Army Corps Air Leakage Testing Protocol

INTRODUCTION

On October 30, 2009 the United States Army Corp of Engineers (US ACE) issued a directive in Engineering Construction Bulletin (ECB) No. 2009-29. This directive requires that all new buildings and those undergoing major renovations (renovatons equal or exceeding 25% of replacement value) shall have an air leakage rate that does not exceed set values when tested in accordance with the U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes (test protocol). This test protocol was originally developed by the U.S. Army Corps of Engineers with assistance from the private industry using ASTM E779 as a basis. ASTM E779 is not the governing document in this standard except where specific provisions of it are mentioned. The 2011 version of this test protocol which was updated in collaboration with the Air Barrier Association of America supercedes the previous document published in 2009.

This document is intended to provide a higher level of detail than the directive to ensure that tests are conducted, and the results are reported uniformly and consistent with the directive. This document and the accompanying Test Form in appendix A (normative) both contain mandatory procedures and testing requirements. In addition to the test form in appendix A, there are accompanying sections specifically intended for Specifiers and Witness Guidance (section 3) and Testing Agency Guide (section 4). This organizational scheme, however, does not avoid the need for all test participants to read the entire document in order to be fully informed.

Unavoidably, there is an even higher level of detail required to conduct these tests that is beyond the scope of this document. For example, there are detailed and equipment-specific procedures to be followed for generating the air flows and measuring the air flows and pressures. This level of detail is left to the individual manufacturers of such equipment and, in some cases, to the expertise of the test agency. This is brought to the attention of the reader as appropriate. This document clarifies but does not alter the requirements of the ECB 2009 29, now archived, and adds air barrier continuity requirements. When questions arise regarding this protocol, the reader shall seek clarification from Dr. Alexander Zhivov at alexander.m.zhivov@usace.army.mil. Technical inquiries can be directed to the Building Air Tightness Testing Standards Committee with the Air Barrier Association of America at abaa@airbarrier.org with the subject line ‘Question regarding US ACE Air Leakage Test Protocol for Building Envelopes’. Questions will be reviewed at monthly meetings.

US ACE REQUIREMENTS FOR BUILDING AIRTIGHTNESS

The following sections outline US ACE requirements from ECB 29-2009 for building airtightness and building air leakage testing for new and major renovation Army construction:

2.1 BUILDING AIRTIGHTNESS REQUIREMENT

The basic airtightness requirements and processes for US ACE projects is the following:

1. 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 the boundary limits of the building air barriers and of the portion or portions of the building to be tested for building airtightness on the construction documents. 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.

2. Join and seal the air barrier materials of each assembly to the air barrier materials of adjacent assemblies, allowing for the relative movement of these assemblies and components. Clearly identify air barrier system continuity on the plan and section construction drawings.

3. Provide details to seal all penetrations of the air barrier assembly, including but not limited to electrical, plumbing and HVAC components; windows and doors; compatibility of materials with one another.

4. Support the air barrier so that it shall withstand the maximum positive and negative air pressures that will be placed on the building without displacement, or damage, and transfer the load to the structure. The air barrier assembly must be durable to last the anticipated service life of the envelope.

5. Provide a motorized damper in the closed position and connect it 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. Dampers and controls shall close all ventilation or make-up air intakes and exhausts, atrium smoke exhausts and intakes, etc where leakage can occur during inactive periods. Garages under buildings shall be compartmentalized by providing air-tight vestibules at building access points. Provide air-tight vestibules at building entrances with high traffic.

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

2.2 BUILDING AIRLEAKAGE TESTING – PERFORMANCE REQUIREMENT AND SUBSTANTIATION:
Demonstrate performance of the continuous air barrier assembly for the building envelope by the following steps:

1. Submit the qualifications and experience of the testing entity for approval.

2. Verify with client that the building has been sufficiently completed for testing.

3. The client shall notify the US ACE at least three (3) working days prior to tests being conduct-ed to
provide them the opportunity to witness the testing procedures.

4. Test the completed building and demonstrate that the air leakage rate of the building enve-lope
does not exceed the requirements in accordance with this document.

5. Determine air leakage pathways using ASTM E1186-03(2009) ‘Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems’. Retest after corrective work is completed as necessary to achieve the whole building air leakage rate specified in (3) above.

6. The client shall provide the US ACE with written test results of all testing and inspection pro-cedures.
3 Specifier and Witness Guidance

3.1 APPLICATION AND SCOPE

The witness and specifier should be familiar with ECB 2009-29 as well as all sections of this document. Use the Application and Scope (section 4.3) to gain a general understanding of the air leakage testing, how it should be specified and how to monitor whether the air leakage test has been properly performed. See the included Glossary and Acronyms (section 5).

