Standard Test Method for Building Enclosure Airtightness Compliance Testing

1. Designation

To be designated once sent to ASTM.

2. Scope

2.1 This standard test method provides a quantitative field-test procedure and calculation method for assessing compliance of a building enclosure with an airtightness specification using fan-induced pressure differences.

2.2 Building setup conditions appropriate for testing the enclosure's airtightness are defined in this standard.

2.3 Guidelines to identify the air barrier system boundaries of the test enclosure to be tested are provided in this standard.

2.4 This test method applies to all building types and portions thereof.

2.5 This test method is applicable to typical indoor-outdoor temperature differentials and low to moderate wind pressure conditions.

2.6 This standard defines three test procedures: multipoint regression, repeated single point and repeated two-point airtightness testing.

2.7 This standard allows for testing compliance with the test enclosure in a pressurized condition, a depressurized condition, or an average of both.

2.8 This standard applies to airtightness specifications with a reference pressure greater than 45 Pascals (Pa) and not greater than 100 Pascals (Pa).

2.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific hazard statements, see Section 8.*

3. Significance and Use

3.1 Unintentional air leaks through the building enclosure can cause various building related problems such as excessive energy use for heating and cooling, occupant comfort, poor indoor air quality, freezing pipes, ice dams, and premature building degradation from condensation and fungal growth.

3.2 This test method does not establish requirements for airtightness but provides means of assessing compliance with airtightness requirements established elsewhere.

3.3 This test method is used to determine the airtightness of building enclosures or portions thereof at a specified reference pressure. This is different than field testing of air leakage using tracer dilution methods (see ASTM E741). In service tracer gas test results are a combination of the airtightness, weather conditions, and operation of mechanical or passive ventilation systems. Thus, such tests do not isolate the airtightness of building enclosures.

3.4 This test method goes beyond existing methods (e.g. ASTM E779 and E1827) by providing:

3.4.1 a detailed procedure for combining the calculated airtightness with its precision and bias in determining whether the building enclosure has sufficiently demonstrated compliance with a target airtightness level,

3.4.2 guidance for testing under a wider range of weather conditions,

3.4.3 additional direction and requirements for testing commercial, multi-family, industrial, and institutional buildings.

3.5 This test method measures the airtightness of the constructed building enclosure. Test methods that measure airtightness of materials (ASTM E2178) or assemblies (ASTM E2357) alone do not address the various complexities of the constructed building enclosure, including design, sequence, constructability, and workmanship.

3.6 This test method may be applied to whole buildings or subsections of buildings. It can be used to test enclosures that consist of a single zone or subsections that can be tested as a single zone. Test enclosures that are entirely composed of subsections separated by interior partitions, floors, or both may be tested as a single zone by maintaining baseline relationships between subsections throughout testing. (See Appendix X1). Isolated subsections, each with it's own airtightness requirement, must be treated as separate test enclosures and tested separately.

3.7 The building preparations prior to testing (fenestration positions and preparation of intentional openings such as HVAC penetrations and equipment) are critically important and can have a strong influence on the final test results. This test method includes guidance for testing of the building enclosure both including and excluding HVAC related openings.

3.8 In new construction this test is typically conducted near the completion of the building enclosure. This timing is meant to ensure that all construction activities which could affect the air barrier system have been completed. In existing buildings this test is typically conducted after all air-sealing measures are complete.

3.9 Compliance with an airtightness specification does not imply that all problematic leaks have been sealed. Air leaks might be important to address even in enclosures which are determined to meet specified airtightness requirements.

3.10 While this test determines the airtightness of an enclosure, it does not identify the location of leakage sites. See, for example, method ASTM E1186 for locating leaks. The location of leaks, in addition to their cumulative leakage area, is also an important determinant of leakage under normal operating conditions.

3.11 This test method may be used for training and quality assurance purposes (i.e. mockups and top-floor corner rooms) or in combination with ASTM E1186.

3.12 In most commercial, multi-family, industrial, or institutional buildings, outdoor air is introduced by design; however unintended air leakage can be a significant addition to the designed outdoor airflow.

4. Referenced Documents

ASTM E1827 - Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door
ASTM E779 - Standard Test Method for Determining Air Leakage Rate by Fan Pressurization
ASTM E1258 - Standard Test Method for Airflow Calibration of Fan Pressurization Devices
ASTM E1186 - Standard Practices for Air Leakage Site Detection in Building Enclosures and Air Barrier Systems
ASTM E2178 - Standard Test Method for Air Permeance of Building Materials
ASTM E2357 - Standard Test Method for Determining Air Leakage of Air Barrier Systems

5. Terminology

5.1 *Air Barrier System:* Combination of air barrier assemblies and air barrier components, connected by air barrier accessories, that are designed to provide a continuous barrier to the movement of air through the building enclosure.
5.2 *Air Barrier System Enclosure Test*: Airtightness test to determine airtightness of a building enclosure excluding HVAC-related penetrations.
5.3 *Air Leakage:* The flow of air through unintended openings in the building enclosure, which is driven by either, or both positive (exfiltration) or negative (infiltration) pressure differences (also see Airtightness).
5.4 *Airtightness:* Property of a building enclosure which will inhibit air leakage. Airtightness is determined by measuring the air flow rate required to maintain a specific induced test pressure.
5.5 *Baseline Pressure*: The enclosure pressure with test fans off and sealed, recorded while the building is configured in the test condition. The terms bias, static pressure readings, and zero-flow pressure difference are used interchangeably with the term baseline pressure in other documents and standards used in the industry.
5.6 *Building Enclosure*: The building enclosure consists of roofs and skylights; above grade walls, windows, curtain walls, and doors; and below grade walls and floors; and connecting flashings, air barrier, and moisture control transition membranes, sealants and expansion joints that separate the interior environment from the outdoors and any adjoining unconditioned spaces.
5.7 *Enclosure Pressure*: Differential pressure between the interior of the building being tested and the outdoors, measured with the outdoors as the reference.
5.8 *HVAC*: Heating ventilating air conditioning.
5.9 *Induced Enclosure Pressure*: The change in enclosure pressure caused by operation of the test fans.
5.10 *Operational Enclosure Test*: Airtightness test to determine airtightness of the building enclosure including HVAC-related penetrations.

5.11 *Single-Zone Condition*: A single-zone condition exists if during testing, the maximum difference in induced pressure between any two locations within the test enclosure is no greater than 10% of the induced enclosure pressure. (See Appendix X1)
5.12 *Specified Reference Pressure:* The induced enclosure pressure at which the results are required to be reported by the specification.
5.13 *Test Enclosure:* A building or a portion of a building that is configured as a single-zone to be tested in accordance with this standard.
5.14 *Test Pressure:* The enclosure pressure (not baseline adjusted) measured while test fans are in operation.

6. Summary of Test Method

6.1 Building enclosures or portions of building enclosures are tested to determine whether they have met an airtightness specification. This standard provides three quantitative test and analysis methods to determine whether or not a building enclosure has met a specified airtightness target. All three methods consist of mechanically inducing an pressure difference between a test enclosure and the surrounding spaces or outside the building. During the test, the total airflow through the test fans and corresponding induced enclosure pressure are measured. The relationship between the airflows and induced pressures is used to determine the airtightness of the enclosure. Airtightness specifications for enclosures are written in terms of a maximum allowable airflow rate needed to induce a specified reference pressure.
6.2 The three allowable test methods are multipoint regression (based on ASTM E779),repeated single point (based on ASTM E1827) and repeated two-point pressure testing (based on ASTM E1827).

7. Apparatus

7.1 The following is a general description of the required apparatus. Any arrangement of equipment using the same principles and capable of performing the test procedure within the allowable tolerances shall be permitted.
7.2 Major Components:
7.2.1 Air-Moving Equipment—Fans, blowers, HVAC air movement components or blower door assemblies that are capable of moving air into and out of the conditioned space at the required air flow rates under a prescribed range of induced test pressure differences. The system shall provide control of airflow sufficient to perform the selected test sequence (See section 10).
7.2.2 Pressure Gauges must be digital with a resolution of 0.1 Pa (0.0004 in.WC) and accurate to within ±1% of reading or ±0.25 Pa (0.001 in.WC), whichever is greater, and must have a means of adjusting time averaging intervals. Pressure gauges shall be calibrated against a National Institute of Standards and Technology (NIST) traceable standard over at least 16 pressures in a range from at least +250 to -250 Pa (1.0 in.WC) or to the greatest pressure used during a test. The minimum (absolute value) calibration pressures must be no

greater than 25 Pa (0.10 in.WC). Gauges must be checked and their accuracy verified intervals in accordance with the manufacturer's recommendations. Follow manufacturers' recommendations for field check procedures.

