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U.S. Army Corps of Engineers Air Leakage Test Protocol for Measuring Air Leakage in Buildings

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1 Introduction

The 2005 Energy Policy Act requires that Federal facilities be built to achieve at least 30 percent energy savings over the 2004 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2004. The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) of the U.S. Army Corps of Engineers (USACE), in collaboration with Headquarters, USACE and centers of standardization for respective building types, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), and the ad hoc ASHRAE Military Technology Group has developed design guides to help U.S. Department of Defense (DOD) facilities achieve at least 30 percent energy savings over a baseline built to the minimum requirements of the ASHRAE Standard 90.1-2004 for new buildings to be constructed under the Military Transformation Program.

The design guides were completed in 2007 and 2008, and pertain to building types that include barracks ("Unaccompanied Enlisted Personnel Housing," or UEPH), trainee barracks, administrative buildings (e.g., a battalion headquarters, a company operation facility), a maintenance facility, a dining facility, a child development center, and an Army reserve center.

Among the major factors contributing to mold prevention and reduced energy use in all climate zones is air leakage through the building envelope. Over the past several years, ERDC-CERL has conducted building envelope leakage tests on existing facilities to gain a better understanding of the general leakiness of Army buildings, and to analyze the effect of increased air tightness on building energy consumption, and to develop air tightness criteria and performance requirements to include in design/construction strategies.

Based on the results of these studies USACE set a requirement that all new buildings and buildings undergoing major renovation shall pass an air leakage test, the results of which must be less than or equal to 0.25 CFM/sq ft of exterior envelope at 0.3 in. of water gage (75 Pa) pressure difference. The test is to be performed as outlined in the protocol developed by ERDC-CERL together with industrial partners. Depending on the climate, the total building energy cost savings due to improved building air tightness can range from 5 to 25 percent.

Since introduction of the requirements to air barrier and a maximum allowable air leakage rate, several Army buildings were constructed and tested for air tightness. Some of them were proven to have an air leakage rate between 0.16 and 0.25 CFM/sq ft at a pressure difference of 0.3 inches of water gage (75Pa). Few buildings have to be sealed and re-tested to meet these requirements. This experience has shown that, when buildings are designed and constructed with attention to details, they can meet U.S. Army requirements for air tightness with only a minimal cost increase (due primarily for development of architectural details and testing).

2 USACE Requirements For Building Air Tightness

The following sections outline USACE requirements for building air tightness and building air leakage testing for new Army construction:

2.1 Building Air Tightness Requirement

Design and construct the building envelopes of office buildings, office portions of mixed office and open space (e.g., company operations facilities), dining, barracks and instructional/training facilities with a continuous air barrier to control air leakage into (or out of) the conditioned space. Clearly identify all air barrier components of each envelope assembly on construction documents and detail the joints, interconnections and penetrations of the air barrier components. Clearly identify the boundary limits of the building air barriers, and of the zone or zones to be tested for building air tightness on the drawings.

Trace a continuous plane of air tightness throughout the building envelope and make flexible and seal all moving joints. The air barrier material(s) must have an air permeance not to exceed 0.004 CFM/sq ft at 0.3 in. wg [0.02 L/s.m^2 @ 75 Pa] when tested in accordance with American Society for Testing and Materials (ASTM) E 2178. Join and seal the air barrier material of each assembly in a flexible manner to the air barrier material of adjacent assemblies, allowing for the relative movement of these assemblies and components.

Support the air barrier so as to withstand the maximum positive and negative air pressure to be placed on the building without displacement, or damage, and transfer the load to the structure. Seal all penetrations of the air barrier. If any unavoidable penetrations of the air barrier by electrical boxes or conduit, plumbing, and other assemblies are not air tight, make them air tight by sealing the assembly and the interface between the assembly and the air barrier or by extending the air barrier over the assembly. The air barrier must be durable to last the anticipated service life of the assembly. Do not install lighting fixtures with ventilation holes through the air barrier

Provide a motorized damper in the closed position and connected to the fire alarm system to open on call and fail in the open position for any fixed open louvers such as at elevator shafts. Damper and control to close all ventilation or make-up air intakes and exhausts, atrium smoke exhausts and intakes, etc when leakage can occur during inactive periods. Compartmentalize garages under buildings by providing air-tight vestibules at building access points. Provide air-tight vestibules at building entrances with high traffic.

Compartmentalize spaces under negative pressure such as boiler rooms and provide make-up air for combustion.

2.2 Building Air Leakage Testing – Performance Requirement and Substation:

1. Submit the qualifications and experience of the testing entity for approval.
2. Demonstrate performance of the continuous air barrier for the building envelope by the following tests:
    a. Test the completed building and demonstrate that the air leakage rate of the building envelope does not exceed 0.25CFM/sq ft at a pressure differential of 0.3 in. wag (75 Pa) in accordance with ASTM E- 779 (2003) or E- 1827-96 (2002). Accomplish tests using BOTH pressurization and depressurization. Divide the average measured air leakage flow rate in both directions in CFM @ 0.3 in. wag (L/s @ 75 Pa) by the surface area of the envelope enclosed by the continuous air barrier of the building, including roof or ceiling, walls and floor to produce the air leakage rate in CFM/sq ft @ 0.3 in. wag (L/s.m2 @ 75 Pa). Do not test the building until verifying that the continuous air barrier is in place and installed without failures in accordance with installation instructions so that repairs to the continuous air barrier, if needed to comply with the required air leakage rate, can be done in a timely manner.
    b. Test the completed building using Infrared Thermography testing. Use infrared cameras with a resolution of 0.1 °C or better. Perform testing on the building envelope in accordance with International Organization for Standardization (ISO) 6781:1983 and ASTM C1060-90(1997). Determine air leakage pathways using ASTM E 1186-03 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier

Systems, and perform corrective work as necessary to achieve the whole building air leakage rate specified in (a.) above.

c. Notify the Government at least 3 working days before the tests to provide the Government the opportunity to witness the tests. Provide the Government written test results confirming the results of all tests.

Existing buildings undergoing major renovations (especially the ones located in cold or hot and humid climates) shall be sealed to the same standard as newly constructed ones.

3 Specifier and Witness Guidance

3.1 Application and Scope

Use this Guide to gain a general understanding of the air leakage test, how it should be specified, and how to monitor whether the air leakage test has been properly performed. This air leakage test specification and the required pass/fail result must be applied to the entire exterior enclosure area as a single entity. See the included glossary (p 26) for definitions. In many circumstances, it is useful (but not currently required) to isolate components such as individual walls or floors to diagnose more closely the source of air leakage. In the future, individual components such as horizontal floor slabs may have their own more stringent requirements, but for now, only the air leakage of the entire exterior envelope is measured.

The architect or design engineer is responsible for defining the bounds of the enclosure and for calculating its surface area to be used in the results calculation. The surface area will include the floor, walls/fenestrations, and roof/ceiling. This enclosure is often the "exterior envelope" of the building, but does not always include all exterior walls. Of interest is the functional "air barrier" for the enclosure under test, which may not be the exterior envelope. For example, heating, ventilating, and air-conditioning (HVAC) rooms with large louvers open to outdoors, laundry rooms with dampers opening to outdoors, and loading docks with overhead coiling may be outside the air barrier enclosure if the design dictates such. This would force their interior walls to be insulated and air sealed to the same standard as other parts of the enclosure that face the outdoors.

The boundary of the air barrier must be clearly defined in the project drawings. Once properly considered by the design professional, the calculated surface area of the air barrier should be indicated on the design drawings.

For buildings where doorways from each apartment, office, meeting room, or other area that open from a common hallway or zone and not at the air barrier boundary, the entire building air barrier system must be tested as a whole.

For buildings where doorways of each apartment/office/room lead to the outdoors (i.e., where there is no direct interior connection between all the rooms), each apartment/office/room must be tested individually. Walls abutting adjacent apartments are to be treated as part of the envelope in spite of the fact that an argument can be made that leakage of the adjacent walls would be to another conditioned apartment and could therefore be ignored. To allow for efficient testing, common walls will be treated as part of the total envelope for the apartment and each apartment must pass the criteria. In multi-unit apartments, each style of apartment must be tested, including all corner rooms, and at least 20 percent of all other apartments must be tested.