DEFINING THE TEST BOUNDARY
The design professional is responsible for defining the test boundary and for calculating the associated surface area to be used in the normalized air leakage calculation. The location and surface area of the test boundary shall1 be clearly defined in the project documents.

When possible, the whole building will be tested as a single space (single zone). When this is not practical, one of the following alternate methods can be used:

• All individual spaces within the building will be tested as individual zones and subject to the building envelope air leakage requirements in Table 3.2.1. In this case the results are normalized to the surface area of all six sides of the enclosed test space.

• A guarded test can be conducted. In a guarded test, the air pressure difference between the test zone and surrounding conditioned zones is maintained at zero during each test point. In this way, the air leakage through the exterior test zone enclosure is measured. In this case, the test result is normalized to the surface area of the test zone enclosure. A test plan shall be proposed by contractor and accepted by the US ACE prior to a guarded test being performed.

WHOLE BUILDING TESTING

Whenever a single zone building test is performed, there will be a single test boundary for the entire building. This boundary may not always be comprised exclusively of exterior walls. For example, heating, ventilating, and air-conditioning (HVAC) rooms with large louvers, electrical rooms, laundry facilities with mechanical ventilation to the outside with dampers and loading docks which all open to outdoors may be designed to be outside of the air barrier assembly. As such, the test boundary will not encompass these spaces and it will align with the interior walls of these spaces. In such building envelope designs, these examples of interior walls are part of the air barrier of the building, and must be air sealed to the same level of detail as other parts of the air barrier that face the outdoor elements.

When performing a single zone test in a building that is not completely open inside, the interior zones in the building need not be interconnected by large openings if they can be tested to demonstrate compliance with the test pressure uniformity requirements in section 4.

INDIVIDUAL ROOM OR DWELLING TESTING

When it is not possible to test a whole building as a single zone, the multiple zone tests must include all the surfaces which make up the entire building envelope. For example, in a building where doorways of the apartments/offices/rooms do not lead to common spaces such as hallways, it would be impractical to simultaneously test all spaces together as a single zone, and each apartment/office/room must be tested individually.

In this case of individual room testing, walls between adjacent rooms are to be treated as part of the envelope in spite of the fact that some leakage would be to another conditioned space and could therefore be ignored. Common walls will be treated as part of the test boundary for the zone and each zone must pass the normalized leakage test criteria, with the following exception.

1. When testing an individual room or dwelling, all adjacent spaces must be open to the outdoors.
2. When conducting individual room testing in multi-unit apartments, at least 20% of the apartments must be tested, including all corner rooms, and including at least one of each style of apartment.

TEST SPACES CONTAINED WITHIN LARGER ZONES

Buildings may include spaces that require testing which are partially or wholly located within unconditioned zones that do not require testing. For example, office and break room facilities located within an unconditioned equipment maintenance facility require air barrier testing, but the maintenance facility envelope does not. In such cases the air barrier test boundary surrounds the envelope of each conditioned space that requires testing. The spaces requiring testing may be adjoined or detached, have some exterior walls or may be entirely within the unconditioned enclosure. These spaces are also often small relative to the entire building, and smaller capacity fans meeting equipment requirements may be used. Testing should be conducted with the unconditioned zone open to the outdoors. Each of the detached and contiguous spaces may be tested separately; adjoined, unconnected spaces will require separate test fans or temporary, intentional openings between the adjacent zones in order to maintain uniform building pressures during testing. Multiple spaces may be tested simultaneously provided that the pressures meet the pressure uniformity requirement in Section 4.6.

LARGER BUILDINGS

Some larger buildings (typically those requiring test air flow in excess of 125,000 CFM75 at 75 Pa) may require special test techniques not covered in this document primarily because of limitations in test fans. One option is to separate the building into multiple temporary test zones using boundary pressure neutralization techniques. A second option is to erect temporary walls to create multiple test zones. A third option may be to use the building HVAC system to establish test pressures. These three 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 with the help of the testing agency. 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 for option three. In summary, the importance of airtightness testing must not be lost on buildings with envelopes requiring test air flows in excess of 125,000 CFM75, and tests of these buildings should be performed, even if some limitations of the standard test procedure are necessary.

3.2 AIR LEAKAGE SPECIFICATION

The ECB 2009-29 air leakage test specification can be summarized as follows:

The air leakage test must be performed in accordance with this document.

