FINAL VERSION FOR PUBLICATION – Quality Control of Air Barriers During Construction

Brandon S. Buchberg[1], Jason S. Der Ananian[2]

ABSTRACT

With increased emphasis and interest on energy efficiency of buildings and commissioning of building envelopes and mechanical systems, reliance on a tight air barrier assembly plays a key role to minimize loss of conditioned air, which can reduce building-envelope performance and decrease mechanical system efficiency. The importance of the air barrier is often recognized, but the air barrier design and installation is not always given the attention it deserves by the design and construction team.

Inadequate drawing details at transitions and intersections and improper detail construction can result in air barrier discontinuities and increased air leakage through the building enclosure. The consequences of uncontrolled air leakage can increase energy costs, promote condensation and moisture buildup issues, cause thermal discomfort, and reduce mechanical system efficiencies. In addition, competitive budgets and accelerated construction schedules can often result in poor workmanship exacerbating the extent of air barrier breaches. These consequences are often observed after building occupancy, which amplifies the total repair costs and disruption to the building occupants.

The design community lacks any current industry standards for air barrier construction, particularly to address complex geometries, intersections, or transitions in building enclosures. In some cases, the construction manager and subcontractors do not have a fundamental understanding of the air barrier. As a result, breaches in the air barrier due to difficult transitions or geometries are not identified during construction and repaired. However, field testing of the completed air barrier assembly can identify these breaches. Often, consultants and third-party testing agencies rely on quantitative test methods to determine a whole-building or fenestration air leakage rate. These tests assess the performance of the air barrier assembly as a whole, but may not identify localized breaches. Field testing using qualitative methods can be more effective in evaluating the installation of the air barrier.

This paper/presentation will briefly discuss quantitative testing methods and criteria; emphasize quality control methods that can be employed during design and construction; and provide examples of challenging building geometries, intersections, and transitions that are problematic.

By employing effective quality control methods during design and construction, the risk of damage associated with a leaky air barrier can be minimized.

[1] Brandon S. Buchberg, Senior Staff II – Building Technology, Simpson Gumpertz & Heger Inc., Waltham, MA

[2] Jason S. Der Ananian, Senior Staff II – Building Technology, Simpson Gumpertz & Heger Inc., Waltham, MA

1. INTRODUCTION

Industry agencies and code officials in the United States are realizing the need for tighter building air barriers. As a result, more state building codes and industry standards are requiring improved performance and continuity of air barriers in the building enclosure. The provisions for tighter air barriers in the US are relatively new compared to other countries such as Canada where the design and construction industry is further ahead.

Continuous air barriers reduce energy consumption, allow more precise control of building interior conditions, and can prevent premature failure of building enclosure cladding systems in certain building types. Proper design detailing and air barrier installation are critical to achieving an airtight building enclosure. The experience of designers and installers with respect to air barrier design and construction varies widely within the design and construction industry. Adequate construction oversight and quality-control measures with respect to the air barrier design and installation can help narrow the disparity in experience. Designers less familiar with air barriers may not fully appreciate the difficulty of providing continuity at complex transitions, the importance of clearly detailing these transitions to adequately illustrate the design intent to the installer, and the need for material compatibility for long-term performance.

If these issues are not addressed during the design, they often lead to inadequate installation or field performance. For the above reasons, quality-control measures should be implemented during design and construction to help identify discontinuities that warrant correction before building occupancy.

This paper will summarize problems associated with discontinuous air barriers, examines the current air barrier standards and building codes, discusses common air barrier materials, and presents simple quality-control measures for air barrier design and installation.

2. AIR BARRIER PROBLEMS

In general, the air barrier system consists of a combination of materials joined in an airtight manner to restrict air infiltration or exfiltration through the building enclosure. An air barrier must be structural and able to resist pressure differentials without tearing or displacement. To be effective, these systems must be continuous at walls, roofs, penetrations, and transitions between systems. Laps, transitions, and terminations should be tight to prevent the uncontrolled passage of air. The term “uncontrolled air” is used because the air barrier materials, assemblies, and system allow a small amount of air to pass through each component as defined by the industry standards or building codes. Most problems arise when breaches, voids, and other defects allow large quantities of air to bypass the air barrier. Air barriers that contain voids can have several consequences depending on climate and building pressurization.

