Commissioning the Air Barrier System

By Wagdy Anis, AIA, Member ASHRAE

Building enclosures should be designed and constructed to be as airtight as possible. This statement confuses many people. They ask: "Shouldn't buildings breathe?" "Don't tight buildings make people sick?" "If you tighten up a building enclosure, won't you trap the interior moisture and keep it in?" These questions show a lack of understanding about water vapor diffusion through building materials and its control; the buffering of moisture by building materials, and air leakage and its role in transporting moisture through the cavities of the building enclosure; and the control of air leakage using air barrier systems.

Andrew Persily, Ph.D., Fellow ASHRAE, at the National Institute of Standards and Technology (NIST) concluded that institutional and commercial buildings in North America are generally inadequately constructed and, therefore, are quite leaky.[1] Recent analysis by NIST of the tested commercial buildings[2] confirms that. It also establishes that the average leakage rate for low- to mid-rise commercial buildings in the northern United States are tighter than the average of similar buildings in the South, but all are too leaky (*Figure 1*).

Figure 1 shows a graph between the two data points analyzed for southern and northern buildings, assuming a gradual decrease in attention to construction quality as you go further south (to convert L/s·m^2 at 75 Pa to cfm/ft^2 at 0.3 in. w.g. [1.57 lbs/ft^2] multiply by 0.2.)

My experience bears out that commercial buildings are built too leaky. This has nothing to do with code compliance. It is caused by a lack of understanding and attention to tightening the opaque enclosure of a building and a lack of target verifiable performance criteria.

Uncontrolled air leakage in buildings adds dramatically to the heating and cooling energy consumption of a building (up to 40%).[3] One of the most serious consequences of air infiltration and exfiltration is the disruption of a building's HVAC system's design air

About the Author

Wagdy Anis, AIA, is a principal and director of technical resources at Shepley Bulfinch Richardson and Abbott in Boston.

Laboratory mockup during an ASTM E283 air infiltration test, which tests assemblies of opaque walls, curtain walls and windows.

pressure relationships.[4] This could prove catastrophic when lives depend on maintaining these relationships, such as in hospital operating rooms, protected environment rooms, and infection control rooms. Or in other circumstances, pollutants can migrate from containment spaces to other spaces, and water vapor in the air can condense on colder surfaces within the enclosure assemblies to cause indoor air quality problems, mold growth, corrosion, rot and premature failure of the building enclosure.

Prudent care during design and construction to commission the air barrier system is necessary to reasonably ensure that the design intent of the mechanical system can be achieved. For those concerned about lack of adequate ventilation if the enclosure is tight, they should be aware that commercial buildings are required to be ventilated in accordance with ANSI/ASHRAE Standard 62.1, *Ventilation for Indoor Air Quality*, which specifies sufficient outdoor ventilation air that is filtered, conditioned and delivered to the breathing zone to provide more than adequate outdoor air for breathing and for building pollutant dilution.

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The building enclosure should be designed and constructed tightly so the ventilation system can operate without disruption or loss of control (i.e., to promote durability and maintain comfort with good indoor air quality, acoustical isolation and energy conservation). To achieve this, an air barrier system needs to be designed and constructed into the building enclosure. The air barrier system should be:

- Constructed of relatively air-impermeable materials and assemblies, interconnected with flexible joints;
- Continuous throughout the enclosure;
- Structurally supported to withstand positive and negative air pressures (including design wind pressures and gusts, as well as persistent low pressures such as stack effect and fan pressurization) without displacement and failure; and
- Durable to last the life of the enclosure if inaccessible, or maintainable.

Air barrier systems for a building enclosure are assembled from relatively air-impermeable materials (less than 0.004 cfm/ft^2 at 1.57 lbs/ft^2 [0.02 L/s·m^2 at 75 Pa]) interconnected to form assemblies and the assemblies (such as opaque walls, windows, etc.) interconnected with flexible joints that can accommodate the expected relative movement of these assemblies.

All penetrations of the air barrier system are sealed. When such air-impermeable materials are assembled using sealants, tapes, gaskets, etc. and then penetrated by screws, anchors, electrical outlets, etc., even though the connections and penetrations are carefully installed and sealed, the assembly becomes more leaky than the original basic air barrier material. Acceptable numbers for the air leakage of assemblies depend on what they are made of and their tolerance to condensation moisture.