7.2.3 For each test fan configuration airflow measuring devices shall be accurate to within ±5% of reading and shall be calibrated in compliance with ASTM E1258 at a minimum of three flow rates where one is above or within 10% of the maximum flow measured during the test and one is below or within 10% of the minimum flow measured during the test. Calibration at each of these three flow rates must be performed at three backpressures (induced pressures) where one calibration point is above or within 10% of the maximum backpressure measured and one is below or within 10% of the minimum backpressure measured. Test fans must be checked and their accuracy verified at intervals in accordance with the manufacturer's recommendations. Follow the manufacturer's recommendations for field inspection procedures. Digital pressure gauges and test fans may be calibrated separately and used interchangeably as long as they meet the requirements of this section.

7.2.4 Temperature-Measuring Device—Instrument to measure temperature with an accuracy of ± 2°C (4°F) according to the manufacturer's specifications.

8. Hazards

8.1 Activity Hazard Analysis- the building testing team shall make a daily activity hazard analysis for their work exposures and shall conduct and document a daily test team safety meeting.

8.2 Personal Protective Equipment – On active construction sites the testing team personnel shall wear eye protection, hard hats, and safety shoes, and other safety equipment as required by local laws.

8.3 Fall Protection – Testing team personnel shall be trained on the hazards of equipment used for the tests – such as ladders, aerial lifts, scissor lifts, stages, scaffolds, and roofing.

8.4 Fall Protection Equipment – the testing team shall be trained in the use of fall protection and arrest equipment and utilize fall protection equipment during fall risk exposures.

8.5 Noise – Hearing protection shall be available to testing team personnel exposed to fan noise.

8.6 Equipment Guards – Air moving equipment shall have proper guards or cages to house the fan or blower and to prevent access to any moving parts of the equipment.

8.7 Security –Consideration shall be given for adequate security of the equipment and personnel during the course of the testing.

8.8 Electrical – Testing equipment shall have ground fault protection and licensed electricians shall be utilized to install temporary power if required for testing equipment.

8.9 Debris, Fumes and Temperature – The blower or fan equipment used to pressurize or depressurize the test enclosure presents hazards to the interior with dust, debris, indoor air quality, occupancy, occupant comfort, plants, furnishings, finishes, and artwork.

8.10 Combustion Appliances - Adjust all combustion appliances so they do not turn on during the test. This is commonly done by temporarily turning off power to the appliance, or setting the appliance to the "Pilot" setting. Open fireplaces shall be clear of ashes.
8.11 Elevators - Ensure, if elevator doors are open, that there are handrail barriers across the openings on each floor and the elevators are locked out and not operational.
8.12 Existing Condition Hazards - Address airtightness testing impacts to the testing team and to the occupants where the building has known or suspected presence of asbestos, lead, mold and/or other potentially hazardous materials.

9. Sampling

9.1 If a test specification allows for sampling of similar units, then a written sampling protocol shall be developed.
9.2 If the specification does not contain a sampling protocol, units with different air barrier assemblies (top floor units, units over crawlspaces, corner units, etc.) must be included.

10. Procedure

10.1 Write a building specific test plan based on the test specifications for the project.
10.2 Identify the purpose of the test. If the purpose of the test is not included in the project test specifications, request clarification.
10.3 Coordinate the test with the building owner, manager or authorized representative.
10.3.1 Identify dates for conducting the test when the following requirements can be met:
10.3.1.1 the lowest occupancy rates are expected e.g. weekends, holidays, and evenings,
10.3.1.2 the owner or their representative with authorized access to all spaces in the test enclosure shall be present,
10.3.1.3 a person authorized by the building owner or their representative to set mechanical equipment to the mode required for the test shall be present (e.g. place motorized dampers in the closed position, de-energize exhaust and dedicated make-up air fans, and turn off required combustion appliances),
10.3.1.4 a person authorized by the building owner or their representative to reset breakers if need be,
10.3.1.5 the designated test enclosure shall be completed for testing.
10.3.2 Arrange security procedures:
10.3.2.1 Identify safety, security, and privacy concerns.
10.3.2.2 Identify any areas where interior doors cannot be opened under any circumstances or opening doors may be a safety, privacy, or security issue.
10.3.2.3 Develop a security plan to address security issues.
10.3.3 Inform the building contact person that the test may be canceled due to high wind speeds, gusting winds, or large indoor – outdoor temperature differences.
10.4 Collect and record building related data (See section 14 for reporting requirements).

10.5 Review available construction documents, including but not limited to, architectural drawings and mechanical schedules.

10.6 In narrative or on floor plans identify the location of the walls, floors, ceilings, and roof assemblies bounding the test enclosure. The testing agency shall:

10.6.1 Derive this information from the design specifications, documents, and the stated purpose of the test.

10.6.2 Identify whether the test is for:

10.6.2.1 a single-zone,

10.6.2.2 two or more subsections tested as a single zone,

10.6.2.3 isolated subsections tested independently.

10.6.3 Make a list of ancillary spaces that are not clearly included in the test enclosure by the test specifications or construction documents (such as mechanical rooms, elevator equipment rooms, loading docks, crawlspaces, basements, and attics).

10.6.3.1 Include an ancillary space within the test enclosure if it is thermally separated from outdoors (i.e. by assemblies that include insulation and continuous air barriers) and is not thermally separated from adjoining indoor portions of the test enclosure. Windows and doors to the outdoors shall be closed and latched. Doors to the adjoining portions of the test enclosure shall be open during the test if it is an Air Barrier Systems Enclosure test and closed if it an Operational Enclosure Test.

10.6.3.2 Do not include an ancillary space within the test enclosure if it is thermally separated from all adjoining portions of the test enclosure and is vented to the exterior by passive openings that do not include motorized or gravity dampers. Windows,doors and passive ventilation openings to the outdoors shall be open during the test and doors to all adjoining portions of the test enclosure shall be closed and latched if it is an Air Barrier Systems Enclosure Test. Many older commercial, institutional, and industrial buildings have separate mechanical rooms that contain boilers connected to multi-story chimneys; these spaces often include passive or fan powered make-up air inlets. In this case treat the boiler room as a separate space which is outside the test enclosure.

10.6.3.3 After applying 10.6.3.1 and 10.6.3.2 f it is still unclear whether a space is inside or outside the test enclosure, consult with the designer, or close and latch doors and windows to both the test enclosure and the outside during the test.

10.7 Identify the specified reference pressure and the maximum allowable airflow required to conduct the test. The specified reference pressure and the specified airtightness should be in the test specifications or construction documents. Airtightness specifications are written in terms of the air flow required to create a specified induced enclosure pressure. The required air flow is normalized to either the surface area or the volume of the test enclosure. For example: 0.25 cubic feet per minute per square foot of test enclosure at an induced enclosure pressure of 75 Pa is frequently specified as an air-tightness target. In this case the surface area of the test enclosure is taken from the project specifications or calculated from measurements made on site. If the test enclosure surface area is 100,000 square feet, the maximum allowable flow rate required to change the indoor-outdoor pressure difference by 75 Pa would be 25,000 cfm. *Note: the 0.25cfm/ft^2 flow rate value has been accepted by several standards and agencies, it is being used as an example throughout the document.* If multiple test enclosures are utilized, airflows for each test enclosure must be determined.

10.8 Identify whether the test will be conducted using the regression, single-point or two-point method. If the test method is not identified in the specification, any of these methods may be used.

10.9 Determine whether the test will be conducted by depressurization, pressurization, or both.

10.10 Determine how the airflow needed to conduct the test will be provided and measured at the test site.

10.11 Determine how effective distribution of test airflow will result in single-zone conditions for each test enclosure.