Buildings over 500,000 sq ft. of envelope area may require special test techniques not covered in this protocol. The building may have to be broken up into zones separated using boundary pressure neutralization techniques or by the erection of temporary walls. In other cases, the use of the building HVAC or large truck mounted fans may be required to establish useful test pressures. These special techniques will require a higher level of experience and engineering to establish useful results. It is up to the specifier to establish conformance criteria and test procedures for these unique buildings. The Canadian General Standards Board (CGSB) standard CAN/CGSB-149.15, "*Determination of the Overall Envelope Airtightness of Buildings by Fan Pressurization Method Using the Building's Air Handling Systems*" could be referenced by the specifier and used by the testing agency. However, the importance of air tightness should not be lost on buildings with enclosures over 500,000 sq ft.

3.2 Air Leakage Specification

The air leakage test specification could be written as follows:

> The air leakage test must be performed in accordance with ASTM E- 779 with the following additions and exceptions shown below.

The test consists of measuring the flow rates required to establish a minimum of 12 positive and 12 negative building pressures. The lowest test pressure shall be 25 Pa; the highest test pressure shall be 75 Pa; and there must be at least 25 Pa difference between the lowest and highest test pressures. The test pressure must be measured in a representative location such that pressures in the extremities of the enclosure can be shown to not exceed ∀10% of the measured test pressure. At least 12 bias pressure readings must be taken across the envelope and averaged over at least 20 seconds each before and after the flow rate measurements. None of the bias pressure readings must exceed 30 percent of the minimum test pressure when testing in both directions. Where it can be shown that it is impossible to test in both directions, then the building may be tested in the positive direction only, provided the bias pressure does not exceed 10% of the minimum test pressure.

The mean value of the air leakage flow rate calculated from measured data at 0.3 in wg (75 Pa) must not exceed 0.25 cu ft/ minute per square foot of envelope area (0.25 CFM75/ft^2) and the upper confidence limit as defined by ASTM E-779 must not exceed (0.27 CFM75/ft^2) or the upper confidence limit must not exceed (0.25 CFM75/ft^2). Measurements must be referenced at standard conditions of 14.696 psi (101.325 KPa) and 68F (20°C). The envelope area is to be supplied and/or confirmed by the architect of record (AOR).

Additional information for the specifier

The Testing Agency Guide provides detailed information as to exactly how the test must be performed. The Air Leakage Test Form details the exact procedure that the testing agency followed. A completed test must consist of all pages of the Air Leakage Test Form with required attachments plus a seventh page titled Air Leakage Test Results, upon which the testing agency must make a pass or fail declaration.

Of note to anyone specifying the air leakage test, or under the requirement of an air leakage test, is that:

1. The test is conducted with ventilation fans and exhaust fans turned off and the outdoor air inlets and exhaust outlets sealed (by dampers or masking). In some cases, recirculating air handlers may also need to be turned off. The contractor must provide a responsible HVAC technician with the authority to place the HVAC system in the correct mode for the pressure test. The testing agency must have unhindered access to mechanical rooms, air handlers, exhaust fans, and outdoor air and exhaust dampers.
2. Portable pressurization door fans manufactured for the purpose of pressure testing buildings often require significant electrical power (e.g., 20 amps) and may trip circuit breakers. The contractor must have someone on site with access to and the authority to reset circuit breakers or must have access and authority granted to them.
3. Airflow and enclosure pressure differences are drastically affected when exterior doors or windows are opened. At the time of the test, if subcontractors are still working in the building, the contractor must ensure that all windows in the bounding enclosure are kept closed. Entry and exit through doors in the test enclosure must be eliminated during the test. Data collected while the pressures and flows are affected by a door opening and closing must be discarded.
4. Portable fan pressurization doors are placed in doors or windows in the bounding enclosure. The testing agency must have access to these locations, be able to open them, and to remove closure hardware that interferes with equipment set-up.
5. The contractor shall ensure that no sub-contractors are working in the area of the fan pressurization test equipment. During pressurization tests, air will be blown into the building at high enough velocity that it will cause debris, dust, and litter to become air borne. When exhausting nearby debris and litter may be drawn to the fan guards or become entangled in fan blades where it can block airflow and result in erroneous measurements.
6. The fan pressurization test to determine final compliance with the airtightness requirement shall be conducted when all components of the air barrier system have been installed and inspected, and have passed any

intermediate testing procedures as detailed in the construction drawings and specifications. The test may be conducted before finishes that are not part of the air barrier system have been installed. For example, if suspended ceiling tile, interior gypsum board, or cladding systems are not part of the air barrier system, the test may be conducted before they are installed.

7. The testing agency is required to perform a diagnostic evaluation in accordance with ASTM E1186, whether the building achieves the air tightness requirement or not. The diagnostic evaluation will assist the contractor and responsible parties in identifying and eliminating air leakage so the building meets the requirement upon re-testing. The testing results will also be expressed in terms of the Equivalent Leakage Area (EqLA) at 75 Pa. The EqLA is a the equivalent area of a flat plate that leaks the same amount as the building envelope at 75 Pa. This information helps those responsible for further sealing the envelope know the approximate size of total hole area they should be seeking. Air leaks can consist of many small cracks, or a few very large openings or a combination of both. It is not unusual for large buildings to have a leakage area of up to 100 sq ft. Is also common for air sealing efforts to be focused on the small cracks while large holes that are a major contributor to failing the test, go unnoticed. Even if the building achieves the air tightness requirement, a diagnostic evaluation should be conducted to help the construction team identify additional areas of leakage that could be sealed on the current building or similar future buildings.

4 Testing Agency Guide

4.1 U.S. Army Corps of Engineers (USACE) standard for air leakage

The USACE requires all new buildings to pass an air leakage test where the results are less than or equal to 0.25 CFM/sq ft of exterior envelope at 75 Pa pressure at standard conditions.

4.2 USACE Procedure

The following sections provide useful background information that will give the testing agency more information so that they can more easily understand the step-by-step approach in the Air Leakage Test Form and the Air Leakage Test Form Guide. This test protocol was developed by the U.S. Army Corps of Engineers with assistance from the private industry using ASTM E- 779-03 as a basis. This protocol includes modifications and adjustments needed to account for the potential for bias pressures (due to wind and stack) that are found in high-rise buildings and unobstructed environments, and to strike a balance between accuracy, repeatability and ease of use with a variety of test equipment, test methods, and testing agencies. The section titled “Technical Justification for Differences with ASTM” (p 22) documents the main deviations from ASTM and the reasons why such deviations may occur.

4.3 Application and Scope

See the “Application and Scope” under the Specifier’s Guidance section.

The four-story building shown in Figure 1 (top left) has an enclosure that is described by the shape (bottom left top right), and that is accessed by an exterior stairway with no direct interior connection between floors. It therefore must be tested with multiple door fans simultaneously to measure the total enclosure leakage (top right bottom left). Note that a variety of fan setups are allowed under this protocol as long as a single zone with uniform pressure differentials is achieved.