The test consists of measuring the flow rates required to establish a minimum of ten (10) positive and ten (10) negative approximately equally spaced induced envelope pressures. Induced envelope pressure test points shall be averaged over at least 20 seconds and shall be no lower than 25 Pa. The highest point must be at least 75 Pa, no greater than 85 Pa, and there must be at least 25 Pa difference between the lowest and highest. Pressures in the extremities of the envelope must not differ from one another by more than 10% of the average induced envelope pressure. Pre and post-baseline pressure points must be taken across the envelope where each point is an average taken over at least 120 seconds. The initial baseline pressure point must not exceed 30% of the minimum induced envelope pressure test point used in the analysis. There are no further restrictions on wind speed or temperature during the test.

Building envelopes shall be tested under pressurization and de-pressurization conditions unless an air flow in excess of 125,000 CFM75 is required to perform the test and the only air flow testing method can pressurize or depressurize but not both.

The mean value (of pressurization and depressurization if both are performed) of the air leakage flow calculated from measured data at 0.3 in wc (75 Pa) must not exceed the building envelope air leakage requirements in Table 3.2.1 and the confidence intervals requirements of **TABLE 4.10.1.**

TABLE 3.2.1 – BUILDING ENVELOPE AIR LEAKAGE REQUIREMENT

Building Type	Maximum Building Envelope Air Leakage Requirement (CFM75/sq ft)
All buildings	0.25

3.3 ADDITIONAL INFORMATION FOR THE SPECIFIER:

The Testing Agency Guide (section 4) provides detailed information as to how the test must be performed. A completed test must consist of all items from the Air Leakage Test Form included in 3.2 Air Leakage Specification

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The air leakage test must be performed in accordance with this document.

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4.1 U.S. ARMY CORPS OF ENGINEERS (US ACE) STANDARD FOR AIR LEAKAGE
The US ACE requires all new buildings and major renovation projects to pass an air leakage test where the results must not exceed the building envelope air leakage requirements in Table 3.2.1 of differential pressure at standard conditions specified in ASTM E779-10.

4.2 US ACE PROCEDURE

4.3 THE FOLLOWING SECTIONS ALONG WITH THE AIR LEAKAGE TEST FORM IN APPENDIX A DEFINE THIS TEST PROTOCOL. APPLICATION AND SCOPE.

See the Application and Scope (section 3.1) for specifiers and witnesses. Pay special attention to the discussion of whole building testing versus individual room or dwelling testing.

4.4 TEST EQUIPMENT AIR FLOW CAPACITY
The minimum induced pressure for a valid test is 75 Pa. In planning for a test, the test agency must determine how much test air flow capacity they will need on site and supply that amount for the test. For whole building testing in single-zone buildings, and in the absence of any other information, plan for 0.30 CFM/sq ft of flow against a pressure of 75 Pa for sizing the air moving testing equipment. Since the true minimum test pressure is only 75 Pa, this allows a

comfortable margin to account for baseline pressures, reduced on-site voltages or other effects which could prevent the theoretical induced pressure from being attained. For example, if the building had 100,000 sq ft of envelope area, then it would theoretically require 100,000 x 0.25 = 25,000 CFM75 to induce a pressure of 75 Pa. If the test agency brings equipment capable of 30,000 CFM75, they should very easily be able to reach 75 Pa if the building meets the specification. If 25,000 CFM is brought into the building and 75 Pa cannot be achieved, the building fails the air leakage test. There are other very important considerations, some of which are listed below.

BOTTLENECKS OR ZONES WITHOUT INTERIOR ACCESS

If a building is not well connected internally (relative to its leakage rate) fans may need to be separated from one another, amongst two or more locations in order to achieve pressure uniformity. This may increase the number of fans required for the test as opposed to increasing the total fan capacity.

TEST LOGISTICS

In some cases, multiple buildings are scheduled for testing on the same day or days. Depending on the test equipment used, it may be more efficient to set up multiple buildings for testing in advance of the witnesses arriving and then be prepared to run the tests back to back without the delays associated with moving the equipment. In this case more test fans and other associated equipment may be required.

POWER CONSIDERATIONS

For certain test equipment, due to power quality considerations such as long extension cords, the test fans might not deliver their full rated capacity when used on site. Consult the fan manufacturer for information of this nature.