10.12 Determine building preparations required for intentional openings. It is assumed that the overall purpose of testing the building enclosure is to determine whether it meets an airtightness specification. Building preparation should be in accordance with requirements in the test specification for the particular building. In the event that building preparation is not clearly stated in the test specification, Table 1 lists default conditions for preparing a building for two common test purposes:

10.12.1 Air barrier systems enclosure test (HVAC-related openings excluded)

10.12.2 Operational enclosure test (air barrier systems and HVAC-related openings included)

TABLE 1 Default Conditions for Building Preparation

Intentional Openings	Air barrier systems enclosure test (HVAC-related openings excluded)	Operational enclosure test (air barrier systems and HVAC-related openings included)
Doors, hatches, and operable windows inside the test enclosure	Open	Open
Fire Dampers	Remain as found	Remain as found
Windows, doors, skylights, and hatches in the bounding enclosure	Closed and latched	Closed and latched
Windows, doors, hatches, and operable windows in ancillary spaces as identified in section 10.6.3	Treat in accordance with 10.6.3	Treat in accordance with 10.6.3
Dryer doors and air handler access panels	Closed and latched	Closed and latched
Vented combustion appliance	Off, unable to fire	Off, unable to fire
Pilot light	As found	As found
Chimney or outlet for vented combustion device in a separate mechanical room	As found	As found
B-vent or other insulated chimney serving a vented combustion appliance located within the test enclosure	Sealed*, **	As found
Solid fuel appliances (fireplaces, wood burning stoves, pellet stoves)	No fires; dampers closed; chimney sealed*, **	No fires; dampers closed
Exhaust, outdoor air, make-up air fans, air handlers that serve areas inside and outside the test enclosure	Off	Off
Clothes dryers	Off	Off
Air intake inlet with motorized dampers	Dampers closed and sealed*, **	Dampers closed
Air intake inlet with gravity dampers	Sealed*, **	As found
Air intake inlet with no dampers	Sealed*, **	Open unless fan(s) serving inlet is operated greater than 8000 hours per year, then sealed*, **
Exhaust or relief air outlet with motorized dampers	Dampers closed and sealed*, **	Dampers closed
Exhaust or relief air outlet with gravity dampers	Sealed*, **	As found

Exhaust or relief air outlet with no damper	Sealed*, **	Open unless fan serving outlet is operated greater than 8000 hours per year, then sealed*, **
Active or passive smoke control systems - air reliefs and intakes	Sealed*, **	As found
Intended powered or non-powered openings for vented shafts/stairwells	Sealed*, **	As found
Waste or linen handling systems and equipment	Sealed*, **at rooftop chute vent opening.	Rooftop chute vent – open , chute intake doors – closed, chute intake room, and chute discharge room doors – closed and latched, fire dampers - left as found
Clothes dryer outlets	Sealed*, **	As found; sealed*, ** if dryers are not yet installed
Exhaust, outdoor air, or make-up air fan that runs >8000 hours per year	Sealed*, **	Sealed*, **
Ductwork that serves areas inside and outside the test enclosure	Sealed*, ** at supply and return	Sealed*, ** at supply and return
Floor drains and plumbing	Traps filled	Traps filled
*Sealed means that an opening has been temporarily masked airtight (e.g. covered with self-adhering plastic film, taped polyethylene film, or rigid board stock). See Appendix X1. **See article 10.12.4.		

10.12.3 Make a table of intentional openings that are present in the test building. Use Table 1 as a guide. Record how the intentional openings were prepared for each test conducted. Note any observed deviations from the prescribed test conditions.

10.12.4 If the test result meets the passing criteria for the method used then the building is deemed to pass even if not all of the HVAC related openings were sealed during the test.

10.13 Prepare an activity hazard analysis for the test.

10.14 Review the test plan with the client. Be sure there is agreement on the boundaries of the test enclosure, the airtightness test standard, and what allowable maximum airflow rate meets the required specifications.

10.15 Determine whether the building is ready to be tested:

10.15.1 Inspect the building to determine whether the designated test enclosure is completed for testing in accordance with 10.12.

10.15.2 Determine whether the HVAC systems can be set as required for the test.

10.15.3 Determine if weather conditions will be likely to prohibit testing. Conditions must meet requirements in sections 11, 12, or 13. High winds, gusty winds, and a combination of a tall building and large indoor-outdoor temperature differential, are factors which may prohibit testing.

10.16 Create single zone conditions within each separate test enclosure.

10.16.1 Close and latch all doors and windows in the bounding walls, floors, ceilings and roofs of the test enclosure, excepting those in which test fans are placed.

10.16.2 Open a sufficient number of doors in the interior walls of each test zone.

NOTE: Interior doors may remain closed if it has been demonstrated that closing them has insignificant impact on the test result (e.g. pressure monitoring demonstrates that the space meets single zone condition). Interior doors may also be closed to manage airflow so that single-zone pressure distribution conditions are met.

10.16.3 Close interior and exterior doors in the enclosure of the ancillary spaces in accordance with 10.6.3.

10.16.4 Turn off all exhaust and make-up air fans.

10.16.5 Turn off all air handlers and fans identified to be de-energized in the table developed in 10.12.3. NOTE: Air handlers and fans that were not de-energized may have an adverse effect on the test and may be de-energized to enable testing.

10.16.6 Set all dampers to the position identified in the table developed in 10.12.3 and air seal all intentional openings as identified in 10.12.3. Document any HVAC related openings found in the building that were not identified in 10.12.3 and status of associated fans, dampers, and temporary sealing during the test.

10.16.7 Turn off all combustion equipment, where practical, identified in the table in 10.12.3. Document any combustion equipment which cannot be turned off.

10.16.8 Treat fireplaces and chimneys as identified in the table in 10.12.3. If the test will be a depressurization test that might draw soot or ashes into the building, the chimney may be sealed and this deviation from normal building preparation shall be noted in the test report as a deviation from the standard.

10.16.9 Fill dry plumbing traps.

10.17 Deploy test equipment:

10.17.1 Enclosure pressure measurements: Place micro-manometers, sensing tubes, and electronic data acquisition equipment so as to measure enclosure pressure. Enclosure pressure measurements must be made across at least one wall, but may be made across multiple walls and averaged for use in data analysis. Locate the exterior pressure tap or taps ideally at grade, close to the building, in locations where they will be sheltered. A good location avoids exterior corners and should be close to the middle (horizontally) of the exterior wall. When wind causes adverse pressure fluctuations, it may be advantageous to average enclosure test pressures measured across multiple walls, for example, one across each facade. If using a single pressure tap avoid the windward side of the building (See Appendix X1 for more information). The open end of the tubing must be protected from liquid water entry. Avoid puddles and spigots, and provide rain protection for the end of the tubing. Avoid direct sunlight on pressure tubing, especially vertical sections. Exterior pressure taps may not be moved to the neutral pressure level so as to meet the requirements in equation (1). See Appendix X1 for further recommendations.

10.17.2 Test Fans: Install test fans in exterior door or window openings. Follow manufacturer's instructions for setting up test equipment. During windy conditions avoid locations on the windward side of the building. Locate test fans so that a single zone condition is created. See Appendix X1.

10.17.3 Internal induced pressure uniformity measurements: Place micro-manometers and sensing tubes so as to measure the maximum air pressure differences between different sections of the test enclosure. For example, significant pressure differentials can exist between different sections of the test enclosure if there are barriers to air flow (e.g. walls or floors with either no intentional openings or intentional openings that have a small enough area that the expected airflow through them will induce significant pressure drop). In the case of buildings without interior restrictions, such as warehouses or buildings with central atria, no measurements are required to confirm the uniform internal pressure. In buildings consisting of multiple zones connected by man-door size openings (or smaller), measurements must be made to determine, and if needed, to correct pressure uniformity. In multi-story buildings, measurements shall be made every ten stories; and include the top floor, bottom floor, and middle floor at a minimum. If all the rooms in a test enclosure are interconnected with a man door or larger openings and total test fan air flow at the highest induced test pressure is less than 6000 CFM, then pressure uniformity can be assumed, and no pressure uniformity measurements are required. These measurements will be used to inform the test technician and allow them to take measures to maintain single zone pressure conditions during the test. See Appendix X1.

11. Collect and Analyze Data for Regression Test

11.1 Pre-test Baseline Pressure: All the test fans shall be turned off and sealed for at least 30 seconds after which a pre-test baseline pressure measurement of at least 120 seconds duration shall be recorded. Baseline measurements shall be the temporal average of the baseline data from all enclosure pressure locations. When analyzing the data, use the same enclosure pressure locations for all baseline enclosure pressures and unadjusted enclosure pressures. Divide the baseline into 12 equal length intervals. Calculate the temporal average of each interval and the

standard deviation of these averages. The baseline standard deviation ($STDev(P_{base,pre})$ is used in Equation (1) to calculate the minimum allowable induced enclosure pressure.
11.2 Measure and record the pre-test indoor and outdoor air temperature and wind speed. Determine the site altitude above mean sea level within 300 ft (100 m).
11.3 Unadjusted Enclosure Pressures and Flow Measurements: Measure and record the air flows through all operating test fans for a series of at least ten approximately equally spaced unadjusted enclosure pressures. Each unadjusted enclosure pressure and its corresponding flow measurements from all fans must occur within 20 seconds of each other. Each induced enclosure pressure shall be averaged over a minimum of two times the length of the equal length intervals in 11.1. There shall be at least a 25 Pa difference between the lowest and highest induced enclosure pressures. Calculate the minimum induced enclosure pressure using the following equation:

$$P_{induced,\ min} \geq Max\ (|P_{base,pre}| + 10xSTDev(P_{base,pre}),\ P_{stack}/2,\ 10\ Pa) \qquad (1)$$

Where:

$P_{induced,\ min}$ = the minimum induced enclosure pressure that may used in the test analysis
$P_{base,pre}$ = the pre-test baseline enclosure pressure
P_{stack} = the total calculated stack pressure given by equation (2)

$$P_{stack} = abs(\rho_{out} - \rho_{in}) * g * h \qquad (2)$$

Where:

ρ_{in} = Inside air density (kg/m^3) from ASTM E779-2010 equation X1.1
ρ_{out} = Outside air density (kg/m^3) from ASTM E779-2010 equation X1.2
g = acceleration of gravity as 9.81 m/s^2
h = height of building (m), measured from grade up to highest portion of the test enclosure.