The American Architectural Manufacturers Association (AAMA) suggests a maximum of 0.06 cfm/ft² at 1.57 lbs/ft², (0.3 L/s·m² at 75 Pa), which may be suitable for glass and aluminum components. The appendix of the National Model Building Code of Canada recommends 0.02 cfm/ft² at 1.57 lbs/ft² (0.1 L/s·m² at 75 Pa) as a maximum allowable leakage rate for building assemblies more vulnerable to moisture damage (and half of that for high humidity buildings).

Again, if the drying potential of the assembly is low, then the tolerable leakage is less. This makes sense in all climates, even though the specific studies were done for cold climates.[5] It becomes more complicated if the air is infiltrating or exfiltrating, how much, the characteristics of the interior and exterior air, the size of the holes, the nature of the materials in the assembly, and the weather. Studies are ongoing at Oak Ridge National Labs,[6] the National Research Council Canada, and elsewhere in Europe. The air leakage rate of whole buildings per square foot of enclosure at the reference pressure of 75 Pa is a higher number than for assemblies by another order of magnitude.

The allowable air leakage for whole buildings has been described in *ASHRAE Handbook—Fundamentals.* Researchers Tamura and Shaw[7] in the 1980s measured and studied the air leakage of seven high-rise office buildings. They concluded that buildings are tight if they achieve a *normalized air leakage rate of the building enclosure* not to exceed 0.1 cfm/ft² at 0.3 in. w. g. or 1.57 lbs/ft² (0.5 L/sm² at 75 Pa) (see sidebar).[8]

Contemporary researchers such as Robert Dumont[9] have confirmed this number as a good maximum target for buildings, and it has been achieved and improved upon in projects that have been carefully monitored during design and inspected during construction. Other evidence suggests this target may be difficult to achieve if you do not have an effective quality assurance/quality control program in place for the building enclosure during design and construction.

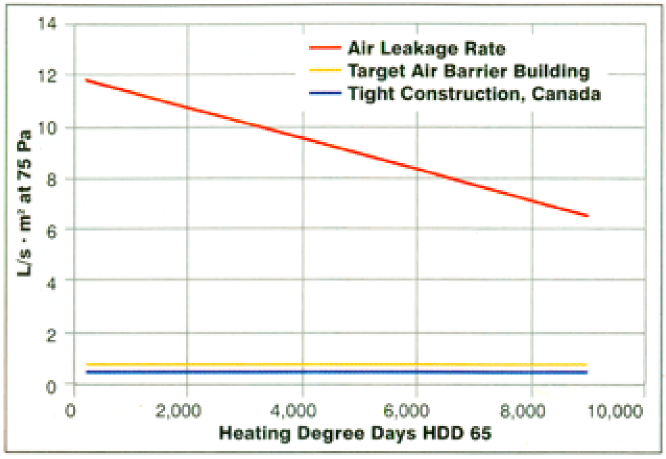

Figure 1: Buildings in the North are tighter than buildings in the South; all are leaky.

A more readily achievable number with reasonable care in this author's opinion is 0.15 cfm/ft² at 0.3 in. w.g. In fact, 6% of all low-rise commercial buildings measured equal to or have lower air leakage rates than this number, without a special program in place for the enclosure.[10] It is likely that compliance with this number should be readily achievable with a target requirement in place.

Doing it Right. The air barrier system needs to be identified by the architect in the construction documents on the building enclosure details, with a strong focus on intersections of different enclosure systems and transitions. You have to be able to trace through from one identified plane of airtightness in the first assembly through a sealed joint to the plane of airtightness in the adjacent assembly. The specifications should have a special section on the air barrier system that includes all accessory materials.

An ISO 9000 methodology in construction involves building quality into the process itself. The Air Barrier Association of America's[11] (ABAA) licensed contractors with trained and certified air-barrier technicians, follow a predefined quality assurance program (QAP) that includes documenting daily

Calculating Normalized Air Leakage Rate

Normalized Air Leakage Rate of the Building Enclosure: $NLR_{75} = Q_{75}/S$, the average volume of air in cfm (L/s) that passes through a unit area of the building enclosure in ft² (m²), expressed in cfm/ft² at 0.3 in. w.g. (L/s·m² at 75 Pa), where Q_{75} is the volume of air in cubic feet per minute (L/s) flowing through the whole building enclosure when subjected to an indoor/outdoor pressure of 0.3 in. w.g. (1.57 lbs/ft²) (75 Pa) in accordance with ASTM E779; *S*, measured in ft² (m²), is the total area of the enclosure air pressure boundary including any below-grade walls, slab, plus the gross area of suspended floors, above-grade walls and roof (or ceiling), including windows and skylights, separating the interior conditioned space from the unconditioned environment.