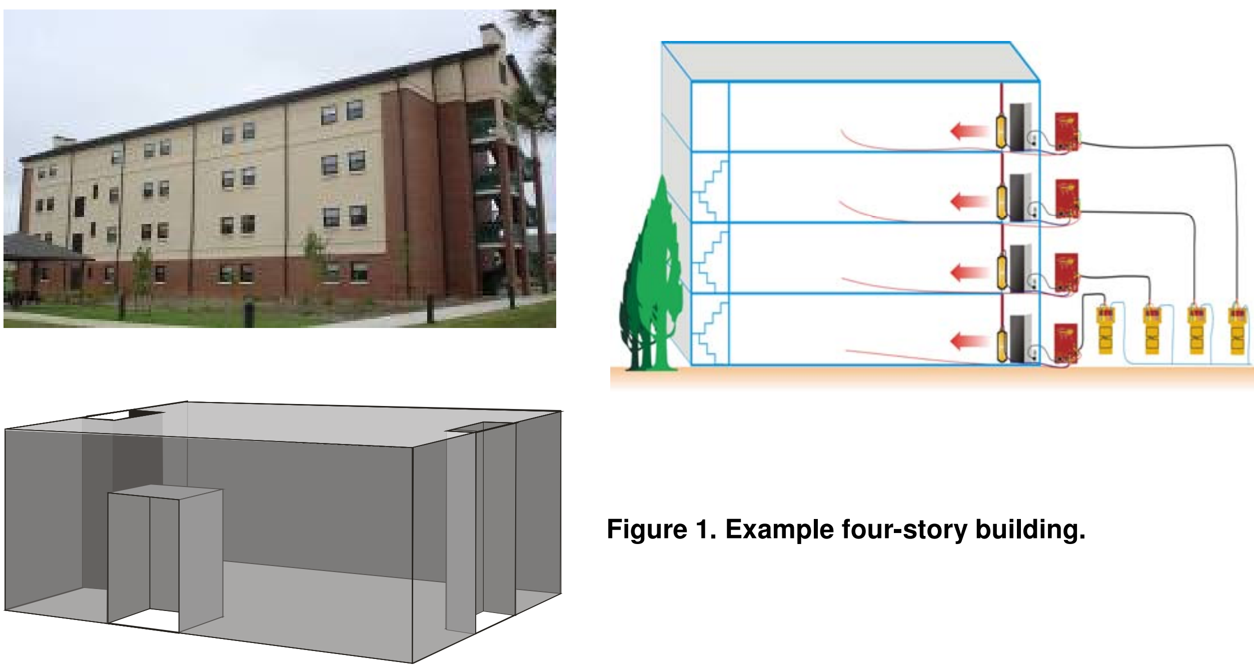

Figure 1. Example four-story building.

In buildings where individual apartments have doors to the outside (Figure 2, top left), the test must be performed on an individual apartment with the adjacent apartments open to outdoors. Perform door fan tests on all corner apartments plus a random 20 percent of those remaining. If they all pass then it can be assumed the rest of the apartments would also pass. Should any one apartment fail, an additional apartment must be added for each failure to the test until at least 90 percent of the tested units pass.

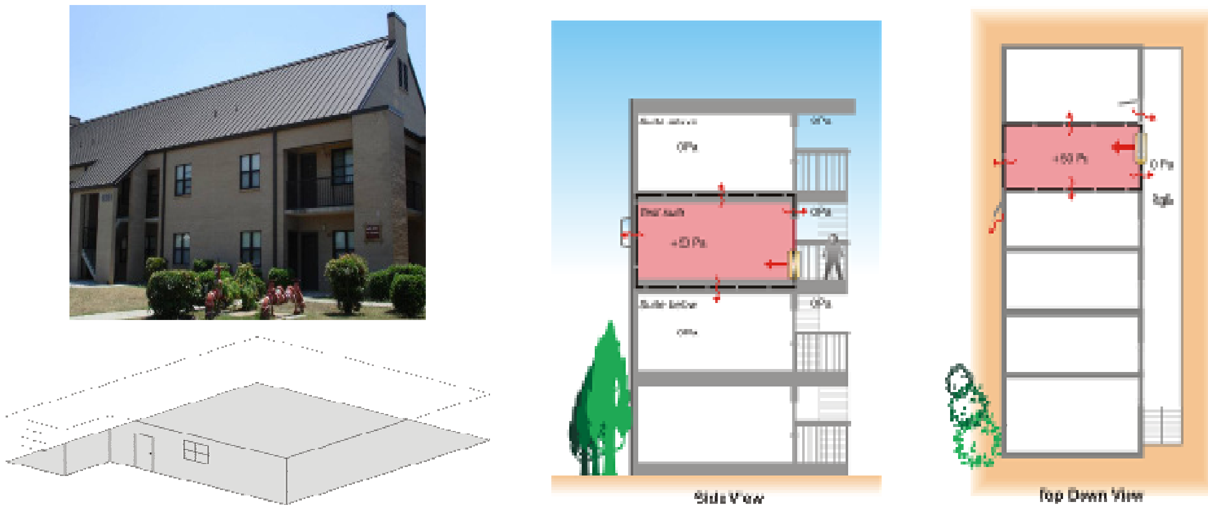

Figure 2. Example building where individual apartments have doors to the outside

4.4 Equipment Selection

Since a passing building requires the envelope to attain a leakage rate of 0.25 CFM/sq ft of envelope or less, multiply the envelope square footage that will be tested by 0.25 to get the approximate “passing” CFM needed at a 75 Pa pressure. Using the fan equipment manufacturer’s literature, you can select the amount of airflow-producing equipment needed to perform the test. Portable fans that can test in both positive and negative directions must be used unless it can be shown that it is impossible to do so. The testing agency must have sufficient airflow-producing equipment to achieve at least 100 percent of the required passing CFM under the 0.25 requirement.

For example, if the building had 100,000 sq ft of envelope area, then it would require 100,000 x 0.25 = 25,000 CFM to be supplied by the testing agency. This generally requires the simultaneous operation of multiple portable fans and pressure monitoring equipment strategically placed throughout the building. If the specifications call for an air leakage requirement that is relaxed to a greater leakage rate such as 0.75 CFM/sq ft for special buildings (i.e., storage facilities with overhead coiling doors), then the testing agency should use the 0.25 value as a minimum fan capacity required for the test. Building HVAC systems may be used to measure envelope leakage in some cases where a proficient testing agency is capable of measuring air flows through outdoor air and exhaust ventilation equipment using:

- Pitot tube or hot wire anemometer traverse.
- Pressure compensated shrouds (which work well on rooftop exhaust units, and which are very accurate because they include air from duct leakage as well as through grilles).
- Tracer methods for measuring airflows in ducts (ASTM 2029 Volumetric and Mass Flow Rate Measurement in a Duct Using Tracer Gas Dilution). NOTE: Tracer decay, constant injection and constant concentration methods for estimating total ventilation rate of the test zone itself are prohibited.
- Outdoor air flow stations may be used if one of the above methods is used to check accuracy at least on air flow for each station, or if the design of the HVAC system specifically placed outdoor air flow stations in good measurement locations that are field verified.

For whole building tests on buildings with air handling systems that have been designed to provide accurate outdoor airflow stations or for very large buildings, with over 500,000 sq ft of envelope, this may be the practical option.

The standard CAN/CGSB-149.15, *Determination of the Overall Envelope Airtightness of Buildings by Fan Pressurization Method Using the Building's Air Handling Systems* could be referenced and used by the testing agency. In the hands of experienced personnel, reasonable results may be achieved, but note that accuracies have been no better than ∀20 percent when 75 Pa was achieved.

It may be possible to isolate and test individual floors for buildings in excess of four stories, if the testing agency's equipment is not capable of achieving a full building uniform pressure due to the geometry of the interior partitions and limited shaft areas. However, the floor-by-floor method requires exceptional preparation and knowledge of airflow characteristics within chases, shafts, and wall cavities, in addition to maintaining an identical or balanced pressure at the floors above and below. Refer to the ASHRAE study, *Protocol for Field Testing of Tall Buildings to Determine Envelope Air Leakage Rate 935-RP* (Bahnfleth 1998) for additional information on the floor-by-floor method of testing. It is recommended that the whole building achieve a uniform pressure to avoid the uncertainty inherent in the floor-by-floor method, but this protocol does not prohibit the application of the floor-by-floor method as an option for buildings greater than four stories in height.

Pressure gauges must be digital and accurate to within ∀1 percent of reading or ∀0.25 Pa, whichever is greater, and must have adjustable time averaging to compensate for wind. Calibrated fans must be accurate to within ∀5 percent of the flow reading. Sufficient tubing must be available so that all gauges used can be manifolded together and referenced to the same outdoor pressure. These tubes will be connected to the negative port of all gauges. Tubing must also be available to run from the center of each separate test zone to the positive port of a gauge.

A minimum of one exterior pressure monitoring station is required. The testing agency is allowed to use additional exterior pressure monitoring stations, especially if bias pressures exceed the values stipulated in Section 4.5 of the Air Leakage Test Form.

