

United States Army Corp of Engineers Requirements for Air Barrier Systems in Buildings

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This study identifies reasons for controlling air leakage in buildings. It also describes materials and testing methods used in establishing a sufficient air barrier. Air barriers are becoming more popular in residential and commercial practice and are required in buildings built under the U.S. Army Corps of Engineers. These air barriers have the capability to keep pollutants from entering a particular conditioned space, as well as reduce the energy usage of the building's HVAC system. There are different methods used in the testing of air barriers. Standardized testing is used by the U.S. Army Corps of Engineers and all of their buildings must maintain an air leakage rate of 0.25 cfm/sq ft based on a test pressure of 0.3 iwg (75 Pa).

Key Words: Air Barrier, Air Leakage, Energy Conservation, ASTM

Introduction

An air barrier is an intricate system of components that envelopes any required conditioned space to keep air from leaking out of, or into a building. Untreated air has the ability to cause problems in buildings. This air may contain pollutants that are unhealthy to people or moisture that can cause mold or decay. Air barriers deny entry of untreated air into the envelope that they protect. They also have the ability to reduce the energy usage that is required to maintain the pressure needed to condition a space. This energy usage reduction allows the building to contain a smaller HVAC system than would be required in a building that allows air leakage. Air barriers have the ability to reduce the production of mold and other pollutants that may affect the building as well as conserve energy. Air barriers also control air leakage out of the building driven by negative pressure. Negative pressure occurs when the air pressure on the outdoor side of a building envelope is lower than the pressure on the indoor side. They also control air infiltration into the building caused when pressure on the indoor side of the building envelope is greater than that on the outdoor side. These pressures also affect the structural integrity of the building. This structural integrity may be influenced by wind loads on the building, which could affect the pressures in and out of the building.

Background

Causes of air infiltration and exfiltration must be understood in order to comprehend the importance of having an air barrier. Infiltration is classified by air that leaks into the building envelope from the outside. Exfiltration is air that leaks out of the envelope from the inside. Pressure differentials, inside and outside of the building, are the main causes for air leakage. Anis (2007) identifies three ways that air can infiltrate or exfiltrate a building envelope. These leakages are classified as orifice flow, diffuse flow, and channel flow. Leakage described as orifice flow is air that enters or exits the envelope on a linear pathway. This usually occurs where there is a crack between a window and its frame. Diffuse flow is leakage that occurs when the materials used in the air barrier do not meet the standards expected. Improper installation of materials may result in diffuse flow. Channel flow occurs when there is a great enough distance from the envelope entry point to the exit for the air to be cooled. This may occur if the air is allowed to travel long distances in the cavities of the building. Channel flow will cause moisture to accumulate inside the building envelope.

Air pressure on a building is the main cause of envelope infiltration and exfiltration. Anis (2007) classifies the three main air pressures that affect the building envelope as wind pressure, HVAC fan pressure, and stack pressure.

Buildings are affected by the wind in different ways. For example, the wind will not affect a one story house in the same way that it will affect a high rise building. The side of the building that is hit by the wind is generally pressurized positively, while the other sides are pressurized negatively. When the wind hits a building, it cavitates and speeds up around the edges. This causes a pressure differential on the building envelope. HVAC fan pressure is an effect of the pressurization of the HVAC system in the building. Stack pressure characterizes the atmospheric pressure differential at the top and bottom of the building. This occurs mainly due to a temperature difference across the building. Reaction to stack pressure occurs differently in heating and cooling climates. HVAC fan pressure generally reacts positively against wind and stack pressure. Genge (2009) describes how these pressures react with each other in some cases:

> As height increases, the pressures on the building due to wind and stack increase in a complex way. As height doubles, the increased pressures experienced due to wind roughly double. As height quadruples, stack pressures double. Combining these two pressures to any existing HVAC imbalance creates a bias pressure experienced by the building before any additional test pressures are applied.

