Designation: E 1827 – 96 (Reapproved 2007)

Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door[1]

This standard is issued under the fixed designation E 1827; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods describe two techniques for measuring air leakage rates through a building envelope in buildings that may be configured to a single zone. Both techniques use an orifice blower door to induce pressure differences across the building envelope and to measure those pressure differences and the resulting airflows. The measurements of pressure differences and airflows are used to determine airtightness and other leakage characteristics of the envelope.

1.2 These test methods allow testing under depressurization and pressurization.

1.3 These test methods are applicable to small indoor-outdoor temperature differentials and low wind pressure conditions; the uncertainty in the measured results increases with increasing wind speeds and temperature differentials.

1.4 These test methods do not measure air change rate under normal conditions of weather and building operation. To measure air change rate directly, use Test Methods E 741.

1.5 The text of these test methods reference notes and footnotes that provide explanatory material. These notes and footnotes, excluding those in tables and figures, shall not be considered as requirements of the standard.

1.6 *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 7.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

E 456 Terminology Relating to Quality and Statistics

E 631 Terminology of Building Constructions

E 741 Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution

E 779 Test Method for Determining Air Leakage Rate by Fan Pressurization

E 1186 Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems

E 1258 Test Method for Airflow Calibration of Fan Pressurization Devices

2.2 *ISO International Standard:*[3]

ISO 9972 Thermal Insulation—Determination of Building Airtightness—Fan Pressurization Method

2.3 *Other Standard:*[3]

ANSI/ASME PTC 19.1—Part 1, Measurement Uncertainty, Instruments, and Apparatus

3. Terminology

3.1 *Definitions*—Refer to Terminology E 456 for definitions of accuracy, bias, precision, and uncertainty.

3.1.1 ACH_{50}, *n*—the ratio of the air leakage rate at 50 Pa (0.2 in. H_2O), corrected for a standard air density, to the volume of the test zone (1/h).

3.1.2 *air leakage rate,* Q_{env}, *n*—the total volume of air passing through the test zone envelope per unit of time (m^3/s, ft^3/min).

3.1.3 *airtightness*, *n*—the degree to which a test zone envelope resists the flow of air.

NOTE 1—ACH_{50}, air leakage rate, and effective leakage area are examples of measures of building airtightness.

3.1.4 *blower door*, *n*—a fan pressurization device incorporating a controllable fan and instruments for airflow measurement and building pressure difference measurement that mounts securely in a door or other opening.

3.1.5 *building pressure difference, P*, *n*—the pressure difference across the test zone envelope (Pa, in. H_2O).

3.1.6 *fan airflow rate,* Q_{fan}, *n*—the volume of airflow through the blower door per unit of time (m^3/s, ft^3/min).

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[1] These test methods are under the jurisdiction of ASTM Committee E06 on Performance of Buildings and are the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventilation Performance.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.1.7 *nominal airflow rate, Q_{nom}, n*—the flow rate indicated by the blower door using the manufacturer's calibration coefficients (m^3/s, ft^3/min).

3.1.8 *orifice blower door*, *n*—a blower door in which airflow rate is determined by means of the pressure drop across an orifice or nozzle.

3.1.9 *precision index of the average*, *n*—the sample standard deviation divided by the square root of the number of samples.[3]

3.1.10 *pressure station*, *n*—a specified induced change in the building pressure difference from the initial zero-flow building pressure difference (Pa, in. H_2O).

3.1.11 *single zone*, *n*—a space in which the pressure differences between any two places, as indicated on a manometer, differ by no more than 2.5 Pa (0.01 in. H_2O) during fan pressurization at a building pressure difference of 50 Pa (0.2 in. H_2O) and by no more than 5 % of the highest building pressure difference achieved.

NOTE 2—A multiroom space that is interconnected within itself with door-sized openings through any partitions or floors is likely to satisfy this criterion if the fan airflow rate is less than 3 m^3/s ($6 \times 10^3 ft^3$/min) and the test zone envelope is not extremely leaky.