The pressure difference between interior zones shall be monitored to determine whether pressure differences between interior locations are within 10 percent of the indoor-outdoor pressure difference during all tests or not. If they are not, then adjustments to test set-up shall be made until they are within 10 percent. Interior pressure difference measurements shall be referenced to a single interior zone that is unaffected by velocity pressure created by test equipment. Thus, at an average 75 Pascal pressure difference across the enclosure, the difference between the highest and lowest interior pressure difference measurements should be within 15 Pascals of each other. The number of indoor pressure difference measurements required depends on the number of interior zones separated by bottle necks that could create significant pressure drops (e.g., doorways and stairwells).

4.5 Pre-Test Inspection

A pre-test inspection must be performed to determine whether there is something that would prevent the test from being completed. Check local weather forecasts for rain or strong winds before travelling to the test site. Ensure that the test equipment has arrived at the test site on time, and that it is in operable condition. The operation of the equipment is the simplest part of the test, whereas preparing the building is the most complex, takes the most time, and is the most likely factor to prevent the testing agency from completing the test.

4.5.1 Record Set-up Conditions

Accurately record the exact set up conditions. Pictures should be taken of representative setup conditions and should be attached to the final report. The intent of this protocol is to ensure buildings are set-up and prepared in an identical manner so the tests are repeatable. The testing agency is responsible to ensure the building is properly prepared and maintained throughout the test, but the contractor typically performs the actual preparation labor described below.

4.5.2 Preparation of the Building

Seal or otherwise effectively isolate all “intentional” holes in the building enclosure. This includes air intake or exhaust louvers, make-up air intakes, pressure relief dampers or louvers, dryer and exhaust vent dampers and any other intentional hole that is not included in the air barrier design or construction. Intentional openings can be sealed by using an air-tight film or by motorized or manual dampers held in the closed position.

NOTE: Exterior windows and doors (fenestrations) are not intentional openings. Fenestrations are included in the air barrier test boundary. Exterior windows and doors shall be in the closed and locked position only; no additional films or additional means of isolation at fenestrations is allowed.

Ensure that all plumbing traps are filled with water.

The HVAC system must be shut down or disabled for the duration of the test. If the HVAC system activates during the test, additional air movement across the enclosure is introduced and is not measured by the agency, resulting in inaccurate data.

All interior doors that access the building enclosure (roof, walls and fenestrations, floor) must be held open during the test to create a single uniform zone. If the door services only an interior room such as a storage closet, it is allowed to remain closed only if a dropped ceiling plenum is present above and it does not access an air barrier boundary. If doorways cannot be opened and the volume on the other side of the door is considered to be within the envelope, then the pressure across that doorway must be measured with the door fan running to ensure that the pressure on the other side of the door, as measured with an under door probe, is within ∀10% of the average building pressure.

Buildings with a dropped ceiling plenum must have tiles removed at a rate of one per every 500 sq ft. Additional tiles may be removed at the discretion of the testing agency so a uniform pressure distribution in the plenum space is achieved.

Combustion equipment must be disabled or be in the “pilot” position.

If the test zone is within a larger building enclosure such as a Tactical Equipment Maintenance Facility or Company Operations Facility, the areas outside of the test zone must be at ambient (outdoor) conditions. This can be achieved by open man-doors or overhead coiling doors in the open position.

Optional: Set-up the door fan and run preliminary test

If using door fans to pressurize the air barrier, perform a test with only one door fan. Occasionally, no additional testing will be required, as a preliminary test can help determine the following:

1. The quantity of additional door fans needed to achieve the desired test pressure.
2. A rough estimate as to whether the enclosure could pass, which may force the testing agency to spend more time investigating enclosure problems, instead of using time to verify an obvious failing enclosure.

For the preliminary test:

1. Record interior and exterior weather conditions
2. Record average and maximum wind speed and direction at least 5-feet off the ground and 25-feet away from the building in the direction of the wind.
3. Record interior and exterior temperatures before and after the test.
4. Record site elevation in feet above sea level.
5. Perform a multi-point test in both directions from at least + 25 to + 50 Pa, then - 25 to - 50 Pa.

Because this test is performed by pressurizing and depressurizing the air barrier envelope, bias pressure effects are minimized, yielding more accurate results. This is the preferred test method since it is not only more tolerant of test conditions, but also gives a more accurate representation of the envelope leakage under ambient conditions, where pressures can be either positive or negative in direction. Bias pressures may be up to 30 percent of the lowest test pressure, allowing this method to be used in a wider range of weather conditions. If fan power is sufficient, then testing up to 75 Pa would be even more accurate and would allow tests to be completed where bias pressures were higher.

The testing agency must achieve at least 50 Pa, but there is no requirement that it must achieve a maximum pressure of 75 Pa. The agency is encouraged to achieve the highest building pressure possible, but should not exceed 75 Pa.

It is noted that some buildings will have air barrier systems that have not been properly designed and/or installed, resulting in the maximum building pressure being less than 50 Pa. Although the building does not meet the air leakage requirement of 0.25 CFM/sq ft, the testing agency must still perform a multi-point test in general accordance with this protocol so an approximate air leakage value can be provided to the prime contractor. This will allow them to estimate the magnitude of the repairs necessary to meet the air leakage requirement.

4.6 Reporting of Results

The data collected during the multi-point tests will be corrected for standard conditions and used to determine the air leakage coefficient, *C*, and the pressure exponent, *n*, in accordance with ASTM E779-03, from:

$$CFM = C * \Delta P^{n}$$

In general, the *C* and *n* values are obtained by plotting the data in log-linearized fashion to obtain a curve fit that will produce the required coefficients. The testing agency must use a minimum of 12 data points from each test, but is not limited to the maximum number of data points taken during the test. It is recommended to take additional data points so in the analysis the "outliers" can be omitted from the calculation procedure. Outliers are most frequently caused by wind gusts, changes in wind direction at the time that data pair was recorded, among other reasons.

One flow rate must be calculated for both the pressurization and depressurization tests at a ΔP of 75Pa (CFM@75Pa). The average of those CFM values will be divided by the enclosure area given in the project drawings to determine the normalized air leakage rate. This average value will be used as the basis for determination if the building meets or does not meet the requirement of 0.25 CFM/sq $ft_{envelope}$@75-Pa. The value is to be rounded to the nearest hundredth. Therefore, a value of 0.255CFM/sq ft does not meet the USACE requirement.

In addition to reporting the normalized air leakage as CFM/sq $ft_{envelope}$@75Pa, the agency is also required to report the correlation coefficient (r^2) and 95 percent Confidence Intervals (95%CI) to determine the accuracy of the data collected and the quality of the relationship between flow and pressure that was established during the test. The 95%CI should be calculated in strict accordance with the methodology contained in ASTM E779-03 and the r^2 value can be obtained by data analysis of the plotted data.

In general, a narrower 95%CI to the mean value and higher r^2 value indicates a clear relationship for the building's air leakage characteristics was established. For the collected data to be statistically significant, the 95%CI must not exceed ∀0.02 for mean values of 0.25 or less, which equates to approximately 8 percent. For example, if the calculated mean value is 0.25 and the 95%CI is shown to be 0.23 to 0.27, the test data is statistically significant. However, if the mean value is 0.25 and the 95%CI is 0.16 to 0.33, this exceeds 0.02 and indicates that the data is not statistically significant, and that a clear relationship between flow and pressure was not established during the test; the test must be repeated. In cases where the 95%CI exceeds ∀0.02, but the upper limit is 0.25 or less, the test would be considered a pass in spite of the statistical insignificance because there is a strong likelihood that the building passes the requirement. Likewise, the r^2 value must be above 0.98 for the data to be statistically significant. Test data should have correlations above 0.99.

Similarly, the pressure exponent, *n*, will also provide some insight as to the accuracy of the test and relative tightness of the building enclosure. Exponent values less than 0.5 or greater than 1.0 in theory indicate a bad test, but in practice, tests outside the range of 0.45 to 0.8 would generally indicate an inaccurate test or calculation methodology. The reason comes down to basic fluid dynamics and the characteristics of developing airflow through orifices, which is too lengthy to discuss within this protocol. Except for very rare circumstances, *n* values should not take on values less than 0.45 or greater than 0.8. If the *n* value exceeds these boundaries, the test must be repeated. In general, an *n* value closer to 0.5 indicates large holes that are much shorter in length than they are wide, where an *n* value above 0.65 indicates the hole characteristics that are smaller cracks or holes that are much longer than they are wide. Most "tight" residential homes exhibit an *n* value of 0.60 to 0.65, where larger buildings will likely have an *n* value slightly less.