Primarily, heat/cooling loss through air barrier breaches results in poor mechanical system performance requiring additional energy to condition a building. As a result, building owners incur additional operating costs, or in some cases require systems to be replaced where the breaches are large enough.

Uncontrolled air leakage through the building enclosure can also allow environmental allergens/pollutants and other airborne particulates to contaminate interior air. In heating climates for all building types, uncontrolled air leakage can exacerbate icicle formation or ice dams at roof eaves (Photo 1) and increase the risk of condensation in wall assemblies and associated deterioration of cladding assemblies, but this risk is particularly present in specialty high-humidity buildings such as natatoriums or museums.

Photo 1 – Severe icicle and ice dam formation at metal roof eave.

In cooling climates, exterior warm/moist air infiltration can cause condensation on interior surfaces and biological/mold growth within the building enclosure.

3. AIR BARRIER STANDARDS

Various standards or organizations provide guidelines for qualitative and quantitative performance, as well as inspection and construction of the air barrier. Several building codes incorporate air barrier guidelines or identify standards for installation.

Organizations such as ASHRAE (ASHRAE Standard 90.1) and the Air Barrier Association of America (ABAA) publish standards that emphasize making tighter transitions between air barrier materials and between air barrier assemblies. These standards also require standard performance levels for materials, assemblies, and total building envelopes. The U.S. Army Corps of Engineers further developed performance requirements for whole building air infiltration testing based on actual building test data.

Concurrently, states are adopting air barrier provisions either explicitly or via the International Energy Conservation Code. These states include Florida, Georgia, Massachusetts, Michigan, Minnesota, New York, Oregon, Rhode Island, Washington, and Wisconsin. The provisions comment on air barrier performance and construction.

4. AIR BARRIER MATERIALS

The air barrier material specified for a building depends primarily on whether the wall consists of barrier or cavity wall construction. Air barrier materials in barrier walls are typically limited to concrete or concrete masonry unit (CMU) walls themselves, sealant, coatings, or spay-applied expanding foam insulation. Cavity wall construction, such as masonry veneer, provides a water-resistive barrier (WRB) behind the exterior surfacing to collect and drain water that penetrates the veneer back to the exterior. For ease of construction in cavity wall systems, the WRB commonly functions as the air barrier and/or vapor retarder depending on its vapor resistance.

4.1 Common Air Barrier Materials

Common air barrier materials consist of sheet products, fluid-applied products, spray-applied expanding foam insulation, and the sealant accessories compatible with each product.

Sheet Products. Sheet-applied air barrier products are either self-adhering or loose-laid, mechanically fastened to the substrate. Self-adhering sheet membrane (SASM) bonds intimately to substrates and to adjacent sheets at lap joints and flashings. Other products emerging in the market include SASM materials constructed from multilayer spun bonded polypropylene sheet membrane with an adhesive backing. SASM products have a consistent, uniform thickness and are less sensitive to ambient moisture during application than fluid-applied or spray-foam insulation systems, although these products cannot be installed onto wet substrates. Fishmouths (i.e., debonded areas of sheet air barrier membrane in the field of the sheet or at sheet edges) are problematic because the unsealed sheet edges can result in discontinuities in the air barrier; a similar concern exists with fastener penetrations through the membrane. Sheet membranes such as SASM, preformed silicone, or uncured ethylene propylene diene monomer (EPDM) can be used to transition from fenestration perimeters to the main air barrier membrane as long as the materials are compatible.

Loose-laid air barrier products typically consist of spun-polyethylene or polypropylene sheet materials. These sheets are mechanically fastened to the substrate, and all seams and transitions are sealed with tape. Loose-laid air barriers are more susceptible to damage; damage due to high wind pressures is a particular concern during installation.