Canadian researchers and investigators are reporting to this measurement unit. England is reporting to this unit too, although to a pressure of 50 Pa.

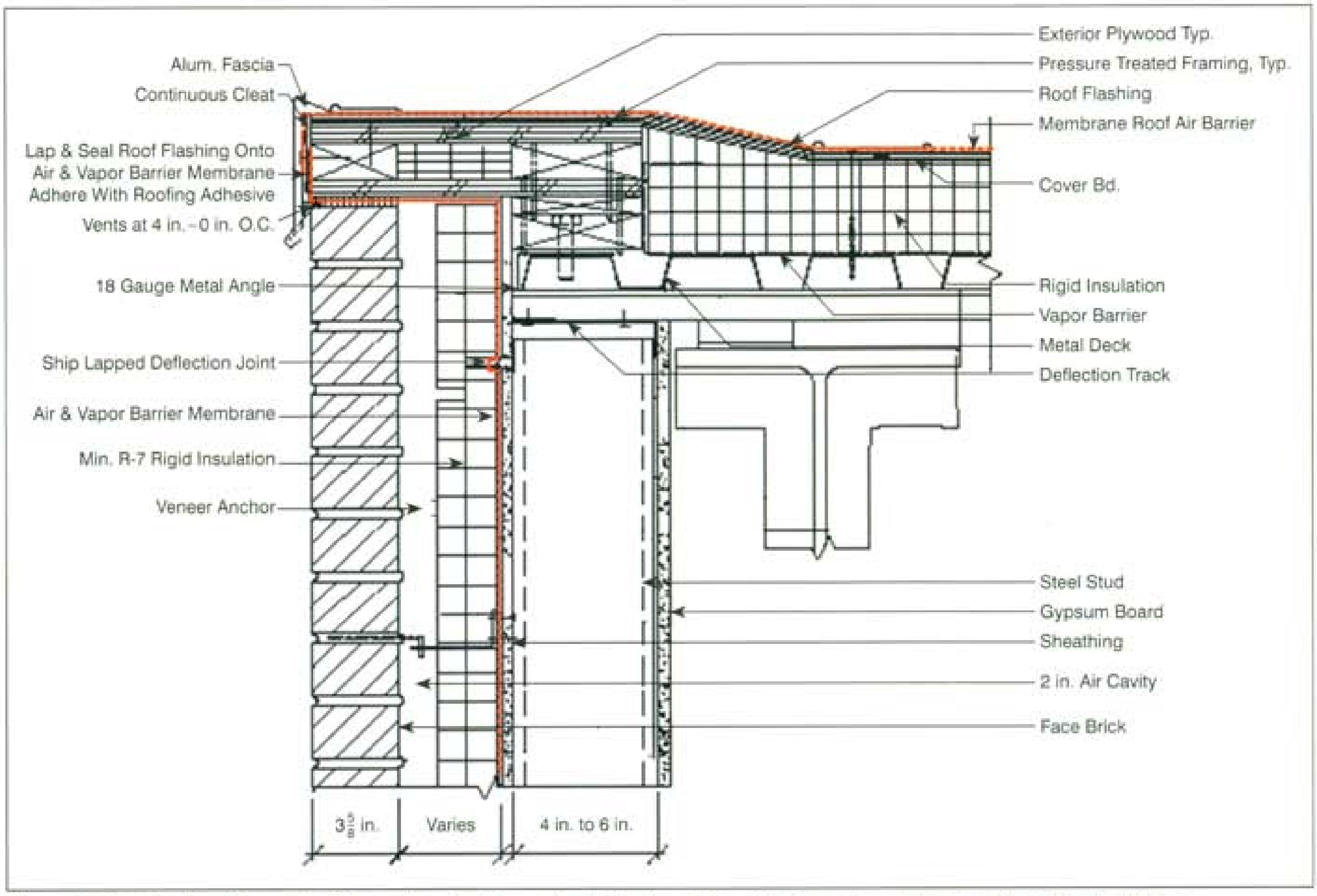

Figure 2: Continuity of the wall air/vapor barrier through a deflection joint with the roof membrane used as the air barrier.

progress and daily self-testing of the air barrier system. An ABAA auditor in a surprise visit(s), verifies that the QAP is followed and verifies the air barrier system's installation quality. The subcontractor's standing and certification may be affected by noncompliance.