The testing agency is required to produce the data used in the analysis and results in tabular and graphical form, including the curve fitted coefficients and correlation coefficient.

Several common conditions that will cause test results to be very low are:

1. Interior pressure monitoring stations are placed too close to direct air flow that is typically produced by the test fans.
2. Usually tests are conducted with the fan orifice fully open, allowing maximum airflow. For testing smaller envelopes that require smaller test flows, a flow restriction device such as a plug or plastic ring can be installed on the fan. When limiting the fan air flow, the gage manufacturer requires that the digital gage's configuration be adjusted. If the gauge is incorrectly set on a lower range than the fan, then the measured flow will be much lower than the actual flow.
3. Interior doors have been left closed.
4. Exterior envelope is very tightly sealed.

Several common conditions will cause results to be very high are:

1. Intentional openings have not been properly sealed or have opened during the test (i.e., pressure relief dampers, plumbing traps).
2. Windows or exterior doors are left open.
3. HVAC equipment is not properly disabled.
4. If the gauge is set on a higher range than the fan, then the measured flows will be much higher than the actual flow.
5. It is possible the building contains significant holes in the air barrier enclosure and the high readings are simply an indication of the performance of the building.

4.7 Locating Leakage Sites with Pressurization and Depressurization

If the building fails the test, it is important to determine the source of the air leakage. It is also beneficial for the design-build team to understand the locations and details that are susceptible to leakage, even if the building as a whole passes the test. The testing agency is required to perform a diagnostic evaluation in accordance with ASTM E1186. The testing agency can use additional methods to discover leaks.

Neutral buoyancy smoke, theatrical smoke and infrared (IR) are effective means to find leakage sites. When testing equipment pressurizes the enclosure, air leaks can be seen from outdoors (provided exterior walls have not been heated by radiation from the sun) using infrared thermography or large scale smoke generation. When testing equipment depressurizes the enclosure, air leaks can be observed from the inside using infrared thermography and smoke generation. The manipulation of the HVAC system is required to perform an effective infrared thermography scan to achieve a temperature differential of at least 10 °F.

An Infrared Training Center (ITC) Level I Certified Infrared Thermographer is required by this protocol to perform the infrared diagnostic evaluation. Otherwise, the agency must submit the qualifications of the infrared thermographer, who must have at least 5 years experience in building science applications with infrared thermography. Anomalies such as thermal bridges and emissivity reflections are commonly mistaken as air leakage. The testing agency must employ thermographers with experience in building enclosures and building physics to achieve accurate diagnoses and to make effective recommendations to the design-build contractor in the event of failure and repair.

In general, when locating leaks, the airflow equipment should be adjusted to establish a minimum of +25 Pa pressure differential to use smoke and infrared while viewing the building from outdoors. A pressure differential of -25 Pa should be used for using infrared from the interior. Additional information is required in the diagnostic evaluation in accordance with ASTM E1186.

5 Air Leakage Test Form

For buildings constructed in compliance with the U.S. Army Corps of Engineers Air Leakage Protocol

Building name:
____

Building address: ____

Prime Contractor: ___________________________________ Contact: ______________

Testing agency: ______________________________________ ______________________________

Address: ____ ______________________________

Testing Agency Contact: ______________________________ Phone: ________________

Lead on-site personnel: ______________________________ Phone: ________________

Test date: __________________________________

Witnesses:

Name	Organization	Telephone/email
______________________	__________________________	____________________
______________________	__________________________	____________________
______________________	__________________________	____________________
______________________	__________________________	____________________

INSERT PHOTOGRAPH OF SUBJECT BUILDING

Testing agency to provide a Compact Disk (CD) with digital photographs of subject building, setup, test procedures, and diagnostic evaluation.

Step	Description	Result
1	**Enclosure Area:** Record the total exterior enclosure surface area including walls, floor and ceiling from design plans as supplied by the Architect of Record (AOR). Verify the dimensions used by the AOR in the calculations match as-built conditions and that the arithmetic was performed correctly.	sq ft
NOTE: Testing agency to attach a description of the building characteristics, including intended use, wall, roof, and floor construction, fenestrations, HVAC system, air barrier system, and any additional information that may be relevant to the air leakage test.		

2	Set Up Checklist				
2.1	Confirm HVAC shutdown/disabling.		2.2	Confirm all dampers in the enclosure perimeter are closed and/or isolated.	
2.3	Confirm exhaust fans & dryers are off and isolated at the enclosure level.		2.4	Confirm combustion appliances are on pilot or are disabled.	
2.5	Confirm all air inlets at the enclosure perimeter are sealed or isolated.		2.6	Confirm all interior doors are propped open.	
2.7	Confirm all air outlets at the enclosure perimeter are sealed or isolated.		2.8	Note rain or snow conditions that may be affecting leakage of walls.	
2.9	Confirm exterior doors and windows are closed and latched.		2.10	Confirm ambient conditions provided are outside of air barrier envelope.	
2.11	Confirm all plumbing traps are filled with water.		2.12	Confirm dropped ceiling tiles are removed at specified rate.	
2.14	Confirm uniform interior pressure distribution by establishing at least 30 Pa and using a minimum of four pressure monitoring stations with one common exterior pressure monitoring station. Measure pressures at the four interior stations to ensure the interior pressure is within ∀10% of target value. List interior stations and pressures measured: Interior Station Locations: _______________________________________ ____ _______________________________________ ____ Pressure: ___ Pa ___ Pa ___ Pa ___ Pa				

2.15	Describer the approximate locations of the exterior pressure monitoring stations and whether the stations will be manually averaged or a manifold used. Exterior Station Locations: ____ ____ ____ ____ Means of averaging: ____
Additional Set up notes:	

3	Testing equipment used			
Gage 1	Model:	Serial #:	Accuracy:	Calibration Date:
Gage 2	Model:	Serial #:	Accuracy:	Calibration Date:
Gage 3	Model:	Serial #:	Accuracy:	Calibration Date:
Gage 4	Model:	Serial #:	Accuracy:	Calibration Date:
The gage must have an accuracy of ± 1 % or 0.5 Pa, whichever is greater and must have had its calibration checked against a National Institute of Standards and Technology (formerly National Bureau of Standards, or NIST) traceable standard within 2 years.				
Fan 1	Model:	Serial #:	Accuracy:	Calibration Date:
Fan 2	Model:	Serial #:	Accuracy:	Calibration Date:
Fan 3	Model:	Serial #:	Accuracy:	Calibration Date:
Fan 4	Model:	Serial #:	Accuracy:	Calibration Date:
The fan must have an air flow measurement accuracy of ± 5 percent of the measured flow and must have had its calibration checked against a NIST traceable standard within 5 years.				
Infrared Camera	Model:	Serial #:	Accuracy:	Calibration Date:
The infrared camera must have a sensitivity of ∀0.1℃ and must have been calibrated within 1 year of the test date.				
Attach calibration certificates for all equipment listed above to air leakage test form. If additional fans or gauges are used during the test, attach calibration certificates.				

4	**Perform a multipoint pressurization door fan test**		
4.1	Record indoor and outdoor temperatures before and after the test.	Indoor Pre-Test	Indoor Post-Test
		Outdoor Pre-Test:	Outdoor Post-Test:
4.2	Record wind speed and direction	Average mph	Direction
4.3	Record elevation of building above sea level.		ft
4.4	Record 12 **Bias Pressure Test Points** where each test point consists of at least 12 readings taken over at least 10 seconds. Show positive and negative signs.		

Bias Pressure Test Points	1	2	3	4	5	6	7	8	9	0	11	12
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa

4.4.1	Record the magnitude of the greatest **Bias Pressure Test Point**.	Pa
4.4.2	Record the amount of time taken to collect each **Bias Pressure Test Point.**	___sec
4.5	If this value is 15 Pa or less, proceed with step 4.6. If greater than 15 Pa, repeat step 4.3 over a longer time period.	

Pressurization test. Adjust the door fan speed to establish a series of a minimum of 12 equally spaced **Building Pressure Test Points** where each **Test Point** is an accumulation of at least 10 readings taken over a time period that is at least double the time taken to collect **Bias Pressure Test Points** in 4.4.