Under windy conditions, if this condition is not met, it is recommended to repeat using a longer pre-test baseline. In no instance shall the induced enclosure pressure be lower than 10 Pa or greater than100 Pa. In order for a test to be valid, the absolute value of the largest induced enclosure pressure must be greater than 0.90 times the absolute value of the specified reference pressure.
11.4 Maintain Single Zone Conditions: Pressure differences within the test enclosure shall be measured and recorded (see 10.17.4 for open building exceptions). For a test point to be used in the analysis, the difference between the highest and lowest pressure difference within the test enclosure must be less than 10% of the induced enclosure pressure. Make any corrections needed to maintain single zone conditions. Exception: if uniformity was not maintained within

10% during a test, the building may be deemed to pass if the test specification is met when the results are analyzed using only the building enclosure pressure measurements made at the location of the induced enclosure pressure difference with the smallest absolute value.
11.5 Post-test Baseline Pressure: All the test fans shall be turned off and sealed for at least 30 seconds, after which a post-test baseline pressure measurement of at least 120 seconds duration shall be recorded. Baseline measurements shall be the temporal average of the baseline data averaged over all enclosure pressure locations.
11.6 Measure and record the post-test indoor and outdoor air temperature and wind speed.
11.7 Pressurization and Depressurization: Repeat 11.1 through 11.6 for each required test mode (depressurization or pressurization). When performing both pressurization and depressurization measurements, record the pressurization and depressurization data separately including all preliminary environmental measurements and baseline readings as if performing two separate or individual tests.
11.8 Data Analysis and Calculations:

11.8.1 If the airflow required to meet the specified reference pressure as determined in 10.7 is exhausted from or supplied to the test enclosure, and the induced enclosure pressure is less than 90 % of the specified reference pressure, the building is deemed to fail.

11.8.2 Data shall be analyzed in accordance with ASTM E779 (un-weighted regression).

11.8.3 For each test, if the calculated flow exponent, n, is less than 0.45 or greater than 1.05, the test is invalid. If n is less than 0.5 or greater than 0.9 check test enclosure set-up to determine whether openings have inadvertently opened or closed during the test. If a problem is found, correct the problem and retest. See Appendix X1 for discussion of this issue.

11.8.4 . An r^2 less than 0.99 may indicate problems with the test. Review testing procedure, data and enclosure set-up for problems. Take corrective action as needed. See Appendix X1 for discussion of this issue.

11.9 If the test result is:

11.9.1 greater than the airtightness specification, the test enclosure fails,

11.9.2 less than or equal to the airtightness specification and the 95% confidence interval (CI) is less than or equal to 8% of the airtightness specification then the test enclosure passes,

11.9.3 less than or equal to the airtightness specification and the 95% CI is greater than 8% and the sum of the test result and the 95% CI is less than or equal to the airtightness specification, the test enclosure passes,

11.9.4 less than or equal to the airtightness specification and the 95% confidence interval is greater than 8% and the sum of the test result and the 95% CI is greater than the airtightness specification, the test enclosure fails.

11.10 Test result will be reported in specified units along with 95% CI.

12. Collect and Analyze Data for Repeated Single Point Test

12.1 Pre-test Baseline Pressure: All the test fans shall be turned off and sealed for at least 30 seconds after which a pre-test baseline pressure measurement of at least 120 seconds duration shall be recorded. Baseline measurements shall be the temporal average of the baseline data from all enclosure pressure locations. When analyzing the data, use the same enclosure pressure locations for all baseline enclosure pressures and induced enclosure pressures. Divide the baseline into 12 equal length intervals. Calculate the temporal average of each interval and the standard deviation of these averages. The baseline standard deviation (STDev($P_{base,pre}$) is used in Equation (1) to calculate the minimum allowable induced enclosure pressure.

12.2 Baseline Pressure: Before each measurement at the induced enclosure pressure, all the test fans shall be turned off and sealed for at least 30 seconds or until the building enclosure pressures stabilize, after which a baseline pressure measurement of at least two times the length of the equal length intervals in 12.1 shall be recorded. Baseline measurements shall be the temporal average of the baseline data from all enclosure pressure locations.

12.3 Alternately baseline measurements may be collected before and after the replicate set of induced enclosure pressure tests described in 12.5 as follows:

12.3.1 Pre-test Baseline Pressure: As defined in 12.1.

12.3.2 Post-test Baseline: All the test fans shall be turned off and sealed for at least 30 seconds, after which a post-test baseline pressure measurement of the same duration as the pre-test baseline shall be recorded. Baseline measurements shall be the temporal average of the baseline data averaged over all enclosure pressure locations.

12.4 Measure and record the indoor and outdoor temperature and wind speed. Determine the site altitude above mean sea level within 300 ft (100 m).

12.5 Induced Enclosure Pressure and Flow Measurements: The specified reference pressure shall be as determined above in section 10.7. If no induced test pressure is specified, test at 75 Pa. Measure and record the air flows through all operating test fans for at least five replicate induced enclosure pressures. Each induced enclosure pressure and its corresponding flow measurement must occur within 20 seconds of each other. Each induced enclosure pressure shall be averaged over a minimum of two times the length of the equal length intervals in 12.1. Air flow measurements shall be the sum of the airflows through all operating test fans. Induced enclosure pressures shall be no lower than 10 Pa and no greater than 100 Pa Calculate the minimum induced enclosure pressure using equation (1). For the Repeated Single Point test $P_{induced, min}$ is the reference enclosure pressure in the airtightness specifications. Under windy conditions, if this condition is not met, it is recommended to repeat using a longer pre-test baseline (see Annex X1 for additional guidance).

12.6 Maintain Single Zone Conditions: Pressure differences within the test enclosure shall be measured and recorded (see 10.17.4 for open building exceptions). For a test point to be used in the analysis, the difference between the highest and lowest pressure difference within the test enclosure must be within 10% of the induced enclosure pressure. Make any corrections needed to maintain single zone conditions. Exception: if uniformity was not maintained within 10%

during a test, the building may be deemed to pass if the test specification is met when the results are analyzed using only the building enclosure pressure measurements made at the location with the induced enclosure pressure difference with the smallest absolute value.

12.7 Pressurization and Depressurization: Repeat 12.1 through 12.6 for each required test mode (depressurization or pressurization). When performing both pressurization and depressurization measurements, record the pressurization and depressurization data separately, including all preliminary environmental measurements and baseline readings as if you were performing two separate or individual tests.

12.8 Data Analysis and Calculations:

12.8.1 If the airflow required to meet the specified reference pressure as determined in 10.7 is exhausted from or supplied to the test enclosure, and the induced enclosure pressure is less than 90% of the specified reference pressure, the building is deemed to fail.

12.8.2 Data shall be analyzed in accordance with ASTM E1827. NOTE: If the pre-test and post-test baseline alternate is chosen, there are two baseline measurements for the test: one before the entire set of replicate induced enclosure pressures, and one after. In this case use the average of the pre-test and post-test baseline measurements as the average baseline for all replicate measurements at the induced enclosure pressure.

12.8.3 In order for a test enclosure to pass, each induced enclosure pressure must be within 10% of the specified induced enclosure pressure.

12.9 If the test result is:

12.9.1 greater than the airtightness specification, the test enclosure fails,

12.9.2 less than or equal to the airtightness specification and the calculated uncertainty is less than or equal to 8% of the airtightness specification then the test enclosure passes,

12.9.3 less than or equal to the airtightness specification and the calculated uncertainty is is greater than 8% and the sum of the test result and the calculated uncertainty is less than or equal to the airtightness specification, the test enclosure passes,

12.9.4 less than or equal to the airtightness specification and the calculated uncertainty is greater than 8% and the sum of the test result and the calculated uncertainty is greater than the airtightness specification, the test enclosure fails.