Was it Done Right? A third-party inspection and testing program may be instituted to peer review the design details and specifications, as well as to conduct pre-functional and functional air barrier system inspection and testing. Inspection of the air barrier system would determine that:

• Continuity of the air barrier system is clearly detailed on the drawings and is achieved throughout the building enclosure with no gaps or holes.

• Continuous structural support of the air barrier system is provided.

• Masonry and concrete substrate surfaces are flush, clean and free of cavities, protrusions and mortar droppings.

• Site conditions for application temperature and dryness of substrates are observed.

Figure 3: Infrared thermography reveals hot spots that are usually air leaks.

Figure 4: Chamber for pressurization/depressurization tests.

• Maximum length of exposure time of materials to ultraviolet deterioration is respected.

• Surfaces are adequately primed prior to application of the air barrier membrane.

• Laps in sheet materials meet the minimum requirements and are shingled in the correct direction (and mastic applied to exposed and cut edges), with no fish-mouths.

• A roller has been used to enhance adhesion.

• Compatible materials have been used.

• Transitions at changes in direction and structural support are provided at gaps.

• Connections between assemblies (membrane and sealants) have been cleaned, and primed prior to sealant application;

• The integrity and structural support of connecting seals are satisfactory; and

• All penetrations have been sealed.

Testing Enclosure Components, Assemblies and Buildings for Air Leakage. Good practice on a project includes testing

		L/s · m²	cfm/ft²
5/16 in.	Plywood	0.0067	0.0013
5/8 in.	Flakeboard	0.0069	0.0014
1/2 in.	Exterior Gypsum	0.0091	0.0018
3/8 in.	Flakeboard	0.0108	0.0021
1/2 in.	Particle Board	0.0155	0.0031
	Non-Perforated Spun Polyolefin	0.0195	0.0038
1/2 in.	Interior Gypsum Board	0.0196	0.0039
	CMHC List		
	Smooth Surface Roofing Membrane, 2 mm	Nonmeasurable	
	Aluminum Foil Vapor Barrier	Nonmeasurable	
	Modified Bituminous Torch-On Grade Membrane, 2.7 mm Glass Fibre Matt	Nonmeasurable	
	Modified Bituminous Self-Adhesive Membrane, 1.3 mm	Nonmeasurable	
	Modified Bituminous Torch-On Grade Membrane, 2.7 mm Polyester Reinforced Matt	Nonmeasurable	
	Plywood Sheathing, 9.5 mm	Nonmeasurable	
	Extruded Polystyrene, 38 mm	Nonmeasurable	
	Foil Back Urethane Insulation, 25.4 mm	Nonmeasurable	
	Cement Board, 12.7 mm	Nonmeasurable	
	Foil-Backed Gypsum Board, 12.7 mm	Nonmeasurable	
	Plywood Sheathing, 8 mm	0.0067	0.0013
	Flakewood Board, 16 mm	0.0069	0.0014
	Gypsum Board (M/R), 12.7 mm	0.0091	0.0018
	Flakewood Board, 11 mm	0.0108	0.0021
	Particleboard, 12.7 mm	0.0155	0.0031
	Reinforced Non-Perforated Polyolefin	0.0195	0.0038
	Gypsum Board, 12.7 mm	0.0196	0.0039
	Particleboard, 15.9	0.0260	0.0051
	AAC	0.0400	0.0079
	Tempered Hardboard, 3.2 mm	0.0274	0.0054
	Expanded Polystyrene, Type 2	0.1187	0.0234
	Roofing Felt, 30 lb	0.1873	0.0369
	Non-Perforated Asphalt Felt, 15 lb	0.3962	0.078
	Rigid Glass Fibre Insulation Board With Spun Bonded Olefin Film on One Face	0.4880	0.0961
	Plain Fibreboard, 11 mm	0.8223	0.1619
	Asphalt Impregnated Fibreboard, 11 mm	0.8285	0.1631
	Spun Bonded Olefin Film (1991 Product)	0.9593	0.1888
	Perforated Polyethylene, #1	4.0320	0.7937
	Perforated Polyethylene, #2	3.2307	0.636
	Expanded Polystyrene, Type 1	12.2372	2.4089
	Tongue and Groove Planks	19.1165	3.7631
	Glasswool Insulation	36.7327	7.2308
	Vermiculite Insulation	70.4926	13.8765
	Cellulose Insulation, Spray-On	86.9457	17.1153