USE OF BUILDING HVAC SYSTEM FOR TESTING

HVAC systems may be used to conduct the building airtightness tests if all of the following conditions are met:

1. In buildings that require 125,000 CFM or less to induce an envelope pressure of 75 Pa , the test must be conducted in both pressurization and depressurization mode. In buildings that require 125,000 CFM or more to induce an envelope pressure of 75 Pa, the building HVAC systems may be used to conduct the building airtightness test in either pressurization or depressurization mode.

2. A proposed test plan must be submitted and pre-approved by the US ACE.

3. The building HVAC system must be specifically designed and installed to conduct the building airtightness test or be modified with flow measuring stations or other devices to allow accurate air flow measurements for testing.

4. Air flow measurement devices must be documented to measure air flows within 5% of actual flows. E.g. in situ calibration of flow stations over the range of expected flow measurements.

5. Pressure gauges must be digital with a resolution of 0.1 Pa and accurate to within ±1% of reading or ±0.25 Pa, whichever is greater, and must have a means of adjustable time averaging to compensate for wind.

For single zone tests on very large buildings, (typically requiring a test air flow in excess of 125,000 CFM75) the techniques above may be the practical option. There may not be an American standard that adequately addresses this issue. Canada uses the CAN/CGSB-149.15 standard for very large buildings. In the hands of experienced personnel, reasonable results may be achieved, but note that accuracies have been reported to be no better than ± 20% when 75 Pa was achieved.

FLOOR-BY-FLOOR TEST METHOD

In buildings in excess of four stories, if the testing agency's equipment is not capable of achieving a uniform pressure within the building due to the geometry of the interior partitions and limited shaft and stairwell interconnections, it may be possible to isolate and test individual floors. However, the floor-by-floor method requires exceptional preparation and knowledge of air flow characteristics within chases, shafts, and wall cavities in addition to the difficulty of maintaining an identical or balanced pressure between 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 GAUGE AND TEST FAN ACCURACY REQUIREMENTS

Pressure gauges must be digital with a resolution of 0.1 Pa and accurate to within ±1% of reading or ±0.25 Pa, whichever is greater, and must have a means of adjustable time averaging to compensate for wind. Pressure gauges shall have their calibration checked and accuracy verified minimum every two (2) years (or sooner, based on the gauge manufacturer's recommendations) against a National Institute of Standards and Technology (NIST) traceable standard over at least 16 pressures from at least +250 to -250 Pa or to the greatest pressure used during a test.

Test fan measurement equipment shall have their calibration verified at least every four (4) years in compliance with ASTM E1258-88(2008). Calibration certificates must show the deviations from the calibration equations that must not exceed ± 5% of the flow reading for a range of air flows and backpressures (the pressure across the fan). For each test fan flow range configuration used in a test, the calibrations shall include the minimum and maximum air flows allowed by the manufacturer for that range plus at least one intermediate flow. For each flow rate, calibrations shall include data at backpressures within +/- 10% of 25, 50, and 75 Pa. Digital pressure gauges and test fans may be calibrated separately and used interchangeably as long as they meet the requirements of this section.

4.5 BUILDING ENVELOPE PRESSURE MEASUREMENT

A minimum of one building envelope pressure measurement channel is required. It has been shown that the use of multiple building envelope pressure measurement locations, averaged together can be helpful in reducing wind-induced pressure deviations. Electronic or pneumatic means of averaging may be used. If electronic averaging is used it is recommended to have available a means of observing the individual points for comparison. This can be helpful in assessing wind impacts as well as identifying problems.

4.6 INTERIOR PRESSURE UNIFORMITY

Pressure differences within the test zone shall be monitored to confirm that it is uniform within 10% of the average induced envelope pressure. Test fans must be installed to satisfy this requirement. This may require test fans to be widely separated from one another.
Care shall be taken to install interior pressure difference measurement equipment to ensure that it is unaffected by velocity pressure created by the test equipment air flow. As an example of the uniformity criterion, for an induced envelope pressure of 75 Pa, the maximum difference between any two locations within the test zone must be 7.5 Pa or less. The number of indoor pressure difference measurements required to prove uniformity will depend on the presence of air flow bottle necks that could create significant pressure drops (e.g., doorways and stairwells).

4.7 PRE-TEST INSPECTION AND EQUIPMENT CHECK

Ensure that the test equipment is in operable condition prior to arriving at the test site. A pre-test visual inspection must be performed to determine whether there are any factors that would prevent the test from being completed. 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 on time.