Fluid-Applied Membrane. Fluid-applied membranes are typically spray- or trowel-applied in the field and cure in place. These membranes can perform well if they are properly installed, but are highly dependent on field workmanship to provide a consistent, reliable, and durable installation. The quality of a fluid-applied system installation is more sensitive to a variety of field conditions than sheet-applied products, including weather, equipment, skill of the applicator, substrate condition (including smoothness), and mixing. Fluid-applied membranes require temporary protection from rain until the membrane completely cures. This temporary protection is usually required for one or two days. Without protection, there is a risk that the membrane may be partially or completely washed off the wall during a rainstorm. Fluid-applied membranes also are affected by cold temperatures that may retard or prevent curing; therefore, they should be protected and contained within heated enclosures if construction extends into the wintertime.

Spray-Applied Expanding Foam Insulation. Spray-applied expanding polyurethane foam (SPuF) insulation is gaining popularity as a means to achieve the four barriers, i.e., air/insulation/water-resistive and vapor barrier in cavity wall construction with a single product (Photo 2).

Photo 2 – SPuF insulation applied to inboard side of precast concrete wall panel (left arrow). Right arrow illustrates precast concrete panel.

Similar to fluid-applied products, SPuF insulation is workmanship sensitive and requires careful surface preparation and detailing to ensure that the insulation maintains adequate long-term adhesion. Unless it is properly restrained at edges and terminations, some SPuF insulation can shrink and debond from substrates at elevated atmospheric temperature and humidity, causing breaches in the air barrier and potentially damaging underlying air barrier/WRB materials. In addition, the voids formed in the SPuF insulation cause a discontinuity in the thermal barrier. For these reasons, design professionals should not rely on SPuF insulation in cavity wall construction as the four barriers because of the lack of built-in redundancy should the SPuF insulation fail in service.

5. CONSTRUCTION GEOMETRIES

Geometries or transitions of enclosure components present distinct challenges to installers. Some designers may not identify these difficult challenges and may not fully detail complex geometry transitions (i.e., building corners) in the contract documents. Setbacks in the elevation, the presences of different claddings, offsets in the structure, or other conditions that cause changes in plane require the installer's attention to detail. In some cases, these conditions may result in tight working conditions where materials cannot be adequately transitioned or lapped, and as a result, the air barrier may be discontinuous. All penetrations through the air barrier, such as fenestrations (Photo 3 illustrates the lack of air barrier continuity at a window-to-wall transition), pipes, conduit, or structural steel, should also be sealed.

Photo 3 – Air barrier discontinuity at window-to-wall air barrier transition (arrow illustrates unsealed gap to building interior).

In these cases, the Designer should not assume the installer will be able to identify discontinuities and correct them to provide a continuous barrier, nor should the installer neglect the importance of these transitions.

Transitions between air barrier assemblies require proper detailing and trade coordination and often utilize custom-shaped sheet metal closure pieces to provide a continuous substrate between the assemblies. The wall-to-roof transition can be a difficult air barrier transition detail where the wall air barrier must connect to the roof air barrier (Photo 4 illustrates a discontinuous air barrier transition at a roof-to-wall intersection).

Photo 4 – Discontinuity in air barrier system at roof-to-wall intersection. Note the exposed metal roof deck and lack of integration between roof air barrier membrane and fluid-applied wall air barrier (arrow).

Where walls intersect the underside of the metal roof deck at overhangs or soffits, light gage metal plates can be sealed and fastened to the topside and underside of the deck and the wall and roof air barriers can connect directly to these plates. The top and bottom metal roof deck flutes need to be sealed to prevent air flow between the plates.

Other unique air barrier transitions occur where interior spaces are conditioned differently. Each space should include its own air barrier that integrates in a continuous fashion with the air barrier in the building enclosure.

6. AIR BARRIERS – QUALITY CONTROL AND QUALITY ASSURANCE

The quality control and assurance for air barrier construction is multifaceted and needs to begin early in the project design phase and be built into the construction schedule. Proper execution of the air barrier requires the involvement of all members of the design and construction team and should include the following steps.