12.10 Test result will be reported in specified units along with the calculated uncertainty.

13. Collect and Analyze Data for Repeated Two-Point Test

13.1 Pre-test Baseline Pressure: All the test fans shall be turned off and sealed for at least 30 seconds after which a pre-test baseline pressure measurement of at least 120 seconds duration shall be recorded. Baseline measurements shall be the temporal average of the baseline data from all enclosure pressure locations. When analyzing the data, use the same enclosure pressure locations for all baseline enclosure pressures and induced enclosure pressures. Divide the baseline into 12 equal length intervals. Calculate the temporal average of each interval and the standard deviation of these averages. The baseline standard deviation (STDev($P_{base,pre}$) is used in Equation (1) to calculate the minimum allowable induced enclosure pressure.

13.2 Baseline Pressure: Before each measurement at the induced enclosure pressure, all the test fans shall be turned off and sealed for at least 30 seconds or until the building enclosure pressures stabilize, after which a baseline pressure measurement of at least two times the length of the equal length intervals in 13.1 shall be recorded. Baseline measurements shall be the temporal average of the baseline data from all enclosure pressure locations.

13.3 Alternately baseline measurements may be collected before and after the replicate set of induced enclosure pressure measurements described in 13.5 as follows:

13.3.1 Pre-test Baseline Pressure: As defined in 13.1.

13.3.2 Post-test Baseline: All the test fans shall be turned off and sealed for at least 30 seconds, after which a post-test baseline pressure measurement of the same duration as the pre-test baseline shall be recorded. Baseline measurements shall be the temporal average of the baseline data averaged over all enclosure pressure locations.

13.4 Measure and record the indoor and outdoor temperature and wind speed. Determine the site altitude above mean sea level within 300 ft (100 m).

13.5 Induced Enclosure Pressures and Flow Measurements: Measure and record the air flows through all operating test fans for two induced enclosure pressures, a primary and secondary induced pressure (P1and P2). The specified primary and secondary induced reference pressures shall be as determined above in section 10.7. If P1 is not specified, assume 75 Pascals for P1. A minimum of five replicate measurements of pressure and airflow at the primary induced pressure and the secondary induced pressure are required. Ensure enough time has been given between readings to ensure the induced pressure has stabilized. Each induced enclosure pressure and its corresponding flow measurement must occur within 20 seconds of each other. Calculate the minimum induced enclosure pressure using equation (1). For the Repeated Two-point test $P_{induced, min}$ is P2, the secondary induced enclosure pressure. Under windy conditions, if this condition is not met, it is recommended to repeat using a longer pre-test baseline (see Annex X1 for additional guidance). P2 shall not be greater than ⅓ of the primary induced pressure P1. Therefore the sequence of testing shall be the primary induced pressure, P1 followed by the secondary induced pressure P2, in order to establish P2. Each induced enclosure pressure shall be averaged over a minimum of two times the length of the equal length intervals in 13.1. Induced enclosure pressures shall be no lower than 10 Pa and no greater than 100 Pa Air flow measurements shall be the sum of the airflows through all operating test fans.

13.6 In order for a test enclosure to pass, P1 or P2 must be within 10% of the specified reference pressure, the test enclosure leakage within the specified allowable leakage and with a calculated flow exponent, n, between the values of 0.45 and 1.05. If the primary induced enclosure pressure is not within 10% of the specified reference pressure, but the flow exponent is within the allowable range, the test results may be deemed as a legitimate test, but the test enclosure does not pass the leakage requirement. If n is less than 0.5 or greater than 0.9 check test enclosure set-up to determine whether openings have inadvertently opened or closed during the test. If a problem is found, correct the problem and retest. See Appendix X1 for discussion of this issue.

13.7 Maintain Single Zone Conditions: Pressure differences within the test enclosure shall be monitored and recorded (see 10.17.4 for open building exceptions). For a test point to be used in the analysis, the difference between the highest and lowest pressure difference within the test enclosure must be within 10% of the induced enclosure pressure. Make any corrections needed to maintain single zone conditions. Exception: if uniformity was not maintained within 10% during a test, the building may be deemed to pass if the test specification is met when the results are analyzed using only the building enclosure pressure measurements made at the location with the induced enclosure pressure difference with the smallest absolute value..

13.8 Pressurization and Depressurization: Repeat 13.1 through 13.7 for each required test mode (depressurization or pressurization). When performing both pressurization and depressurization measurements, record the pressurization and depressurization data separately, including all preliminary environmental measurements and baseline readings as if you were performing two separate or individual tests.

13.9 Data Analysis and Calculations:

13.9.1 If the airflow required to meet the specified test enclosure pressure as determined in 10.7 is exhausted or supplied to the test enclosure, and the induced enclosure pressure is less than 90% of the specified reference pressure, the building is deemed to fail.

13.9.2 Data shall be analyzed in accordance with ASTM E1827, Section 9. NOTE: If the pre-test and post-test baseline alternate is chosen, there are two baseline measurements for the test: one before the entire set of replicate induced enclosure pressures, and one after. In this case, use the average of the pre-test and post-test baseline measurements as the average baseline for all replicate measurements at the primary induced enclosure pressure and the secondary induced enclosure.

13.10 If the test result is:

13.10.1 greater than the airtightness specification, the test enclosure fails,

13.10.2 less than or equal to the airtightness specification and the calculated uncertainty is less than or equal to 8% of the airtightness specification then the test enclosure passes,

13.10.3 less than or equal to the airtightness specification and the calculated uncertainty is greater than 8% and the sum of the test result and the calculated uncertainty is less than or equal to the airtightness specification, the test enclosure passes,

13.10.4 less than or equal to the airtightness specification and the calculated uncertainty is greater than 8% and the sum of the test result and the calculated uncertainty is greater than the airtightness specification, the test enclosure fails.

13.11 Test result will be reported in specified units along with the calculated uncertainty.

14. Report: The following items are required to be reported by the testing agency

14.1 Testing Agency

14.1.1 Name of Testing Agency

14.1.2 Address of testing agency

14.1.3 Primary point of contact for Testing Agency

14.1.4 Name of person conducting test

14.2 Test Enclosure Description

14.2.1 Location

14.2.1.1 Address of testing site

14.2.2 Elevation above sea level

14.3 Building dimensions as required by test specifications (i.e. air barrier system surface test area of test enclosure or test enclosure volume) and person responsible for computation thereof

14.4 Test Results

14.5 Identification of test enclosure boundaries

14.5.1 If available, reference the air barrier specific pages in the construction drawings, and any modifications thereof

14.5.2 In the event of no air barrier specific pages in the construction drawings, identify test boundaries on floor plans and section drawings as actually tested

14.5.3 In the event there are no construction drawings, provide a diagram or illustration showing the location of test enclosure boundaries

14.5.4 Document whether the test is for a single-zone, two or more subsections tested as a single zone or multiple isolated subsections tested independently

14.6 Test configuration of intentional openings in the test enclosure including:

14.6.1 windows, doors, and other areas for access (open or closed position),

14.6.2 mechanical System Related Penetrations (i.e. louvers, grilles, rooftop and wall-mounted fans, air distribution ductwork that serves areas both inside and outside of the test enclosure),

14.6.2.1 masked/unmasked,

14.6.2.2 location of masking,

14.6.3 plumbing traps (filled with water or otherwise sealed),

14.6.4 Deviations from planned test enclosure configuration and reasons for deviation.

14.7 Test configuration of all HVAC equipment: whether disabled or left running during test

14.8 A statement of the purpose for conducting the test and the test procedure used

14.8.1 Purpose of test (eg. air barrier systems enclosure test or operational building enclosure test)

14.8.2 Type of test: (repeated single point, repeated two-point, multi-point with regression analysis, pressurization or depressurization or both

14.8.3 Any deviation(s) in the test procedure from standard practice and the specific reason for the deviation(s)

14.8.4 A description of any procedures and/or equipment used in order to ensure single zone conditions within the building

14.9 Test equipment used

14.9.1 Number of fans, gauges, and their location(s)

14.9.2 Manufacturer, model, and serial numbers of all equipment

14.9.3 Date of last calibration and calibration certificates

14.9.4 Document the results of field check procedures conducted on test equipment

14.10 Test condition data

14.10.1 General weather conditions (i.e. rainy, cloudy, dry, etc.)

14.10.2 Ambient temperatures and inside building temperatures at beginning and end of test

14.10.3 General wind speed data

14.11 Measured test results in tabular form

14.11.1 Start time of each test

14.11.2 Measured air flows

14.11.3 Measured pressure differentials

14.11.4 End time of each test

14.11.5 Results of measurements demonstrating single zone condition

14.11.6 Final results in units of the test specifications

14.11.7 Calculated uncertainties

14.11.8 For multi-point regression analysis report the flow coefficient and exponent.

14.11.9 For repeatedtwo-point test, report the exponent

14.12 Conclusions

14.12.1 Airtightness specification

14.12.2 Test results using the units of the airtightness specification and associated uncertainty

14.12.3 Determination of pass – fail

15. Precision and Bias Statement

15.1 The precision, bias, and overall measurement uncertainty in the flow at the reference pressure shall be calculated in accordance with the standards from which the methods originate (ASTM E779 and ASTM E1827), with the exceptions noted below. Note that the bias errors herein include only instrumental errors and exclude potential failures of the tested enclosure to conform to the assumptions of the underlying model, such as the establishment of uniform enclosure pressures.