It becomes complicated to measure the pressure differentials on a building when these three air pressures affect it. The larger the building, the more unpredictable the pressure reactions will be. In order to properly test and balance a building's HVAC system, an air barrier must be able to control leakage in response to all of these pressures.

Energy Conservation

Another reason a building may be designed with an air barrier is related to conservation of energy in the HVAC system. A properly designed and installed air barrier is capable of reducing the heating load in a building up to 33% (Emmerich, 2007). Furthermore, according to Building Regulations (2008):

> Air leakage in buildings is a major cause of energy losses, resulting in an increase in carbon dioxide emissions into the atmosphere. Reducing the amount of uncontrolled airflow through gaps in the building fabric can therefore have a significant effect on the overall energy performance of the building. With the stricter building regulations requiring better energy efficiency, air tightness is now a fundamental part of creating sustainable buildings.

U.S. Army Corps of Engineers Requirements

The U.S. Army Corps of Engineers will require all of their buildings, including renovation projects, to meet standard air leakage testing requirements in fiscal year 2010. The requirements for the air tightness of the building will be included in the contracts for all of the new and renovation projects. These requirements state that all of these buildings will be designed and constructed with a continuous air barrier that is capable of controlling air leakage into or out of the conditioned space that is designated. Conditioned spaces in buildings that are tested include: office buildings, office portions of mixed office and open space, dining facilities, barracks, and instructional/training facilities. Standard testing will be done on the air barriers of these conditioned spaces. One important requirement of the Corps of Engineers is that the air barrier boundary be clearly identified in the construction documents. The boundary of the air barrier must be outlined, as well as the description and listing of the materials to be used in the air barrier assembly. Materials used in the air barrier system must meet specific air permeance requirements. The air barrier system will be tested in accordance with ASTM E 1827, ASTM E 779, ASTM E 1186, and ASTM E 2178. The permeance of the materials used in the system is not to exceed 0.004 CFM/sq ft @ 0.3 iwg [0.02 L/s.m^2 @ 75 Pa] when tested in accordance with ASTM E 2178. The building envelope will not exceed a permeance of 0.25 CFM/sq ft @0.3 iwg when tested in accordance with ASTM E 1827. All of the materials used in the assembly will be joined and sealed so that they are flexible. This is to allow for deflection in the system. The air barrier system must be able to withstand any negative or positive pressures that are applied to the building from outside or within. It must also be able to transfer these forces to the structure of the building so that the air barrier sustains no damage. The Corps of Engineers also requires that the completed building be tested using Infrared Thermography in accordance with ASTM E 1186. An infrared camera must be used to determine if the building meets these requirements (Building air tightness, 2009).

In order to determine the effect the USACE's requirements have had on facilities constructed recently, Pie Forensic Consultants reviewed the test results of more than 50 buildings tested using the ASTM standards. Projects solicited prior to the implementation of thermal performance requirements exhibited an average leakage rate of 0.6 CFM/sq ft of envelope at 75 Pa, well above the maximum allowable permeance in new projects. Building projects that were solicited with the USACE thermal performance requirements exhibited a 77% improvement in airtightness (Erickson and Spinu, 2011).

Construction of Air Barriers

Air Barrier Location

Much attention should be given to designating the conditioned space that is to be air tight. It is important to select an air barrier design that will perform in the climate in which it is constructed. Wall construction types, connections, and building deflections should also be considered when designing the air barrier. The location of insulation in the building is also an important factor (Osmond, 2007).