6.1 Peer Review

Engaging a peer review by an air barrier specialist to review construction drawings and specifications during the design phase can help reduce the risk of errors or omissions with respect to the air barrier design. The review process should include a critique of the building enclosure details, particularly air barrier systems, to evaluate the technical quality and identify areas where detailing is insufficient. One simple technique to verify air barrier continuity is to review building cross-sections and trace the air barrier on the design details with a colored pen; the reviewer should be able to trace the air barrier throughout the entire building enclosure without lifting his/her pen. Any location where the reviewer has to lift his/her pen while tracing the air barrier represents a breach in the air barrier and should be brought to the attention of the designer. Two-dimensional and isometric drawings along with sequencing details showing step-by-step instruction are the clearest way to depict complex air barrier transitions.

6.2 Project Specifications

The project specifications should provide the physical performance requirements for air barrier materials and assemblies, establish the maximum air leakage rates for the air barrier, provide minimum qualifications for the air barrier installer, outline the submittal requirements and quality-assurance provisions during construction, and describe the proper execution of the air barrier. The project specifications should require the installer to submit shop drawings indicating details of construction for the air barrier for each type of exterior wall and roof assembly required for the project.

The designer is also responsible for specifying a maximum allowable air leakage rate for the building enclosure and the test method to show compliance. Requiring supplemental qualitative testing of air barrier systems should be included in the specifications. Various qualitative tests are discussed in further detail below.

6.3 Shop Drawings

Submission of air barrier shop drawings by the installer is an essential step to ensure a quality air barrier installation. Often, designers may require that the installer submit air barrier shop drawings, but do not enforce this requirement or adequately review the drawings themselves for completeness. Shop drawings should be viewed as a conversation tool within the project design and construction team to confirm that the installer understands the design intent. They also provide an opportunity for the installer to notify the designer of conditions that are not constructible, to propose to the designer alternate detailing to address field conditions, and to notify the designer of any missing air barrier details. The shop drawings also will allow review of installation sequencing so appropriate coordination can be used. At a minimum, shop drawings should show materials, lap construction, and the following transition details:

- Different wall systems.
- Interfaces of roofing systems to walls.
- Interfaces of soffits and overhangs to walls.
- Interfaces of walls to plazas (i.e., horizontal waterproofing system over occupied space).
- Interfaces of walls and plazas to below-grade walls.
- Interfaces of fenestrations to walls.
- Across construction, control, and expansion joints at walls, roofs, and floors.
- Across utility, pipe, and duct penetrations at walls, floors, and roofs.
- Interior partitions separating spaces with different relative humidity.

The designer should formalize any changes to the design by returning annotated shop drawings to the installer or issue an architect's supplemental instructions (ASI) to the project construction team.

6.4 Construction Mockups

Construction mockups are typically required for projects to verify both aesthetic and technical aspects of the design. As part of the project mockup phase, mockups of the air barrier should include typical transitions (i.e., wall-to-fenestration, wall-to-roof, etc.) for review by the Architect or third-party inspector. This work shall be used for testing installation methods; to determine construction defects, if any; and, if necessary, to refine installation methods in accordance with the design intent before construction proceeds. Mockups are also helpful for coordinating between trades. The mockups should be performed as many times as necessary for the approval of the Architect and/or third-party inspector. Inspection of the air barrier should not be pushed to the punch list phase.

These mockups can be constructed as freestanding sample panels with project-representative conditions or in place on the building. Photo 5 illustrates air leakage testing through a freestanding sample panel mockup with cladding and fenestration installed.

Photo 5 – Air leakage testing of construction mockup of an exterior wall assembly with a fenestration.

Photo 6 illustrates air leakage testing for an air barrier-to-fenestration transition on a building. Testing of air barrier mockups should be performed before installation of the cladding for ease in identifying and repairing air barrier breaches.

