. Determine where the plane of the air barrier will be within each component or system. Consider floor edges, vestibules, loading docks, mechanical spaces, balconies, terraces, roof edges, soffits,
and all other transitions and terminations. Wall-to-foundation and roof-to-wall intersections are important. How is the barrier intended to bridge across those joints? Examine the transition from walls to windows and walls to curtainwalls, and determine where the air barrier is to join the window or curtainwall. Determine if the connection is durable, or is it relying on a single line of sealant to create the connection? Expansion joints should be reviewed closely. Make sure the air barrier extends across the joint and can move with the other materials.

Look at the building and determine what spaces are conditioned, as well as those that are under positive or negative pressure. Hospitals and laboratories use pressurization to control contaminants, and those areas should be understood and detailed. Here is an example of an overall section with the location of the air barrier highlighted and an overall depiction of the building with the different spaces and their relationships (Figure 6 and Figure 7).

**EXAMPLES OF AIR BARRIERS AT THE ROOF AND WALL**

**Example 2**

As an example, let’s look at the roof-to-wall intersection. Where is the air barrier going to be installed? It can be at the roof slab and transition to the wall. It can also extend up the parapet, over the parapet, under the blocking, and tie again into the wall air barrier.
Here are two roof edge conditions with two different air barrier locations. Figure 8 brings the air barrier up the parapet, under the coping, and ties the air barrier in under the blocking. Consider the sequencing required and the coordination needed among trades to build a continuous air barrier. Figure 9 is a much simpler and straightforward approach where the wall and roof air barrier meet at the slab edge. This will require the air barrier from the wall to extend past the roof deck so the roof air barrier can bond to the wall barrier.

**Example 3**

Here is an example where a sloped roof wall, parapet, and roof edge condition created a location where air leaked into the parapet (Figure 10). The warm, moist air entered the cooler parapet and caused condensation that lead to water in the roofing system and corrosion of the metal components.

The sequence of construction did not allow the installation of the air barrier as a continuous membrane (Figure 11). The metal stud wall supporting the parapet was installed on the metal deck with a membrane between the stud track and the deck. When the substrate board for the air barrier for the low-sloped roof or the steep-sloped roof was installed, the membrane under the stud track did not transition and did not join the wall or roof air barriers. There was now a direct path from the interior up into the parapet and into the roofing systems.

**Example 4**

Figure 12 shows a detail of an expansion joint that fails to coordinate the air barrier and creates open paths for air infiltration.

This is a condition where a third-floor wall meets a third-floor roof, and an expansion joint separates the two. The opening is watertight, and it has a cover that can move as the joint opens and closes. The expansion joint seal is positioned at the floor level and seals on one side against the floor slab. The air barrier from the rising wall can extend down to the slab, under the exterior wall framing, and continue across the seal. Where the seal meets the roof, a light-gauge metal stud curb with insulation rises above the roof deck. The air barrier from the roof deck is applied to the sheathing on the curb and extends up to the top of the curb under the expansion joint cover. The detail misses the connection of the air barrier from the top of the curb to the roof side of the expansion joint seal. There is no sheathing on this side, and air can easily move from the interior up through the insulation and stud curb, under the cover, up the exterior wall assembly, and out the flashing for the wall.

[Figure 11 – Section detail at steep-sloped roof and low-sloped roof intersection. Red dashed line illustrates the air barrier location. The blue line is the path for warm, moist air that escaped into the roofing and parapet because of openings in the air barrier at the roof deck.]
CONCLUSIONS
During the design and project reviews, identify challenging transitions and terminations with respect to achieving air barrier system continuity. Document the conditions and communicate clearly the intent.
Specify for performance, continuity, and trade coordination, and consider constructability and compatibility of the air barrier, its components, and the transitions between systems and materials.
Observe installations and validate performance with mock-ups and quality control testing.

REFERENCES