Air barrier systems may be applied to the interior or exterior of the building. There are advantages and disadvantages to either method. The main advantage of applying an exterior air barrier to the building is wind control. Exterior air barriers are also easy to apply. It is less likely that the building will not be sealed in areas where the air barrier meets. A disadvantage to applying an exterior air barrier is that they often allow moisture to enter the building through interior cavities in the building. This can cause many problems within the building such as mold. An advantage of applying an interior air barrier is that it will not allow moisture in the air to enter the building insulation while it is being heated. The main disadvantage to using an interior air barrier is its inability to control the effect that wind may have in the building cavities. Both systems may be installed during construction to ensure that the building will be properly protected. Most air barrier systems also classify as vapor barrier systems. In order for the air barrier to perform properly, the building must be dry. This means that when applying the air barrier, it is important to ensure that the building will remain vapor free (Lstiburek, 2005).

There are many factors to consider when designating the area or portions of the building that will remain air tight. Any garage areas that the building contains must be compartmentalized by the air barrier. These areas are unable to remain air tight due to the large openings created by the doors or garage entryways. Areas in the building that are likely to create negative pressures, such as boiler rooms, must also be compartmentalized. It is very important that any supply or return plenum areas in the ceiling be decoupled from the exterior of the building. These areas provide prime locations for condensate to form, which over time can produce mold or other health risks. Also, any area within the cavities of the building that could produce convection currents must be protected. Convection currents form in areas where insulation separates the warm and cold sides of the building envelope. If these areas are not designed and constructed properly, mold will form in the cavities (Anis, 2007).

Air Barrier Materials

All materials used in an air barrier assembly must contribute to meeting the permeance requirements of the U.S. Amy Corps of Engineers. Various materials are used in design and construction of the air barrier. There are many factors to consider when choosing materials for the air barrier system. It must be possible to make the air barrier continuous throughout the entire system. The barrier must be sealed at all penetrations and continuous over all corners and joints. Strength is a critical factor in choosing the proper material. It must be able to withstand the load that is applied by various pressures and able to transfer the load to the structure of the building. The air barrier must also be able to perform throughout the entire life of the building. Materials used in the system must be durable enough to last this entire life. Repair on many materials in the air barrier can be very complicated and difficult. The permeance levels must be maintained even after the material has been deformed over time, or after bearing heavy loads. Air permeability is the most important feature to consider when selecting which materials will be used. According to the Whole Building Design Guide, the basic materials and thicknesses used most often in air barrier systems are included in Table 1.

Table 1

Material Air Leakage

Measurable Airflow			
Thickness	**Material**	**CFM@0.3"wg**	**L/(s/m^2)@75Pa**
0.315"	Plywood	0.001	0.0067
0.630"	Waferboard	0.001	0.0069
0.500"	Exterior Gypsum	0.002	0.0091
0.433"	Waferboard	0.002	0.0108
0.500"	Particle Board	0.003	0.0155
0.500"	Interior Gypsum Board	0.004	0.0196

Non-Measurable Airflow	
Thickness	**Material**
0.006"	Polyethylene
0.060"	Roofing Membrane
0.106"	Modified Asphalt Torched-On
0.001"	Aluminum Foil
0.060"	Sheet Asphalt Peel and Stick
0.374"	Plywood
1"	Extruded Polystyrene
1"	Foil-Backed Urethane
0.5"	Cement Board

There are also many materials that do not meet air permeance requirements. These materials must have a coating that meets the standard applied to them. These materials include: concrete block, fiberboard, batt and semi rigid fibrous insulation, tongue and groove planks, perforated house wraps, asphalt impregnated felt, cellulose spray-on insulation, and vermiculite insulation. Air barrier products are also available as preformulated systems. These are purchased from a manufacturer and are designed to meet specific permeance requirements. It is important to ensure that the materials used in the air barrier assembly are structurally supported on both sides. Unsupported materials tear frequently at connections due to the pressure applied to them.

When using an air barrier material that is applied to the exterior of the envelope's insulation, it is important to consider the climate in which the air barrier is being constructed. Climates with greater temperature ranges may cause larger or smaller deflections on the materials in the building. Air barrier materials must be durable enough to withstand deflections on the system caused by these temperature changes throughout the year. There are many materials that are able to meet these conditions. Anis (2007) recommends that some form of liquid applied elastomeric air barrier be applied at the joints and connections of these exterior air barriers. A material such as wet silicone may be applied, which would allow for the movements caused by temperature changes over the building.