Photo 6 – Air leakage testing for an air barrier-to-fenestration transition on a building.

6.5 Field Inspection

As part of the air barrier installation on the building, the contractor should conduct an air barrier quality-control program that includes, but is not limited to, the following:

- Inspecting all materials to ensure conformity to contract requirements and confirm that all materials are not expired, damaged, and stored improperly.
- Establishing procedures for executing the work.
- Inspecting all surface preparation prior to air barrier application.
- Inspecting work in progress to ensure that work is being done in accordance with established procedures/mockups, manufacturer's instructions, or specific Architect or third-party inspector instructions, if given.
- Inspecting all work and correcting all defective work.

- Obtaining all air barrier materials and accessories from a single manufacturer and providing other system components only as approved by the manufacturer of the primary materials.

Additionally, the Architect or third-party inspector engaged by the owner should conduct field inspections during the air barrier installation. These inspections should include a visual inspection and adhesion testing of the air barrier to confirm that it is continuous and that an adequate bond is achieved to each substrate specified for the project. Where loose-laid sheets are used, the fastening and sealing of the membrane should be verified. Visual inspections for each type of air barrier may include, but are not limited to, the following:

Sheet Membrane (Self-Adhered) Air Barriers

- All substrates scheduled to receive air barrier membrane are primed with the manufacturer's recommended primer to ensure that good bond is achieved.

- All laps in the air barrier membrane meet the minimum required by the manufacturer or contract drawings, whichever is more stringent.

- All laps in the air barrier membrane do not contain "fishmouths" or wrinkles that extend to the edge of the sheet. These unsealed wrinkles can result in air leakage through the air barrier and can also result in water leakage to the building interior if the air barrier is also utilized as the WRB.

- The membrane transitions to adjacent air barrier assemblies without holes, voids, or open edges (Photo 7).

Photo 7 – Membrane edge (arrow) of air barrier sheet is not adhered to sheet of adjacent air barrier assembly.

- All cut edges of the air barrier membrane are covered by the manufacturer's termination mastic or lap sealant, if required.

- All air barrier membrane is rolled using steel or hard neoprene rollers to ensure that an adequate bond is achieved to the substrate.

- All air barrier membrane is fully supported and adhered to the substrate. The air barrier membrane should not "bridge" over any substrates without continuous support.

- Inspection of air barrier membrane for prolonged exposure to ultraviolet (UV) radiation (i.e., curled edges of membrane).

Sheet Membrane (Loose-Laid) Air Barrier

- All laps in the air barrier membrane meet the minimum required by the manufacturer. All seams are sealed with the manufacturer's seam tape.

- Mechanical attachment of air barrier meets the manufacturer's requirements for spacing to project-specific substrates.

Fluid-Applied Membrane Air Barrier

- The air barrier membrane is mixed properly to prevent excessive air trapped in the material.

- Joints in substrates should be treated with sealant or reinforcing fabric as required by the manufacturer.

- Apply the material to the appropriate thickness and prevent excessive application that can result in running of the fluid.

- Flash penetrations and transitions as required.

SPuF Insulation

- All substrates scheduled to receive air barrier membrane are cleaned and primed with the manufacturer's recommended primer, as determined by adhesion tests, to ensure that adequate bond is achieved.

- Edges and terminations of SPuF insulation are mechanically restrained to prevent damage to underlying air barrier membrane (if applicable) or substrates should the SPuF insulation expand or contract.

- SPuF insulation is continuous with the specified thickness and without voids (Photo 8), discontinuities, or debonded edges due to inadequate surface preparation or foam shrinkage.