15.2 Regression tests: The precision, bias, and overall uncertainty of regression tests shall be computed using a combination of equations found in ASTM E779-2010 and ASTM E1827-96(2002). The precision shall be calculated according to E779-2010, Section 9.7 using an un-weighted regression. As ASTM-E779 does not provide a method for calculating bias errors, the bias errors shall be calculated according to E1827-96(2002), equation (A3.2). The overall measurement uncertainty shall be calculated as follows:

$$\delta Q = Q\sqrt{\left(\frac{\delta Q_{bias}}{Q}\right)^2 + \left(\frac{\delta Q_{prec,95\%}}{Q}\right)^2}$$

$where\ \delta Q_{bias}$ is the result of equation (A3.2) and $\frac{\delta Q_{prec,95\%}}{Q}$ the relative precision error from the regression, at the 95% confidence level.
Note: The precision errors given by ASTM E779-2010 may be an underestimate of the true precision errors due to the lack of accounting for the precision errors in the baseline pressures.

15.3 Repeated single point tests: The precision, bias, and overall measurement uncertainty of repeated single point tests shall be calculated according to ASTM E1827-96 (2002) section A3.2, equations (A3.1), (A3.2) and (A3.3), respectively. In equation (A3.1) and (A3.2) a flow exponent n = 0.60 shall be used.
15.4 Repeated two-point tests: The precision, bias, and overall measurement uncertainty of repeated two-point tests shall be calculated according to E1827-96 (2002) section A3.3, equations (A3.6), (A3.7), and (A3.8), respectively.
15.5 Reducing precision uncertainties: recommended practice is to add data points to reduce precision uncertainties. Justification must be given for removing data. Justification must include a description of the problem with the data. (e.g door or window opened, failed masking).
NOTE: Distance from the regression line or mean may justify examination of the data conditions but does not constitute a valid justification for removal of data.

16. Keywords

Whole building pressure test, Enclosure, Building enclosure commissioning (BECx), Airtightness, Fan pressure test, Air leakage

Appendixes

(Informative)

X1. Setting Up and Conducting an Airtightness Test

X1.1 This standard includes derived airtightness metrics, required environmental conditions, requirements for preparing a building for an airtightness test, and acceptance criteria to determine whether or not a test enclosure meets an airtightness target.

X1.2 Two primary measurements are made when conducting a building enclosure airtightness test. They are the specified reference pressure and the airflow needed to induce the specified refence pressure across the test enclosure. Normalizing the airflow rate needed to induce the reference enclosure pressure to the surface area of the test enclosure or the test enclosure volume provides metrics that make test results for different test enclosures more comparable. Two common airtightness metrics referenced in this standard are:

1) the airflow (cfm or m^3/hr) required to induce a 75 Pascal pressure difference between the interior of the test enclosure and outdoor air divided by the total surface area (ft^2 or m^2) of the test enclosure (CFM/ft^2 at 75 Pa or m^3/hr/m^2 at 75 Pa) and
2) the airflow in air changes per hour required to induce a 50 Pascal pressure difference between the interior of the test enclosure and outdoor air (ACH at 50 Pa).

The ACH at 50 Pa metric makes the assumption that test enclosure air leakage increases in proportion to volume, while normalizing to the test enclosure surface area assumes that leakage is proportional to the test enclosure surface area. Historically, test results for single family detached housing have been reported in ACH at 50 Pa . Because of variations in surface to volumeratios, ACH at 50 Pa becomes problematic when comparing small buildings to much larger ones. Larger commercial, institutional, industrial, and multi-family buildings have been reported in units of CFM/ft^2 at 75 Pa or m^3/hr/m^2 at 75 Pa – normalizing the test airflow to the surface area of the test enclosure. Normalizing to the test enclosure surface area is an improvement over ACH at 50 Pa but air leakage sites are associated with specific enclosure features, e.g. the roof-wall intersections, intersections between different wall systems, connection to the foundation, complexity of the building shape, and building geometry. For example, the enclosure surface area of a large low rise building is dominated by very large surface areas of materials that are extremely airtight – concrete slab-on-grade foundations and low slope roofing membranes. When normalized by the test enclosure surface area, the test result is likely to be lower than the test result for a taller building with several wings – the surface area of the roofing membrane and foundation slab is a smaller fraction of the total surface area. It is best to compare test results to buildings of similar size and shape.

X1.2.2 Calculating the surface area or volume of the test enclosure:

If the test results are normalized by dividing by the test flow at the specified reference pressure by the surface area of the test enclosure, then any uncertainty in the calculation of the test enclosure area contributes to uncertainty in the test result. The same is true if the test results are normalized by the test enclosure volume in terms of Air Changes Per Hour at a reference pressure. The best way to reduce the uncertainty is to calculate the test enclosure surface area or volume using a uniform protocol. Unless otherwise directed by test specifications, use the following rules:

- Calculate the surface area or volume using the location of the designated air barrier in the roof, ceiling, and above and below grade wall assemblies. Use the interior surface of floors that form the bottom of the test enclosure.
- If air barriers are not designated, use the midpoint of roof, ceiling, and above and below grade wall assemblies that contain thermal insulation intended to divide the test enclosure interior from the exterior. Use the interior surface of floors that form the bottom of the test enclosure.
- Use the projected area of assemblies that contain small scale articulations or ornamentation; for example, if the roof system air barrier consists of fluid applied air barrier and accessories applied to fluted steel deck, the area of the fluted steel deck projected perpendicular to the plane of the roof is calculated. The extended surface area calculated by tracing the flutes is not used.

X1.3 Wind and stack effects can have a significant effect on test results.

Airtightness tests should ideally be conducted during periods with calm wind conditions. However, given the need to schedule tests several days in advance and the difficulty of predicting the weather, this may not be possible. Further, wind has a more pronounced effect on tall buildings than it does on low-rise construction since wind speed tends to increase in magnitude as the elevation above the ground increases.

The test procedure is predicated on the assumption that the indoor-to-outdoor pressure differential experienced by the building will be constant over the building envelope (at any given test condition). Therefore, even a relatively constant wind will distort the pressure fields experienced by the building and introduce bias in the results. Further, fluctuations in wind speed cause variations in the localized indoor-to-outdoor pressure differentials experienced by the building which introduces variations in the localized leakage rates and ultimately in the results. In fact, wind gusts typically cause more problems during airtightness tests than strong but constant winds.

Wind effects can be further accentuated if a large percentage of the building's leakage area is concentrated in a few, relatively large holes which may have their pressures distorted by the wind to a greater, or lesser, extent than the rest of the building envelope. This can be significant for many tall buildings since their intentional openings tend to be concentrated at the top and bottom of the building where the wind effects are often strongest and weakest, respectively. The problems introduced by windy conditions are reduced as buildings become more airtight. It becomes easier to induce the same enclosure pressure at all points on a building as the enclosure becomes tighter.

Most wind data available from the internet or meteorological offices is recorded at or near airports where local wind-shielding is minimal. Further, these measurements are typically made at an elevation of 10 m above the surrounding terrain where the winds are usually stronger than at grade level. As a result, representative wind speeds at the test building may be significantly different from those measured at a nearby airport, especially if the test building is situated within an urban or geographic environment, which provides significant shielding from the wind. Measuring wind at the site is difficult. During windy conditions, wind speed and direction near a building may vary significantly depending on the wind direction, building shape and height, and the effect of surrounding buildings, trees, and landscape features.

These (and other) factors make it difficult to provide firm recommendations on how wind should be treated within the test procedure. However, the following guidelines can be offered:

- Winds should be relatively constant with few heavy gusts.
- Use data in the analysis that is clearly outside of fluctuations caused by wind. Indications of wind-related problems typically appear in the form of large fluctuations in the baseline pressure readings and may also impact the individual induced enclosure pressures. The standard includes methods for determining whether or not fluctuations in the baseline prohibit a test. See 11.3, 12.1, and 13.1. The calculations in these sections are based on fluctuations in the baseline enclosure pressure data, which is something that must be measured for all tests and reflects the impact of wind on the data. Two things that can be done to reduce the impact of wind on baseline measurements are to average enclosure pressure measurements made across multiple faces of the building and to increase the duration of baseline and test measurements.