Air barrier materials that are used in the roof system of the building must be able to withstand the full load that is applied by the wind. Many forms of roof membranes are qualified to be air barrier assemblies. If a roof system is unable to meet the specified permeance requirements, an air barrier system must be incorporated into it. Spray foam insulation should be used where there are any penetrations. The materials used in the system must work together to meet the required air permeance of the air barrier. Proper installation is critical when assembling the air barrier. It is important that the appropriate materials are selected in the design stage of the project.

Testing of Air Barriers

There are many tests that can be performed on a building's air barrier. On U.S. Army Corps of Engineers projects, a third party testing verification agency is usually hired to perform the required test in the presence of the government. Testing the air barrier is a very detailed and involved process. The testing agency will usually meet with the quality control manager of the project to plan for preparation of the test. This preparation may take up to ten hours. The building must be completely sealed, including all exterior exhaust duct penetrations. All interior doors within the envelope that is being tested must be open. These tests will be performed after all of the exterior sealant joints are 100% complete. All plumbing fixtures must be installed, and all traps need to be filled with water. In some cases, the building's HVAC system and exhaust fans will need to be turned off. Finally, the building must be completely vacant. There may be no breaches in the enclosure during the test. If any seal is broken, the test will be restarted. ASTM designates several methods that are used in testing the air barrier of various types of buildings.

ASTM E 2178 is the Standard Test Method for Air Permeance of Building Materials. This standard is used to determine the air permeance of materials in the air barrier at many pressure differentials. The objective of the test is to assign an air permeance rate to the material at a reference pressure difference of 75 Pa (0.3 iwg). ASTM E 2178 also intends to assess any flexible sheet or rigid panel material using a specimen size of one square meter. The U.S. Army Corps of Engineers maintains that the air permeance of the materials used in the air barrier must not exceed 0.004 CFM/sq ft @ 0.3 iwg [0.02 L/s.m^2 @ 75 Pa] when tested in accordance with ASTM E 2178. This test method requires that no less than five specimens of a material shall be tested unless otherwise specified by the manufacturer of a product. Specimens used in the test shall remain at a temperature of 19° to 21° C and 35% to 45% Relative Humidity for a minimum of seven days prior to testing. The leakage rate test is conducted over six pressure differentials ranging from 25 Pa to 300 Pa. The air permeance rate to be referenced should be at a pressure differential of 75 Pa. This standard is used when determining the air permeance of a material (ASTM E 2178, 2003).

ASTM E 1677 defines an air barrier as a material or system in building construction that is designed and installed to reduce air leakage either into or through all exposed areas of a wall that enclose conditioned space, except openings for windows, doors, and building service systems. This is the standard specification for the minimum performance requirements of an air barrier material or system for low-rise framed building walls. (ASTM E 1677, 2005) An air barrier material must have an air permeance not to exceed 0.2 L/s.m^2 @ 75 Pa [0.04 CFM/sq ft @ 0.3 iwg] when tested in accordance with ASTM E 1677. (Anis, 2007) The objective of the standard is to allow for the proper design of a building's walls to accommodate different climates or functions. It focuses on air barriers used in opaque walls. An opaque wall is any exposed area of the building's air barrier that encloses the conditioned space, except for windows, doors, and building service systems. Areas such as a building's roof, floors, and interfaces are not covered in ASTM E 1677. This standard provides procedures for testing building walls for air leakage, structural integrity, and water resistance (ASTM E 1677, 2005).