Table 1: Air leakage rate for average North American buildings.

component, assembly and even the whole building for air infiltration. It is good verification that it was done right. Although, if you wait until the building is complete to find out if the building has been adequately sealed, then it's probably too late, and may become an expensive proposition to retroactively seal the building. It would be possible only to seal the big holes, not the smaller systemic ones. That's not what commissioning is about!

Two categories of testing are:

1. Laboratory testing of assemblies and mock-ups, and

2. Field-testing of assemblies and the actual building.

Figure 5: The "bubble gun."

Laboratory Testing

Window and door products must be tested and certified in accordance with the National Fenestration Rating Council's (NFRC) test protocols, such as NFRC 500, ASTM E283 or E 330. Garage doors are tested according to ANSI/DASMA 105 to comply with code. Reasonable air leakage rates for glazed products and doors are required by codes and standards as well as recommended by organizations such as AAMA.

The maximum air permeance of air barrier materials is not, as of this writing, regulated by the model codes in the United States. However, air barrier materials should be tested and qualified per ASTM E2178 not to exceed 0.004 cfm at 0.3 in. w.g. or 1.57 lbs/ft² (0.02 L/s·m² at 75 Pa).[12]

Table 1 shows the materials tested by Canada Mortgage and Housing Corporation and their air leakage rates at 0.3 in. w.g. (75 Pa).

Assemblies of opaque walls, curtain walls and windows can be tested in the lab in accordance with NFRC 400 or ASTM E 283 (air infiltration), ASTM E 331 (water penetration under static pressure), AAMA test procedure 501.1 (water penetration under dynamic pressure) ASTM E 330 (structural adequacy), NFRC 500 or AAMA 1502.7 (condensation resistance factor or CRF), NFRC 100 or AAMA 1503.1 (thermal transmittance), NFRC 200 (solar heat gain coefficient), NFRC 300 (solar optical properties of glazing products).

Another test for air barrier assemblies is ASTM E1677; it is a test for low-rise residential buildings and includes an 8 ft by 8 ft (2.4 × 2.4 m) panel that has panel joints, a blanked-off window, a duct penetration, an electric outlet, etc. The maximum test pressure suggested in this test may be too low to simulate wind loads for most building locations and for taller buildings, so a test pressure more representative of design wind and gust pressures at the project site (plus a safety factor) should be required by the A/E. Infiltration is reported with this test as cfm/ft² at 0.3 in. w.g. (L/s·m² at 75 Pa).

Figure 6: Cutting around the disk.

Figure 7: Pulling material to failure.

The Canadian Centre for Materials in Construction has established an elaborate test protocol for air barrier assemblies that includes three test panels. The Air Barrier Association of America is bringing a similar test to ASTM and is planning within ASTM a whole family of test methods, specifications and standards for materials, assemblies and components (sealants and joint materials).

Field Testing

ASTM E 1186 contains several useful qualitative tests to chase down leaks. Infrared scanning with pressurization/depressurization is useful in determining leaks in the winter or summer. In the winter, leaking warm air heats up the enclosure and shows up as a bright spot in the picture (*Figure 3*) (this also can be caused by a thermal bridge, which can be identified from the design details or insulation inadequacies during construction).

The reverse happens in the summer with air conditioning indoors. The dark spots are spots cooled by exiting cool air, or other enclosure problems.

Several other tests within E1186 are rarely used, but two are worthy of note. Chamber pressurization/depressurization in conjunction with smoke tracers is a useful test to determine the location of air leaks in connections between building components such as windows and skylights with their adjacent constructions.

A chamber is created using polyethylene and a simple wood frame (*Figure 4*), a smoke device is released, or generated using theatrical foggers, while air from a fan depressurizes or pressurizes depending on the configuration. Chamber depressurization using detection liquids uses a device nicknamed the "bubble gun" (*Figure 5*). A bubble solution is spread on the suspected penetration or joint, such as a brick tie fastened to a wall. The plastic dome of the device is placed over the area and depressurized to 500 Pa (2 in. w.g.). Bubbles form if an air leak exists.