Testing in two directions: the minimum test pressure must be at least 25 Pa and must also be at least the absolute value of greatest **Bias Pressure Test Point** X 10/3 = _________ Pa. The maximum test pressure should be at least 25 Pa greater than the minimum test pressure. The testing agency is required to supply 100% of the estimated "passing" flow using 0.25 CFM/sq $ft_{envelope}$ to estimate the passing flow.

4.6	Record the actual **Building Pressures** (Pa) from one or more interior pressure monitoring stations and the exterior pressure station(s), averaged or manifolded, with corresponding **Flows** (CFM) for each fan.	
4.6.1	Attach to this test form the results of the pressure and flow readings taken during the test. Results should be provided in tabular and graphical form. Graph should include correlation coefficient (r^2) and plotted in log-linearized fashion. A minimum of 12 points must be provided, but the testing agency is allowed to take additional data points to assist in data analysis and increase the accuracy of the test. There is no limit to the number of data points taken during the test, but a minimum of 12 must reported for data analysis and results.	
4.7	Record the amount of time to be taken to collect each **Building Pressure Test Point**.	sec

4.8	Record 12 **Bias Pressure Test Points** over the same time periods as step 4.4.

	1	2	3	4	5	6	7	8	9	10	11	12
Bias Pressure Test Points	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa

4.9	Calculate the **Average Bias Pressure** for all 24 **Test Points** taken in step 4.	Pa
4.10	Subtract value in 4.9 from all pressure readings taken in 4.6. This is the total corrected building pressure used in the analysis. See step 6.	

5.	**Perform a multipoint depressurization door fan test** Testing in both directions is the preferred method, but if in section 4.6 if it was noted that the test was to be performed in only one direction, then step 5 can be omitted.		
5.1	Record indoor and outdoor temperatures before and after the test.	Indoor Pre-Test	Indoor Post-Test
		Outdoor Pre-Test:	Outdoor Post-Test:
5.2	Record wind speed and direction	Average mph	Direction
5.3	Record elevation of building above sea level.		ft.
5.4	Record 12 **Bias Pressure Test Points** where each test point consists of at least 10 readings taken over the time period determined in step 4.5. Show positive and negative signs.		

	1	2	3	4	5	6	7	8	9	10	11	12
Bias Pressure Test Points	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa

5.4.1	Record the magnitude of the greatest **Bias Pressure Test Point**.	Pa
5.4.2	Record the amount of time taken to collect each **Bias Pressure Test Point.**	___sec

Depressurization test. A pressurization test must already have been performed. Take depressurization test points at the same absolute values of **Building Pressure** as used in section 4.

5.5	Record the actual **Building Pressures** (Pa) from one or more interior pressure monitoring station and a minimum of four exterior pressure stations, averaged or manifolded, with corresponding **Flows** (CFM) for each fan.	
5.5.1	Attach to this test form the results of the pressure and flow readings taken during the test. Results should be provided in tabular and graphical form. Graph should include correlation coefficient (r^2) and plotted in log-linearized fashion. A minimum of 12 points must be provided, but the testing agency is allowed to take additional data points to assist in data analysis and increase the accuracy of the test. There is no limit to the number of data points taken during the test, but a minimum of 12 must be used for data analysis and results.	
5.4	Record the amount of time taken to collect each **Building Pressure Test Point.**	sec

5.7	Record 12 **Bias Pressure Test Points** in exactly the same fashion as step 4.4.

	1	2	3	4	5	6	7	8	9	10	11	12
Bias Pressure Test Points	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa

5.8	Calculate the **Average Bias Pressure** for all 24 **Test Points** taken in step 5.	Pa
5.9	Subtract value in 5.8 from all pressure readings taken in 4.6. This is the total corrected building pressure used in the analysis. See step 6.	
6.	**Calculate and Report Results**	

Subtract the **Average Bias Pressure** from all **Building Pressures** to arrive at **Corrected Building Pressure**. Curve fit pressures and flows from the tables and calculate the following values in strict accordance with ASTM E779-03. Provide tabulated and graphical data as an attachment to this test form.

	Pressurization	
6.2	The air leakage coefficient C_p for	CFM/Pa^n
6.3	The exponent n_p for pressurization. (NOTE: if n_p is less than 0.45 or greater than 0.8, test data is invalid and test must be repeated.)	
6.4	CFM referenced to standard temperature and pressure (STP) at +75 Pa.	CFM
6.5	CFM/sq ft of envelope at +75 Pa	CFM@75/sq ft
6.6	The correlation coefficient, r^2, of the curve fitted data with a minimum of 12 points. (NOTE: if r^2 is less than 0.98, test data is invalid and test must be repeated.)	
6.7	Calculate the 95% confidence interval at +75 Pa for test in pressurization. (NOTE: if the upper confidence interval exceeds 0.27 the test data is invalid and test must be repeated. If the upper confidence limit is 0.25 or more and the lower confidence limit is 0.04 lower, the test data is invalid and the test must be repeated.	CFM@75/sq ft CFM@75/sq ft
	Depressurization	
6.8	The air leakage coefficient C_d for depressurization.	CFM/Pa^n
6.9	The exponent n_d for depressurization. (NOTE: if n_p is less than 0.45 or greater than 0.8, test data is invalid and test must be repeated.)	
6.10	Calculate CFM referenced to STP at -75 Pa.	CFM
6.11	CFM/sq ft of envelope at -75 Pa	CFM@75/sq ft
6.12	The correlation coefficient, r^2, of the curve fitted data with a minimum of 12 points. (NOTE: if r^2 is less than 0.98, test data is invalid and test must be repeated.)	
6.13	Calculate the 95% confidence interval at +75 Pa for test in pressurization. (NOTE: if the upper confidence interval exceeds 0.27 the test data is invalid and test must be repeated. If the upper confidence limit is 0.25 or more and the lower confidence limit is 0.04 lower, the test data is invalid and the test must be repeated.	CFM@75/sq ft CFM@75/sq ft

	Both Pressurization and Depressurization	CFM
6.14	Calculate the average CFM/sq ft from 6.5 and 6.10	CFM@75/sq ft
6.15	Building passes if the value 6.14 is less than 0.25 CFM/sq ft at 75 Pa.	Pass/fail
6.16	For the purpose of visualizing the magnitude of the air leakage of the enclosure, calculate the equivalent leakage area in square feet at 75 Pa.	sq ft
7.	Perform a diagnostic evaluation in accordance with ASTM C1060 and ASTM E1186. Attach results of diagnostic evaluation to this test form.	

8.	**Restore the building to pre-test conditions**

6 Air Leakage Test Results

Testing Agency Certified Compliance with U.S. Army Corps of Engineers air leakage protocol

1	The enclosure area was obtained from the architect of record and was checked on site for reasonableness.	Initial
2	Set up conditions were performed according to section 2 and all deviations and their impact noted.	initial
3	Test equipment used was in compliance respect to accuracy and calibration date.	Initial
4	The test procedure used was in compliance except as noted here.	initial
5	The calculations were done in strict accordance with ASTM E779-03 except as noted in the Protocol.	initial
6	Provide the value calculated in step 6.14.	CFM@75/sq ft
7	Building passes if the value in step 6.14 is less than 0.25 CFM/sq ft $_{envelope}$ at 75 Pa.	Pass/fail
8	All accuracies, pressure limits and data correlations and confidence intervals are within the bounds specified in sections 4, 5 and 6 and all deviations are noted.	
9	Supporting documentation described in 1, 3, 4.6.1, 5.5.1, and 7 is attached to this test form, including all digital photographs of the building and test procedure.	initial

I hereby certify that the results above are in conformance with the U.S. Army Corps of Engineers protocol.

Testing Agency Name

____

Testing Agency Authorized Representative Signature

____

Testing Agency Authorized Representative Printed Name

____

Date ______________________________

7 Technical Justification for Differences with ASTM

7.1 Development of this Standard

The development of this standard and the associated testing protocol considered virtually every standard in widespread use. Standards that played an important part in this development were:

- ASTM E779-03 “Standard Test Method for Determining Air Leakage Rate by Fan Pressurization”
- ASTM E1827-96 “Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door”
- The Canadian Building Code
- Various applicable ASHRAE standards
- Air Tightness Testing and Measurement Association (ATTMA) Technical Specification 1 (United Kingdom [UK])
- CGSB 149.10, Canadian air leakage standard.