Indoor-outdoor temperature differences result in stack induced enclosure pressures. Stack pressures depend on the indoor-outdoor temperature difference and the height of a building. Air leakage distribution also has an impact on stack pressures. Compared to fluctuating winds, temperature induced stack pressures have the advantage of being steady. This standard does not put a specific limit on outdoor temperatures and building height. Stack pressure is used in equation (1) for determining the minimum allowable induced enclosure pressure. In addition, the following guidance is given to improve the results of tests conducted when stack pressures are large:

- Collect exterior enclosure pressures at ground level.
- Do not move the exterior enclosure pressure taps to the neutral pressure level.

- Monitor enclosure pressure across the roof so it is known whether the entire building is depressurized or pressurized (do not include roof data in the analysis).
- Conduct both a pressurization and depressurization test.

X1.4 Building preparation can have a major impact on the results of airtightness tests. Building preparation always includes:

- placing the windows, doors and hatches in the test enclosure boundaries in the closed and latched condition,
- placing HVAC systems into the required test mode (see Table 1),
- closing or otherwise sealing all or many of the HVAC related openings,
- creating a single, open zone within the test enclosure:
  - open all interior doors or demonstrate that single zone condition is met with the door closed. Interior and exterior doors in ancillary spaces such as mechanical rooms, entrance foyers, basements and crawlspaces are handled in accordance with 10.6.3.
  - place test equipment to ensure uniform distribution of pressure across all test enclosure boundaries
- placing exterior pressure taps to minimize the effects of wind on test enclosure pressure measurements.

How a building is prepared for testing depends to some extent on the purpose of the test. This standard requires following the preparation requirements in the test specifications for the project. Building preparation requirements for two common test purposes are included in Table 1 – Air barrier systems enclosure test (HVAC-related openings excluded) and Operational enclosure test (air barrier systems and HVAC-related openings included).

X1.4.1 The first option is testing to determine whether or not the air barriers and connections in the wall, window, ceiling/roof and foundation systems of the test enclosure are installed well enough to meet an airtightness target. Air leakage through the HVAC related openings in the test enclosure is considered extraneous air leakage that is outside the scope of the test. Therefore the building is prepared as listed above except that HVAC related penetrations not only have dampers closed but also may be temporarily sealed. The goal of temporary air-sealing is to eliminate air leakage through HVAC related penetrations. Numerous methods have been used to successfully air seal HVAC openings.

- If possible, it is best to air seal where they pass through the air barrier of the test enclosure. Typically the opening will be covered by a terminal device that allows the passage of air but protects the opening from the entry of rain, snow, rodents, birds, and bats. Typical examples are wall louvers, canopies on a roof curb with intakes on the bottom, and roof or wall mounted exhaust or outdoor air make-up fans. The intention is to temporarily seal the interior of the duct or device that conveys air and not the exterior gap between the HVAC penetration and the surrounding wall or roof air barrier. Some examples are:

- a curb-mounted rooftop exhaust fan may not be temporarily sealed to the roofing system air barrier where the fan meets the curb,
- a wall louver may not be sealed to the wall system air barrier where the louvers meet the wall. Address situations where the louvers are not part of the air barrier system.
- Often it is impractical to safely air seal HVAC openings where they pass through the test enclosure. They may be in a location that cannot be safely reached (e.g. on the side of a fourth story wall or a pitched roof with no attachment points for fall protection). There may be several hundred square feet of wall louvers that serve and simultaneously prevent access to multiple exhaust outlets and outdoor air intakes. In cases like this it may be more practical to make a temporary seal at closed motorized outdoor intake or exhaust dampers. The dampers are often located in air handlers or ductwork inside a mechanical room. If the mechanical room is located inside the test enclosure, the ductwork between the dampers and the inlet or outlet in the exterior wall or roof becomes part of the test enclosure. Air leakage in this section of ductwork is included in the test results. The opposite situation occurs if the outdoor or exhaust air dampers in an air handler are temporarily sealed and the mechanical room is outside the test enclosure. Air leakage in the ductwork and air handler cabinet inboard of the sealed dampers is part of the measured test result.
- NOTE: Section 10.12.4 allows tests to be conducted without temporarily sealing all the HVAC related openings and if it meets the specified airtightness target the enclosure is deemed to pass.
- Methods and materials for temporary sealing include:
    - Plastic film with an adhesive that will release without damaging painted surfaces. Self-adhering film is prone to loosing seal when test pressure pushes it off the surfaces. Care must be taken to clean surfaces in order for the film to adhere to the metal louvers or exhaust fan enclosure.
    - Rigid sheet goods (e.g. gypsum board, rigid plastic foam, cardboard, plywood) with tape, gaskets, or masking film used to seal the sheets over the openings.
    - Weights or fasteners to secure sheet goods.
    - NOTE: The location and nature of temporary sealing is dependent on whether pressurization, depressurization, or both tests will be conducted. For example, temporary sealing that is drawn tighter against a set of louvers is unlikely to loose seal, but may be very likely to blow off when tested in the opposite direction.
    - NOTE: In some cases air leakage through coiling overhead doors is considered extraneous. Coiling overhead doors sometimes have strips of

flexible sheets that form a gravity air seal at the open top of the door. These strips provide effective air sealing during depressurization but blow open during pressurization tests. In this respect they are similar to gravity dampers in mechanical systems, which would be temporarily sealed at the outlet or inlet during a test of the air barrier systems.

X1.4.2 The second option is to test the enclosure in a state as close to normal operating conditions as possible. This test is intended to not only test the effectiveness of air barrier systems but also be more representative of energy use for conditioning the building. In this case, air leakage through HVAC penetrations is not automatically assumed to be extraneous. Generally, HVAC related openings are not temporarily sealed and dampers are in the closed position. HVAC related openings are temporarily sealed only if connected to outdoor air make-up or exhaust air fans that operate more than 8000 hours per year. Air flows through them are assumed to be intentional ventilation. NOTE: There are some exceptions for B-vents and dryer vents which may be temporarily sealed for some conditions – see Table 1. Isolated special use areas with dedicated ventilation systems may be isolated from the rest of the building by closing doors between the special area and the rest of the test building. The ventilation system inlets and outlets may have dampers in the closed position but be temporarily sealed only if they meet the greater than 8000 hour per year requirement. Laundry rooms with multiple dryer outlets, vented gas meter rooms, trash or linen chute rooms are examples.

X1.4.3 Placing exterior pressure taps:
The exterior pressure taps provide the reference for measuring enclosure pressures. Wind pressures are the most common cause of uncertainty in the enclosure pressure measurements. Other potential sources of uncertainty include water, temperature change, waggling tubes and air leaks in the tubing used to connect the pressure tap to the manometer. Recommended practice for reducing the impact of wind, water, temperature changes and air leaks includes:

- Exterior pressure taps:
    - Place in locations that result in the most stable enclosure pressure measurement
    - Locate away from potential sources of water (e.g. puddles, hose spigots, gutter downspouts, roof valleys)
    - Place away from test fan airflows
    - Terminate the tubing using a fitting that:
        - makes it hard for wind pressure to impact the end of the tubing
        - makes it hard for water to enter the tubing
- Single exterior pressure tap:
    - If a single exterior pressure tap is used, the downwind side of the building is a preferred location. Avoid the windward side of the building.
    - A pressure tap placed at the intersection of the exterior wall and grade are assumed to be at stagnation pressures, reducing the effect of wind impinging on

the end of the tube. Place in a sheltered location that is some distance from a potential source of eddy currents.
  - A pressure tap placed in open spaces far enough away from the building to avoid eddy currents and stagnation pressures has proved to be an acceptable location (Minimum of 5 times building height). In this case the pressure tap may be located upwind of the building. Tubing that extends far from the building is more vulnerable to interference.
- Averaging across multiple faces of the building: Averaging enclosure pressures across multiple exterior walls reduces the impact of gusts on analysis results:
  - Place on all four sides if possible
  - Place at wall-grade intersection in sheltered locations away from potential eddy currents
  - Pressure across multiple walls can be averaged using manifolded tubing or calculating the arithmetic average of multiple individual enclosure pressure measurements.
- Tubing:
  - Avoid problems with tubing temperature changes affecting pressure measurments:
    - Place tubing out of direct sunlight when possible
    - Place tubing out of the test fan airflow, especially on days with large indoor-outdoor temperature differences
    - Stack effect in vertical tubing aggravates problems caused by tubing temepratures
  - Use tubing that is less than 100 feet long if the tubing is 1/8 inch inner diameter (ID) when possible. If longer runs must be used then test tubing for air leaks.
  - If the above conditions cannot be met be certain the system has reached steady-state when changing test flows.

X1.4.4 Placing interior pressure taps:
Interior pressure taps are used as the input for enclosure pressure measurements or to determine whether or not single zone conditions have been achieved.