ASTM E 1827 is the Standard Test Method for Determining Airtightness of Buildings Using an Orifice Blower Door. This test method uses an orifice blower door to pressurize the building envelope in such a way that airflow may be measured. The measurement of airflow over the building envelope will provide a measurement of its airtightness. It defines an orifice blower door as a blower door in which airflow rate is determined by means of the pressure drop across an orifice. Figure 1 provides an example of a fan blower door. This test method must be implemented in small indoor-outdoor temperature differentials along with low wind pressure conditions. Any extreme of either case would provide inaccurate test results. ASTM E 1827 is used to determine the leakage rate of the envelope. Fan airflow rate measurements are made at one or more pressure stations during mechanical depressurization or pressurization of a building zone. These measurements are used to determine the air leakage characteristics of the building envelope. It is important to properly define the envelope zone that is to be tested prior to preparing the building for the test. All operable openings outside the intended zone must be closed or sealed airtight while conducting the test. Proper wind speed and temperature measurements must also be recorded during the test. The blower door will pressurize or depressurize the building envelope zone, and measurements may be taken (ASTM E 1827, 1996). The U.S. Army Corps of Engineers requires that an air barrier system accomplish this test in both pressurization and depressurization. When the building envelope is tested using ASTM E 1827, the air barrier's permeance must not exceed 0.25 CFM/sq ft @0.3 iwg (Building air tightness, 2009).

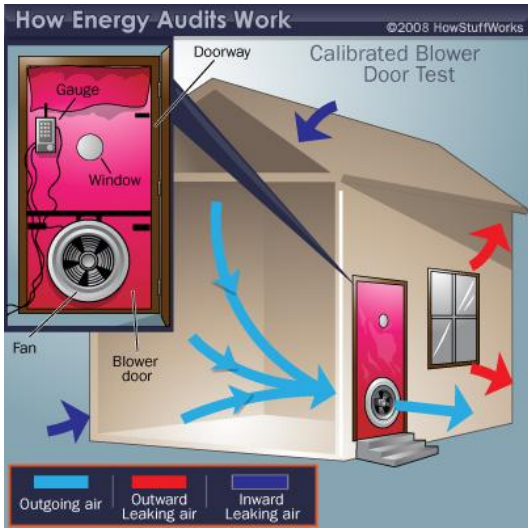

Figure 1: Fan Blower Door.

ASTM E 779 is the Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. It covers the standard method for testing the air leakage rates of a building envelope using fan pressurization. This test is very similar to ASTM E 1827. ASTM E 779 tests the air tightness of the envelope of a single zone building. Fan pressurization is used to determine air leakage rates in the envelope. The range of pressure differentials used in this standard is 10 Pa to 60 Pa. The magnitude of the pressure difference depends on the capacity of the air handling equipment (ASTM E 779, 2003).

ASTM E 1186 covers Standard Practices for Air Leakage Detection in Building Envelopes and Air Barrier Systems. This standard is used when locating areas of the air barrier that allow leakage. It covers infrared thermography, building and test chamber pressurization/depressurization, smoke generation techniques, sound detection, and gas concentration measurement techniques. In the practice of using infrared thermography, there must be an indoor/outdoor temperature difference of at least 5° C (41° F). The process requires that outdoor air be moved through the building by depressurizing the interior. The building's HVAC system or test method ASTM E 779 (Fan Pressurization) is used to depressurize the interior of the building. Due to the temperature difference in locations where air is leaking, the infrared camera is able to visually distinguish these areas from others on the surface. This will identify flaws in the air barrier. The same process may be done in reverse, by pressurizing the envelope and scanning the inside. This is also a required test of the U.S. Army Corps of Engineers (ASTM E 1186, 2009).

ASTM E 283 is the Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen. This is the method used for the laboratory testing to determine the air leakage rates of exterior windows, curtain walls, and doors. Constant temperature and humidity must be maintained for the duration of the test. The test specimens must be sealed into an air chamber in order to maintain a pressure differential used in determining the leakage rate (ASTM E 283, 2004).