4.8 BEFORE STARTING THE TEST

4.8.1 RECORD SET-UP CONDITIONS

Accurately record the exact building and equipment 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 a specified manner so that the tests are reproducible. The testing agency is responsible to ensure that the building is properly prepared and that the preparations are maintained throughout the test documentation showing the type and location of test fans, pressure gauges and the associated pneumatic tubing routes should also be provided in the final report.

4.8.2 PREPARATION OF THE BUILDING
The contractor typically performs the actual building preparations described below. Seal or otherwise effectively isolate all "intentional" holes in the test boundary. 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.

The following requirements pertain to masking HVAC openings other than flues:

a. The test is conducted with ventilation fans and exhaust fans turned off and the outdoor air inlets and exhaust outlets sealed (by dampers and/or masking),

b. Motorized dampers must be closed and may be tested masked or unmasked,

c. Undampered HVAC openings must be masked during testing, and d. Gravity dampers shall be prevented from moving or can be masked.

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 is introduced within the test zone, resulting in inaccurate test data.

All interior doors connecting to rooms within the test zone 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 none of the room's surface is part of the air barrier assembly. If doorways cannot be opened and the volume on the other side of the door is considered to be within the tested volume, then the pressure across that doorway must be measured with the test fan(s) running to ensure that the space on the other side of the door meets the pressure uniformity requirement.

Buildings with a dropped ceiling plenum must have four (4) sq ft of tiles removed for every 500 sq ft of ceiling area. Additional tiles may be removed at the discretion of the testing agency so a uniform pressure distribution in the plenum space is achieved. As an alternative the dropped ceiling plenum pressure can be tested to see if the building meets the pressure uniformity requirements of section 4.6 with the tiles in place.

All vented, non-sealed combustion equipment must be disabled or be in the “pilot” position. Confer with responsible party to ensure safe conditions during pressure test, ie. mechanical contractor, facility manager, building operator or controls contractor. If the test zone is within a larger building envelope such as a Tactical Equipment Maintenance Facility or Company Operations Facility, the areas outside of the test zone must be at ambient (outdoor) pressure conditions. This can be achieved by opening windows, exterior personnel doors or overhead coiling (rollup) doors that open to outdoors.

4.9 PERFORMING THE TEST:
Complete the test sequence as outlined in the US ACE Air Leakage Test Form (appendix A).

There are additional details to be observed which are specific to the test equipment used and beyond the scope of this document. The test agency is required to abide by the test equipment manufacturer’s instructions to ensure proper application of test equipment.

Because this test is performed by pressurizing and depressurizing the building envelope, baseline 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 building envelope leakage under ambient conditions, where pressures can be either positive or negative in direction. Baseline pressures may be up to 30% of the lowest induced envelope pressure, allowing this method to be used in a wider range of weather conditions.

The testing agency must achieve at least 75 Pa at or below the passing leakage air flow to prove the building is sufficiently airtight to pass the building envelope air leakage requirements in Table 3.2.1. The agency is encouraged to achieve the highest building pressure possible, but should not exceed 85 Pa.

Note that some buildings may have air barrier assemblies that have not been properly designed and/or installed, and this may limit the maximum safe building envelope pressure to less than 75 Pa. In such cases the building does not meet the building envelope air leakage requirement of Table 3.2.1. The testing agency shall perform a multi-point test in general accordance with this protocol so an approximate air leakage value can be provided to the building contractor. This will allow an estimate of the magnitude of the repairs necessary to meet the air leakage requirement.

4.10 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 this document:
CFM = NPC * A

The values C and n in the above equation are calculated using a linear regression of the natural log of the flow (in CFM) versus the natural log of the baseline-adjusted building envelope pressures (in Pa). The testing agency must take data at a minimum of ten (10) building envelope pressures for each test, but is not limited to the maximum number of building envelope pressures measured during the test. It is recommended to record data at additional building envelope pressures so in the analysis the “outliers” will not materially affect the calculation procedure. Outliers are pressure and flow data points that do not fit the linear regression well, and they can be caused by wind gusts, changes in wind direction, door openings, etc. Data gathered while exterior doors are open shall not be included in the analysis.

Flow rates in CFM75/sq ft @75 Pa (CFM75/sq ft) must be calculated for the linear regressions for both the pressurization and the depressurization data sets. The average of those two flow rates will be divided by the building envelope area in square feet given in the project drawings to determine the final CFM75/sq ft. This average value will be used as the basis for determination if the building meets or does not meet the requirement for maximum building envelope air leakage requirements in Table 3.2.1. The value is to be rounded to the nearest hundredth. For example, a value of 0.255 would be rounded to 0.26.