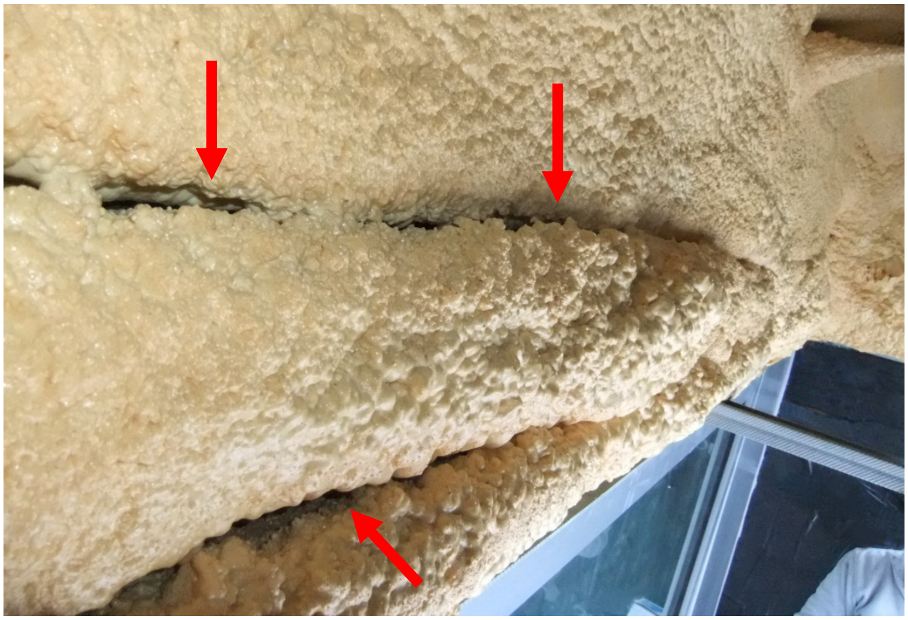

Photo 8 – Open voids in SPuF around structural steel.

6.6 Field Verification and Testing

Performing whole building air infiltration testing can help verify the performance of air barrier installations as well as locating defects in the system. Several agencies and state building codes require whole building air infiltration testing for new buildings. For new construction, it is prudent to perform testing before the air barrier system is concealed by cladding materials or interior finishes so that defects can be identified and repaired more easily. Removing cladding after construction is complete to locate air barrier discontinuities is often costly and can be disruptive to the building occupants.

Field testing requires that the building be positively or negatively pressurized using blower door fans or manipulating the HVAC system to force air to leak through any air barrier discontinuities in the building enclosure. Various quantitative and qualitative techniques are available to identify air leakage paths, including infrared (IR) thermography or tracer smoke. These tests should be discussed with the project team early in the design process and required by the project specifications so that they are scheduled at the appropriate time during construction.

Qualitative Air Infiltration Testing. ASTM International (ASTM) E1186 describes various qualitative methods to locate air barrier discontinuities. One such practice is to pressurize or depressurize the building or individual spaces by using fans (Photo 9) or by manipulating the HVAC system, and then use a tracer smoke source over the interior or exterior surfaces of the building enclosure.

Photo 9 – Test setup for blower door test with calibrated fans.

Placing the tracer smoke source at the building interior and pressurizing the building or space to locate air exfiltration sites reduces the influence of wind or stack effect. In this case, tracer smoke will be drawn from the building interior through any breaches in the air barrier and be identifiable at the building exterior (Photo 10).

Photo 10 – Tracer smoke exfiltration at roof eave (arrow).

Although it is possible for some projects to depressurize the building and locate the source of tracer smoke on the building exterior, this method may be difficult because of the influence of wind and the risk that the tracer smoke will rapidly dissipate before it is drawn into the building interior through the air leakage site.

IR Thermography. IR thermography (per ASTM E1186) is another useful and efficient qualitative method to locate discontinuities in the air barrier. The purpose of the IR scans is to identify locations of elevated heat loss through the building enclosure. Air infiltration or exfiltration through the building enclosure modifies temperatures of wall components in the region of air leakage pathways, given that there is an interior and exterior temperature difference; IR scanning equipment can be used to detect local surface temperature differences (Photo 11).