Many different materials can make up the components of the air barrier system. The performance of the air barrier assembly is more important than the performance of the individual materials used in the system (ABAA, 2009). Materials in the air barrier system must be assembled so that they meet the air permeance requirements of ASTM E 2178 (ASTM E 2178, 2003). Many air barrier systems include a vapor barrier system used in reducing the amount of vapor that is able to leak into the building. The function of an air barrier is different than that of a vapor barrier. Vapor barriers are not always continuous barriers, while an air barrier is continuous over the entire building envelope. Vapor barriers are intended to obstruct the flow of water vapor under the conditions specified. Water leakage is important in the testing of the air barrier. The penetration of water onto the exterior plane of framing or insulation under the specified conditions of air pressure difference across the air barrier is also monitored during the performance test.

U.S. Army Corp of Engineers Air Leakage Test Protocol

In 2010, a standard test protocol for measuring air leakage in buildings on U.S. Army Corps of Engineers projects was developed by a team at the Construction Engineering Research Laboratory at the U.S. Army Engineer Research and Development Center (WBDG, 2012). The team included US Army Corps of Engineers researchers, as well as consultants from various firms leading the nation in architectural testing. The objective of this standard was to provide testing agencies across the nation with a protocol for thermal performance testing on US Army Corps of Engineers (USACE) projects. By implementing a standard protocol, the researchers have aided in furthering the understanding of air barrier testing for USACE representatives, as well as consultants that are capable of performing the test. It is not a requirement in USACE contracts that the testing agencies be certified to implement the standard test protocol currently, but will likely be in future contracts. The protocol mainly provides the consulting firms with knowledge of the thermal performance requirements of the facilities. The standard test protocol was also implemented in order to provide the Government Project Delivery Team with an understanding of the need for thermal performance requirements, and a knowledge of the testing and results that must be fulfilled on the building envelope. Sample test forms and generic reports are provided in the protocol so that there may be some similarity in thermal performance test reports generated on all USACE projects.

The US Army Corps of Engineers Air Leakage Test Protocol for Measuring Air Leakage in Buildings describes the various ASTM standard test methods for thermal performance testing. It also provides a summary of the key differences in the tests that are specified in various contracts. Examples and specifications of equipment that is required to complete the ASTM standard testing are illustrated as well. This protocol was designed to unite the understanding of air barrier testing for testing agencies, as well as the Government Project Delivery Team assigned to witness and ensure that the contract requirements are met (WBDG, 2012).

Conclusions

A major factor in the success of a thermal performance test is ensuring that all parties understand exactly what is required of the building envelope. The requirements in the contract are very specific and if carried out, a pass compliant test will result with little difficulty. Once the requirements of the contract are understood, it is important for the designer to properly identify the building envelope. The designer and contractor must then ensure that the materials to be used in the air barrier meet the requirements of the RFP. After the building envelope has been established, the contractor’s quality control agent must ensure that the builders understand what it will take to properly seal the building. During the preparatory meetings, the QC must stress the importance of sealing repetitively deficient areas. The QC may also take as much precaution as hiring a building envelope consultant to provide quality assurance of the air barrier. These building envelope consultants can also provide valuable suggestions on any additional precautions that can be made to ensure a pass compliant test result.

If the contractor, designer and owner all understand the thermal performance requirements set forth in the contract, construction of an airtight envelope will not be difficult. Much planning and preparation must be done in order to ensure that the envelope will meet the permeance requirements. By putting effort on the design phase of the project, the contractor will be able to save time and money on the construction of the facility. According to Dalgleish (2008), enhancing the air barrier quality control/assurance program will only cost about 2.75 percent of the air barrier contract. This paper further impresses upon the fact that proper planning and quality control will allow for the construction of an air barrier that meets all of the thermal performance requirements of the U.S. Army Corps of Engineers. As the USACE requirements become more stringent, it will be important for designers and contractors to ensure that the proper approach is taken when constructing the air barrier.

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