- Place interior enclosure pressure taps where:
  - they are not impacted by test fan airflows,
  - are out of direct sunlight.
- Place interior single zone pressure monitoring taps so they are measuring the pressure difference between test fans areas and remote parts of the building separated by the most restrictive airflow paths.

X1.4.5 There are several factors to consider when placing test fans in exterior doors or windows:

- Prior to the test, an assessment should also be made of the contents and operation of the building that may be damaged by changes in temperature during the test. Caution should also be exercised to insure that no contaminants are drawn into the building during the test. All security issues must be addressed with the owner prior to the test being conducted.

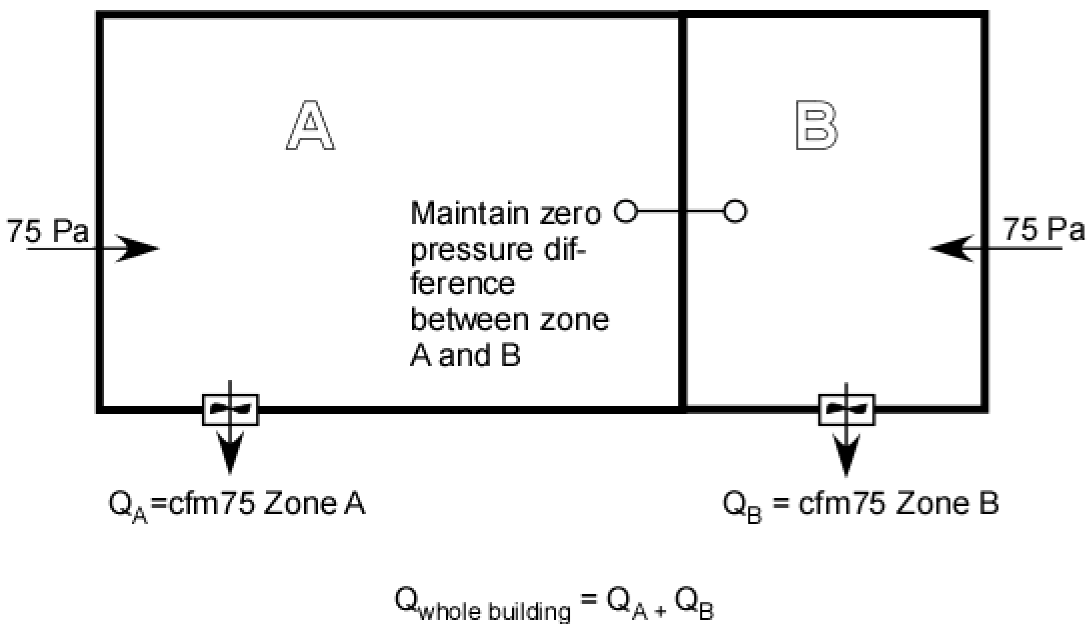
- Wind direction: Do not place test fans on the windward side of a building unless the test cannot otherwise take place.
- Availability of sufficient electric power: Typically a single test fan requires a separate electric circuit. If three test fans are located in a single door opening, then three circuits within reach of the door location must be available. NOTE: Some trailer mounted test fans use gasoline powered motors.
- Creating uniform pressure distribution on the test enclosure: Whether or not a single zone condition has been achieved is determined by interior pressure difference measurements. It is recommended that interior pressure differences be measured and recorded electronically but they may be measured and recorded by hand. Planning test fan locations to make it easy or possible to achieve single zone conditions is good practice. The following bullets provide guidance for locating test fans so single zone conditions can be created:
    - Place test fans in a single open zone that is connected to interior portions of the building with the most unrestricted pathway. For example, in a large warehouse with one or two interior partitions place the test fans anywhere in the large zone. In a tall building with a central atrium with rooms only on the exterior perimeter, locate fans in the atrium. In low-rise buildings with double loaded corridors, locate fans in exterior doors that open to the corridor.
    - If the building is divided into two or more areas by demising walls or floors with few doors, passages, or HVAC ducts connecting them, if more than one test fan is needed then the test fans must be distributed to ensure uniform enclosure pressure distribution. For example, good practice for a single story building with two zones connected by a single 2900 square inch man-door would be to place test fans in each section of the building.
        - Analyzing floor plans and sections to determine where to place fans in buildings that are internally divided: Buildings may be divided internally horizontally by demising walls with few openings through them and vertically by upper story floors with only stairwells connecting them.
            - Examine all floor plans.
            - Identify all exterior doors that open into the test enclosure from outdoors and are suitable for placing test fans (e.g. they are in a size range you can install fans and shrouds, there are enough live, separate circuits to power the fans).
            - Identify the exterior doors that open into the largest indoor space with the most interior doors opening into other parts of the

building (e.g. lobbies, atria, central corridors, fire egress stairwells).

- Estimate how many fans can be setup in that location while maintaining single zone conditions:
  - Calculate the total area of open doors that lead from the open space to other parts of the test enclosure (do not count doors that open into dead-end rooms with no other doors leaving them). Use the following equation to estimate the amount of airflow that can be exhausted from or blown into the space:
    - $Q(cfm) = 1.07 \times Area\ (in^2) \times (0.10 \times \Delta Pmax)^{0.5}$ (Pascals)
  - Where:
    - Q(cfm) = Maximum airflow that can be placed in the door opening,
    - Area (in^2) = calculated total area of the doors identified as opening into other parts of the test enclosure,
    - ΔPmax (Pascals) = the maximum expected enclosure pressure that will be induced between inside and outside during the test.
  - Divide Q(cfm) by the airflow of a test fan when operated at ΔPmax to get the number of test fans that can be set up in the largest indoor space.
  - If this is not enough flow to conduct the test, apply the same logic to the next largest space that opens into other portions of the test enclosure.

- If the building is divided into two or more areas by demising walls with no intentional openings connecting them, they can be tested by placing test fans in each portion of the building and conducting a single zone test by maintaining the pressure between each portion as close to zero* as possible. Consider a building divided into two areas, area A and area B by a fire-wall with no intentional openings in it. Test fans would be placed in each of the two areas separated by the fire-wall. Area A test fans would be controlled to induce test pressure between the inside of area A and outside, while the other set is controlled to maintain zero Pascals pressure difference between area A and area B. As long as the pressure difference between area A and area B is less than 10% of the induced test pressures, single zone conditions have been met. This method produces separate test flows for area A, area B and the whole building.

*NOTE: If the baseline pressure difference between zone A and B is not zero, then the baseline pressure difference between the two zones would be maintained during testing.



X1.5 Verify test enclosure setup and test equipment function for depressurization and pressurization tests:

Check the building setup prior to starting the test and immediately after the test is complete:

confirm pre & post test that all intentional openings are configured per Table 1 (See section 10.12).

Check test equipment function prior to starting each test:

perform manufacturer’s recommended field checks for tubing, pressure gauges, and test fans,

ensure that each test fan is actually operating and blowing the correct direction,

ensure that each test fan is delivering a flow signal roughly corresponding to the control signal being sent to the test fan,

turn test fans on to ensure the maximum enclosure pressure can be achieved. NOTE: More flow is often required for pressurization tests,

check that doors, intentional openings and dampers that do not positively latch or are not held firmly closed, do not open under maximum test pressure.

check interior pressure differences to determine whether they comply with the requirements of 11.4, 12.5 or 13.7,

compare the test enclosure pressure between at least two independent pressure tubes passing from inside to outside the test enclosure to ensure the enclosure pressure tubing is functioning correctly, ensure all test fans are on the correct flow ring configuration and an adequate flow pressure signal is attained from each test fan. Refer to manufacturer's instructions for further guidance.

X1.6 Location of air leaks:
If air leakage sites are to be identified refer to ASTM E1186.

Examples of commonly found air leakage sites include:

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- top of the building
- soffits
- bottom of the building
- expansion joints
- major transitions
- ancillary spaces (mechanical rooms, vented basements and crawlspaces)
- mechanical system penetrations
- windows and doors

X1.7 Interpreting Test Results:

X1.7.1 Calculated exponent for Multipoint Regression: Theoretically it is possible for the exponent, n, to lie between 0.50 and 1.0. To allow for uncertainty and test enclosure with unusually sharp-edged or laminar air leaks Section 11.8.3 allows results between 0.45 and 1.05. However, it is an unusual event if a calculated n is less than 0.50 or greater than 0.90. If a calculated n lies outside these bounds it may be a good test on an unusual test enclosure or it may be that the leakage characteristics of the enclosure changed during the the test. The most likely cause for n being greater than 0.90 is an intentional penetration blowing open changing the slope of the regression line at higher pressures – e.g. gravity dampers, exterior doors or temporary masking coming loose from an HVAC related penetration.