Key differences among these standards are:

- Choice of test pressures (10 Pa, 50 Pa versus 75 Pa)
- Way of expressing results (EqLA, CFM50, ACH50, CFM/sq ft @ 75Pa)
- Necessity and method for accounting for bias pressures (called “zero flow pressures” for the pressure measured with zero flow going through the door fan).
- Necessity and method for accounting for additional parameters (barometric pressure, humidity, temperature, elevation).

Both ASTM standards were originally intended for the testing of residential detached housing. Under these standards, multiple test points are gathered from 10 Pa up to 60 Pa and results are expressed in CFM @ 50 Pa or air changes per hour (ACH) @ 50 Pa (where CFM @ 50 Pa is the flow rate, in CFM, required to depressurize the house to – 50 Pa). It is also referred to as “CFM at 50 Pa,” “CFM @ 50,” or simply “CFM50.” ACH @ 50 Pa is CFM50 divided by the house volume. It is also referred to as “Air Changes at 50 Pa” or “ACH50”). The other commonly required result is Effective Leakage Area (EfLA) at 4 Pa (which is not to be confused with EqLA).

Both ASHRAE and the Canadian Building Code use testing points up to 75 Pa and express their results in terms of flow per square foot of surface area at 75 Pa.

The preferred test method for this standard includes:

1. Multiple test points from 75 Pa to 25 Pa
2. Testing in both the pressurization and the depressurization directions
3. Taking a comprehensive bias pressure over a long time interval to determine the lowest possible test pressure and to provide a more accurate bias correction
4. Expressing results in terms of CFM @ 75 per sq ft of enclosure area

The higher test pressure of 75 Pa was chosen for this standard since larger buildings are subject to higher bias pressures from wind and stack effects. Since wind velocity increases with height above ground, higher pressures due to wind are experienced. As height doubles, the increased bias pressures experienced due to wind roughly double. Houses typically experience bias pressures of 2 to 5 Pa whereas larger buildings can experience 10 to 20 Pa. Taking results at higher pressures helps achieve a more consistent result. A 75 Pa test pressure is about as high a pressure as is practical without vastly increasing door fan power, which would substantially increase the risk of damage due to higher wind velocities and pressures, and which is about the maximum a well-hung suspended ceiling can withstand without tearing it down in depressurize mode or blowing the tiles out in pressurize mode.

A sensitivity analysis was done on the sixth floor of an office building. Data was gathered in no-wind conditions and in conditions with a 10 to 15 mph wind blowing. Six test points were taken per test except for tests in both directions where six points were taken in each direction. Results were measured in CFM at 75 Pa. Twenty-three tests were performed under low wind conditions and another 26 tests were performed under windy conditions. All low wind tests were averaged and that average was used as the true result. The deviation result shown was the average deviation from the true result.

		No wind CFM75			
Direction	Pressure range	Deviation (%)	Error range (%)	Deviation (%)	Error range (%)
Depressurize with Bias	-60 to -12.5 Pa	2	-2.5 to + 1.5	17	-24 to -10
Depressurize with Bias	-50 to -25 Pa	2	-2.5 to + 1.5	10	-13 to -6
Depressurize with Bias	-75 to -50 Pa	1.4	-2 to + 0.5	5.3	-7 to -3
Both Directions with Bias	∀75 to ∀50 Pa	1.1	-1.1 to + 1.5	4.9	-6 to -3
Both Directions without Bias	∀75 to ∀50 Pa	1.5	-1.8 to + 1.5	3	-6 to -1
Both Directions without Bias	∀50 to ∀25 Pa	1.5	-1.8 to + 1.9	4.9	-8 to -3

Direction	Pressure range	CFM75 in 2 to 4 mph wind, deviation %	CFM75 in 10 to 15 mph wind, deviation %
Depressurize	-60 to -12.5 Pa	2%	17%
	-50 to -25 Pa	2%	10%, 30%, 16%
	-75 to -50 Pa	1.4%	5.3%, 9%
Pressurize	+50 to+25 Pa	2%	9%, 15%
	+75 to +50 Pa	1%	3%, 6%, 5%
Both ways	∀50 to∀25 Pa		11%, 10%
	∀75 to ∀50 Pa	1.1%	4%, 3%, 4.9%, 3%

7.2 Observations

1. Under windy conditions, the classic ASTM test procedure (measuring the before and after bias pressure and only testing in one direction from 60 to 12.5 Pa) produced the most unacceptable results. Variations in flow readings from 1 minute to the next, even with time averaging in place, varied as much as 25 percent for one reading.
2. If testing was to be completed in only one direction, reasonable results could be achieved by measuring the before and after bias pressures and testing at higher test pressures, from 75 to 50 Pa.
3. Testing in both directions and averaging the results always yielded results with less deviation than only testing in one direction.
4. Bias pressures taken with 30 second averaging would vary markedly from one sample to the next leading us to conclude that an even more rigorous method was required, such as 12 readings taken over at least 120 seconds.

7.3 Conclusions

7.3.1 General

1. The classic ASTM set of test points from 10 to 60 Pa was unacceptable under windy conditions.
2. The preferred test method is to test in both directions, from 50 to 75 Pa up to a maximum of 75 Pa. Allow for larger bias pressures by taking numerous readings to establish a test point over at least 10 seconds and then taking 12 test points in total. Then the door fan readings would be taken over a time period that is twice as long.
3. If testing in both directions is not possible due to the equipment characteristics, then pressurize only readings would be acceptable, but the test must be from 50 to 75 Pa.

ASTM encourages testing under ideal weather conditions of less than 4 mph wind and a temperature range of 41 to 95 F to keep bias pressures to a minimum, but these ideal conditions are seldom experienced in tall buildings due to their height or their specfic environment, increasing the likelihood that the test will be canceled. A more robust procedure is required to handle bias pressures that allow buildings to be tested in virtually any weather conditions short of storms. ASTM makes small corrections for temperature, barometric pressure, and elevation that do not help much with overall accuracy, but give the impression of accuracy. The overriding source of accuracy and repeatability is due to bias pressure.

7.3.2 Testing in Both Directions

The preferred way to eliminate bias pressure problems is to test the building in both the pressurization and depressurization directions and average the results. Bias pressure errors are non linear and cannot be properly allowed for by merely subtracting the bias from the reading. Testing in both directions cancels out these errors very effectively thus tolerating much larger bias pressures, up to 30 percent of the lowest test pressure.

7.3.3 Allowance to Test in One Direction Only

Making allowances for testing in only one direction acknowledges that very large buildings may require truck- or trailer-mounted blower equipment or that they may require the use of the building HVAC system that logistically will not easily allow testing in both positive and negative directions. Because bias pressures will have a greater impact on single-direction tests, the maximum allowable bias pressure under these circumstances has been reduced to 10 percent of the lowest test pressure of50 Pa in this case. On the other hand, the upper test pressure achieved must be at least 75 Pa. At these pressures, the bias pressure is somewhat masked by the higher test pressure and extrapolation is no longer an issue. Because buildings often leak more in one direction versus the other, testing in only one direction must be considered less accurate than testing in both directions.

The bias pressure in a 40-ft high building where the temperature was 0 °F outside and 68 °F inside and negligible wind for example, would be 10.5 Pa. This bias would typically be broken up into say +5 at the top and -5.5 at the bottom of the building. If bias pressure was a problem during the test the indoor temperature could be brought closer to the outdoor temperature by running door fan for about 5 minutes, which would be sufficient time to replace most of the indoor air with outdoor air, and thereby reduce the bias pressure somewhat.

7.3.4 Summary of Deviations from the ASTM Standard

All pressure tests shall comply with the requirements of ASTM E 779-03 with exceptions indicated in the table below.