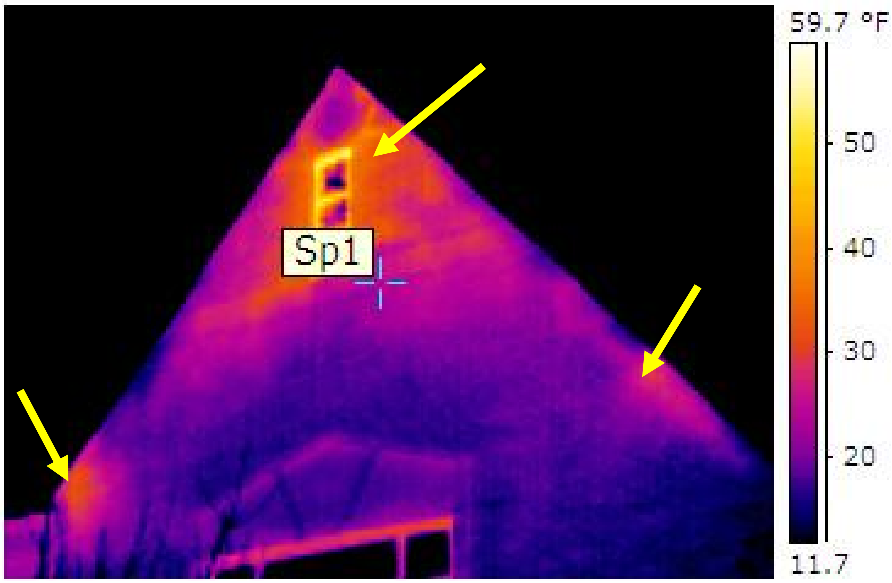

Photo 11 – Infrared image of exterior wall taken during the winter in a heating climate. Orange/yellow regions indicate locations of elevated heat loss (arrows).

The conditions most conducive to accurate IR scans are low winds with a large temperature difference (at least 20°F) between the interior and exterior air temperatures. Additionally, IR scans should be performed before sunrise or after sunset to maximize the temperature difference between the interior and exterior as well as to avoid false readings due to solar exposure. Depending on the building pressurization, the IR scans can be conducted from the building interior or exterior. Using fans or the HVAC system to pressurize or depressurize the building during the IR scan can exacerbate air leakage through discontinuities in the air barrier, making it easier to identify air barrier breaches on an IR image.

Quantitative Air Infiltration Testing. Blower door testing per ASTM E779 is intended to characterize the airtightness of the building enclosure. The test results can be used to compare the airtightness of the subject building to similar buildings or against criteria set by industry standards or governing building codes. The tests are conducted using calibrated fans (Photo 9) to pressurize and depressurize the building under controlled conditions. Before testing, all sources of extraneous air leakage not related to the building enclosure should be identified. These include all ventilation intake and exhaust grills, any floor drains, plumbing stacks, roof drains open to the exterior, or holes in interior doors where hardware is not installed.

The ASTM E779 test procedure typically requires a range of induced pressure difference (pressurization and depressurization) from 10 Pa to 60 Pa. We recommend that each testing area first be depressurized or pressurized to at least 60 Pa, and airflow measurements taken at that point and at each 10 Pa reduction down to 10 Pa. This increased pressure induced during the test may cause sealed openings or dampers to be forced open; these conditions should be monitored and addressed during the test.

The measured air leakage flow rates (cubic feet per minute) are typically normalized using the building surface area (walls, roof, and floor) and calculated as the average of the pressurization and depressurization at 0.30 in. water column (75 Pa) pressure difference using the air flow equation stated in ASTM E779.

Should the initial results of the ASTM E779 exceed the air leakage rates required by the project specifications, various qualitative testing methods are available to help identify breaches in the air barrier system as described above.

7. SUMMARY

Special consideration needs to be made by designers and contractors with respect to air barrier design and construction. Design professionals should be aware that more building codes are requiring continuous air barriers and this trend is likely to increase significantly. Continuous air barriers will help reduce building operating costs and minimize carbon footprint in the face of rising energy costs and higher demand for green buildings. Quality-control methods built into the design and construction schedule can be implemented to identify issues early when correction is more easily achieved than after building occupancy.