In addition to reporting the normalized air leakage in units of CFM75/sq ft, the testing agency is also required to report the squared correlation coefficient (r2) and the 95% confidence intervals (95% CI) of both the pressurization and depressurization test to demonstrate 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 and r2 must be calculated in strict accordance with the methodology contained in this document, and the data used in these calculations must correspond to the data used for the linear regressions. In general, a narrower 95% CI to the mean value and higher r2 value indicates a clear relationship for the building’s air leakage characteristics was established. Use table 4.10.1 to make a pass/fail determination. Regardless of the magnitude of the final result, the r2 value must be above 0.98.

The pressure exponent, n, will also provide some insight as to the validity of the test and relative tightness of the building envelope. Exponent values less than 0.50 or greater than 1.0 in theory indicate a $CFM = nPC * A$

The values C and n in the above equation are calculated using a linear regression of the natural log of the flow (in CFM) versus the natural log of the baseline-adjusted building envelope pressures (in Pa). The testing agency must take data at a minimum of ten (10) building envelope pressures for each test, but is not limited to the maximum number of building envelope pressures measured during the test. It is recommended to record data at additional building envelope pressures so in the analysis the “outliers” will not materially affect the calculation procedure. Outliers are pressure and flow data points that do not fit the linear regression well, and they can be caused by wind gusts, changes in wind direction, door openings, etc. Data gathered while exterior doors are open shall not be included in the analysis.

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Regardless of the magnitude of the final result, the r2 value must be above 0.98.
The pressure exponent, n, will also provide some insight as to the validity of the test and relative tightness of the building envelope. Exponent values less than 0.50 or greater than 1.0 in theory indicate a bad test, but in practice, tests outside the range of 0.45 to 0.80 would generally indicate an inaccurate test or calculation methodology. This range is dictated by basic fluid dynamics and the characteristics of developing air flow through leaks, 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 and not greater than 0.80. If the n value is outside of these boundaries, the test must be repeated.

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 much lower than they should be, 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 inlet fully open, allowing maximum air flow. For testing tighter building envelopes that require smaller test flows, the fan manufacturer provides a flow restriction device such as a plug or plastic ring that can be installed on the fan. When limiting the fan air flow, some systems require that the digital gauge'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.

Several common conditions which will cause results to be much higher than they should be, 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.

4.11 LOCATING LEAKAGE SITES WITH PRESSURIZATION AND DEPRESSURIZATION

The testing agency is required to perform a diagnostic evaluation (including infrared thermography) in general accordance with ASTM E1186-03(2009). The testing agency can use additional methods to discover leaks. It is important to determine the source of the 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.

Neutral buoyancy smoke, theatrical smoke and infrared thermography are effective means to find leakage sites. When testing equipment pressurizes the building envelope, 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 building envelope, air leaks can be observed from the inside using infrared thermography or smoke generation. When the building interior temperature is close to the outdoor temperature, then cooling or heating of the building by the HVAC system may be required to perform an effective infrared thermography scan because it requires a temperature differential of at least 10°F.

In general, when locating leaks, the air flow equipment should be adjusted to establish a minimum pressurization of +25 Pa pressure differential to use smoke or infrared while viewing the building from outdoors. A depressurization differential of -25 Pa should be used when using infrared or smoke from the interior. Additional guidance for the diagnostic evaluation should be in accordance with ASTM E1186-03(2009).

4.12 ACCREDITATION OF THERMOGRAPHERS

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. An Infrared thermographer is required by this protocol to perform the infrared diagnostic evaluation. To be qualified to conduct work under this protocol, the infrared thermographer must have successfully completed, at a minimum, a course of study that fully complies with the Level I educational requirements of the American Society for Nondestructive Testing (ASNT) as described in SNT-TC-1A-2006 and ANSI/ASNT CP-105, Training Outlines for Qualification of Nondestructive Personnel (2006). In addition, the infrared thermographer must also have a minimum of two (2) years experience in building science applications with infrared thermography or have achieved minimum Level II based on ANSI/ASNT requirements listed above.

4.13 INFRARED IMAGING SYSTEM CALIBRATION
The infrared imaging system shall be calibrated by the manufacturer. Field verification of the calibration shall be made by the operator on a periodic basis to ensure the system is within calibration. Written records of verification shall be provided upon request.

4.14 INFRARED IMAGING SYSTEM SPECIFICATIONS
The detector array shall be at least 120 by 120 pixels. The thermal sensitivity (noise equivalent temperature differences, NETD) shall be 100 mK or better.