ASTM E 779-03	U.S. Army CE Protocol	Reason for change
6.2.2 "accuracy of ∀ 5% of measured pressure."	The gage must have an accuracy of ± 1 % or 0.5 Pa, whichever is greater and must have had its calibration checked against a NIST traceable standard within 2 years.	Modern gauges are typically much more accurate than the analog gauges that ASTM was written to accommodate and there is every reason to take advantage of the increased accuracy.
8.4 "If the product of the absolute value of the indoor/outdoor air temperature difference multiplied by the building height, gives a result greater than 1180 ft °F, do not perform the test, because the pressure difference induced by the stack effect is too large to allow accurate interpretation of the results."	The protocol allows for a wider range of heights and temperatures by limiting bias pressure to 30% of the lowest test pressure when testing both ways and 10% when testing one way.	The ASTM requirement of 1180 ft °F would only permit four-story buildings (48 ft high) to be tested when the indoor/outdoor temperature difference was less than 25 °F, which would be impractical. The Protocol is both more stringent and more flexible due to the higher minimum test pressures that tolerate higher bias pressures. The ASTM requirement of 1180 ft °F produces a stack of about 4.2 Pa, which is 42% of the lowest 10 Pa test point whereas the Protocol permits a maximum bias pressure (wind and stack) of 30% of the lowest test pressure when testing both ways and 10% when testing one way. This results in a maximum allowable bias pressure of 7.5 to 15 Pa and 5 Pa for the Protocol.
8.5 "Preferred test conditions are wind speed of 0 to 2 m/s [0 to 4 mph] and an outside temperature from 5 to 35° C. [41 to 95° F.]."	Preferred test condition superseded by requirement to keep bias pressure within limits.	The ASTM preference of wind speeds less than 4 mph and outside temperature range from 41 to 95°F would mean that the rescheduling of test would be required in about 50% of all cases. This is impractical and the more robust procedure in the protocol takes care of wind and temperature differences by accurately measuring bias pressures over a period of time and then requiring that the air leakage measurements are made over the same time period.
8.10 "…. Pressure difference shall be from 10 to 60 Pa…at least five data points…"	"Adjust the door fan speed to establish a series of 12 equally spaced Building Pressure Test Points where each Test Point is an accumulation of at least 10 readings taken over a time period that is at least double the time taken to collect Bias Pressure Test Points"	Because results are required at 75 Pa, taking data up to and including this point of interest vastly increases accuracy and repeatability. The Protocol is far more stringent than ASTM yet with modern equipment takes less effort than the old manual way of taking readings.
8.13 "For each test, collect data for both pressurization and de-pressurization."	Testing in both directions is preferred. Testing from ∀ 75 Pa to ∀ 50 Pa is acceptable because buildings tend to leak slightly more under positive pressure.	Testing in both directions results in simpler and more repeatable tests. Tests with trailer mounted fans or the building's HVAC systems may only be possible in one direction and the protocol allows for then to be used.

8 Glossary and Acronyms

8.1 Glossary and Acronyms

Term	Definition
air tightness	Pertains to how free air leakage may be in an enclosure. In actual fact, measurements can only be made of air leakage rates not air tightness itself so one could think of these terms as being opposites. In spite of the confusion, the terms are used interchangeably.
air barrier	The air barrier defines the surface that separates the inside air from the outside air. Generally this should be an inner barrier such as sheet rock, which prevents air from moving through the insulation. The air barrier should be in contact with the insulation. The air barrier should not be outside the insulation.
air leakage	Pertains to how leaky an enclosure may be. See Air tightness.
average bias pressure	A series of 12 test pressure points that are averaged to produce one value.
baseline pressure	A method of reading or determining the background or bias pressure by having a digital gauge accumulate readings over an adjustable time period .
background pressure	See bias pressure.
bias pressure	This is defined as the pressure that exists when the enclosure has been prepared for the test, but before the fan pressurization system is activated. There is always some bias pressure due to stack, wind, flues and active HVAC systems. There are two components of bias pressure. A fixed static offset (usually due to stack or HVAC) and a fluctuating pressure (usually due to wind or elevator operation). In ASTM bias pressures are called “zero flow pressures” for the pressure measured with zero flow going through the door fan.
blower door	Commonly used term for a door fan, which means a calibrated fan capable of measuring air-flow. The door fan is temporarily mounted in doorway, hence the adjective “door” prefixing “fan.” Door fans do not use blowers. A blower more accurately describes an air moving device of the squirrel cage variety; hence the adjective “blower” does not normally apply to the bulk of door fans since they do not use a blower.
building envelope	See enclosure.
building enclosure	The boundary or air barrier separating the interior conditioned volume of a building from the outside environment. See enclosure.
CFM @ 50 Pa or CFM50	CFM @ 50 Pa is the flow rate, in CFM, required to depressurize the building to – 50 Pa.
ACH @ 50 Pa	ACH @ 50 Pa is CFM50 x 60 minutes/ hour, divided by the house volume. It is also referred to as “Air Changes at 50 Pa” or “ACH50.”
conditioned volumes	Any space maintained above 50 °F in winter and below 80 °F in summer.
door fan	A calibrated fan capable of measuring air-flow of that is temporarily mounted in a doorway. Door fan is more linguistically correct than the common term “blower door.” Since it is not a “door,” but rather a “fan” and since it does not use a “blower.” a more correct term is door fan.
digital gauge	For the purpose of this Protocol, it is a gauge with an electronic pressure sensor and digital display that is capable of reading in tenths of a Pascal.
Effective Leakage Area	EfLA at 4 Pa using 1.0 discharge coefficient which is not to be confused with EqLA which is normally 50% larger

Term	Definition
enclosure	The surface bounding a volume, which is connected to outdoors directly. For example an apartment whose only access to outdoors was through a doorway that leads directly outdoors. Or, a building with a series of apartments or offices whose only access to the outdoors is through a common hallway then the enclosure would be the volume that bounds all of the apartments or offices.
Equivalent Leakage Area	EqLA, usually taken at 10 Pa using 0.61 discharge coefficient, but for the purposes of this document, it is taken at 75 Pa.
envelope	See enclosure.
exterior enclosure	See enclosure. The addition of the word exterior emphasizes the fact that we are primarily dealing with enclosures that face the outdoors. The boundary or air barrier separating the interior conditioned volume of a building from the outside environment. This represents the enclosure that faces the “exterior,” but is actually measured from inside the building.
fan-pressurization method	Term is used in the ASTM standard and does a decent job of describing what a door fan test is except that it may delude us into thinking that depressurization is not an option.
sq ft	This refers to “square feet.” In this document it usually refers to the surface area of the envelope, which is also called “the enclosure.”
micromanometer	A digital gauge that is capable of reading in tenths of a Pascal.
outdoors	Outside the building in the area around the building.
readings	Discrete pressure or flow values read from the gauge(s). Typically five or six readings or samples are taken every second when using a digital micromanometer, which may not be apparent since the display is updated every second.
test points	Consists of a group of readings taken over a 10–30 second time period, which are typically averaged to produce one test point that could be used as one of the multiple points in a curve fit or overall average.
time averaging	Refers to the digital gauge display that must have an adjustable averaging from 1 second to 1 minute for the purpose of averaging fluctuating pressure signals. Averaging can be block averages that will update for the length of the average or rolling (moving) averages that will update continuously by displaying the average over the past time period.
single zone	A space in which the pressure difference between any two places, differ by no more than 5% of the inside to outside pressure difference.
static pressure	See bias pressure.
zero flow pressure	ASTM terminology for bias pressures.

8.2 Acronyms and Abbreviations

Term	Spellout
ACH	air changes per hour
AOR	Architect of Record
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
ATTMA	Air Tightness Testing and Measurement Association
CD	Compact Disk
CE	

Term	Spellout
CERL	Construction Engineering Research Laboratory
CFM	cubic feet per minute
CGSB	Canadian General Standards Board
CI	Confidence Interval
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EfLA	Effective Leakage Area
EqLA	Equivalent Leakage Area
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
HVAC	heating, ventilating, and air-conditioning
IR	infrared
ISO	International Organization for Standardization
ITC	Infrared Training Center
NIST	National Institute of Standards and Technology
STP	standard temperature and pressure conditions of 14.696 psi (101.325 KPa) and 68F (20°C).
UEPH	Unaccompanied Enlisted Personnel Housing
UK	United Kingdom
U.S.	United States
USACE	U.S. Army Corps of Engineers