The bond of the air barrier to its substrate is important because of the requirement of the membrane to transfer the design wind negative loads to the substrate. Manufacturers of most air barrier products that are either peel-and-stick or liquid-applied publish data on quality of adhesion to substrates. Testing using a pull-meter can be done by following ASTM D4541. A disk is epoxied to the material to be tested, and the material is cut around the disk (*Figure 6*). Tightening the device pulls the material to failure (*Figure 7*), and the test pressure is recorded and compared to the manufacturer's specifications. A 12 psi (83 kPa) minimum bond should be satisfactory for long-term durability. Note that patching of the test area will be necessary.

The adhesion quality of air barrier membranes can be affected by the wetness of the substrate before application or by low application temperatures.

ASTM E783 is a test for air infiltration of wall or window assemblies. ASTM E1105 is a spray rack water infiltration testing of wall or window assemblies, using the same pressurization/depressurization equipment as E783 and is usually run at the same time as E783.

Whole Building Testing

Testing whole commercial buildings usually is done for U.S. research, although it is more common in Canada. It has become a requirement for building acceptance in England and Wales since 2002. It is likely that as the importance of airtightness of the building enclosure becomes more appreciated or regulated, whole building testing will become more prevalent in North America. The cost of testing a commercial building can vary from $1,000 to $15,000 depending on complexity and size.

Tests include:

• Whole building, floors, or suites, ASTM E 779, Determining Airtightness of a Building's Air Leakage Rate by Single Zone Air Pressurization.

• CAN/CGSB 1986 Standard 149.10, Determination of the Airtightness of Building Enclosures by the Fan Depressurization Method; and

• CAN/CGSB 1996 Standard 149.15, Determination of the Overall Enclosure Airtightness of Office Buildings by the Fan Depressurization Method Using the Building's Air Handling System.

Trailer-mounted fans (with large blower doors) for testing large buildings, delivering up to 55,000 cfm at 75 Pa (26 000 L/s at 0.3 in. w.g.) or larger are available from a U.S. source. Several of these may be required to test a large, leaky, building, although inaccuracies are introduced with the use of multiple fans. In testing a whole building, all the "intentional holes" such as ventilation air intakes, exhaust fan outlets and louvers, elevator shaft smoke exhaust, flues, etc., have to be sealed, usually with polyethylene and tape. Low wind conditions, lower than 8.5 mph (14 km/h) and only a small temperature differential between indoor and out (outdoor temperature between 40°F and 95°F [5°C and 35°C]) helps reduce the influence of wind and stack effects.

Figure 8: Testing a window enclosure and its perimeter joint using ASTM E 283.

Interior doors need to be open so the building is turned into a single zone. The volume of air being moved is recorded at the pressure differential; this is done for several different pressures in steps of 12.5 Pa to 75 Pa (0.05 to 0.3 in. w.g.). If the building is too large to test with a single fan, multiple fans can be used, or the building's air handlers can be used instead; the fans need to be evaluated for cfm output; the test can then proceed and the fans progressively turned on to pressurize the building with pressure measurements taken at each step.

The flow coefficient C and the flow exponent n are evaluated using the power law equation:

$$Q_{75} = C(\Delta P)^n$$

Where

Q_{75} is the quantity of air leakage (cfm [L/s]) at 0.3 in. (75 Pa)

C is the flow coefficient (C = flow coefficient, cfm/(in. of water)^n (L/s/(Pa)^n

ΔP is the pressure differential between indoors and outdoors (in. water, [Pa])

n = pressure exponent, dimensionless.

The Normalized Air Leakage Rate for the Building Enclosure is then calculated using the method outlined in the sidebar

Conclusion

Commissioning the air barrier system is important in the design and construction of buildings that are sustainable, healthful, durable, and energy efficient. For high-security buildings, unless their building enclosure is designed and constructed as tightly as possible, and the air barrier system commissioned, it would be impossible to pressurize the building adequately to reduce the likelihood of infiltration, thereby potentially compromising the interior environment to chemical, biological or radiological agents.[13] An adequate budget needs to be assigned early in the project process to fund the commissioning activities needed to ensure a successful outcome that meets the owner's project expectations for a tight building enclosure.

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