3.1.12 *test zone*, *n*—a building or a portion of a building that is configured as a single zone for the purpose of this standard.

NOTE 3—For detached dwellings, the test zone envelope normally comprises the thermal envelope.

3.1.13 *test zone envelope*, *n*—the barrier or series of barriers between a test zone and the outdoors.

NOTE 4—The user establishes the test zone envelope at such places as basements or neighboring rooms by choosing the level of resistance to airflow between the test zone and outdoors with such measures as opening or closing windows and doors to, from, and within the adjacent spaces.

3.1.14 *zero-flow building pressure difference*, *n*—the natural building pressure difference measured when there is no flow through the blower door.

3.2 *Symbols*—The following is a summary of the principal symbols used in these test methods:

Alt	=	altitude at site, m (ft),
C	=	flow coefficient at standard conditions, m^3/s (Pa^n) ft^3/min (in. H_2O^n),[4]
L	=	effective leakage area at standard conditions, m^2($in.^2$),
n	=	envelope flow exponent (dimensionless),
P	=	building pressure difference (see 3.1.5),
P_1	=	average pressure, $\bar{P}_{sta}$, at the primary pressure station, Pa (in. H_2O),
P_2	=	average pressure, $\bar{P}_{sta}$, at the secondary pressure station, Pa (in. H_2O),
P_{ref}	=	the reference pressure differential across the building envelope, Pa (in. H_2O),
P_{sta}	=	station pressure, Pa (in. H_2O),
P_{test}	=	test pressure, Pa (in. H_2O),
P_{zero1}	=	zero-airflow pressure before test, Pa (in. H_2O),
P_{zero2}	=	zero-airflow pressure after test, Pa (in. H_2O),
Q_{env}	=	the air leakage rate, m^3/s (ft^3/min),
Q_{env1}	=	average air leakage rate, $\bar{Q}_{env}$, at the primary pressure station, m^3/s (ft^3/min),
Q_{env2}	=	average air leakage rate, $\bar{Q}_{env}$, at the secondary pressure station, m^3/s (ft^3/min),
Q_{fan}	=	fan airflow rate (see 3.1.6),
Q_{nom}	=	nominal airflow rate (see 3.1.7),
T	=	temperature,° C (°F),
t	=	value from a two-tailed student t table for the 95 % confidence level,
δn	=	measurement uncertainty of the envelope flow exponent (dimensionless),
V_{zone}	=	volume of the test zone, m^3(ft^3),
δQ_{env}	=	measurement uncertainty of the average air leakage rate, m^3/s (ft^3/min),
δQ_{50}	=	the measurement uncertainty of Q_{50}, m^3/s (ft^3/min),
δQ_{bias}	=	estimated bias of the flow rate, m^3/s (ft^3/min),
δQ_{bias1}	=	estimated bias of the flow rate at the primary pressure station, m^3/s (ft^3/min),
δQ_{bias2}	=	estimated bias of the flow rate at the secondary pressure station, m^3/s (ft^3/min),
$\delta Q_{precision}$	=	precision index of the average measured flow rate, m^3/s (ft^3/min),
δQ_{prec1}	=	precision index of the average measured flow rate at the primary pressure station, m^3/s (ft^3/min),
δQ_{prec2}	=	precision index of the average measured flow rate at the secondary pressure station, m^3/s (ft^3/min),
δP	=	measurement uncertainty of the average measured pressure differential across the building envelope, Pa (in. H_2O),
δP_{bias}	=	estimated bias of the pressure differential across the building envelope, Pa (in. H_2O),
δP_{bias1}	=	estimated bias of the pressure differential across the building envelope at the primary pressure station, Pa (in. H_2O),
δP_{bias2}	=	estimated bias of the pressure differential across the building envelope at the secondary pressure station, Pa (in. H_2O),
$\delta P_{precision}$	=	precision index of the average measured pressure differential across the building envelope, Pa (in. H_2O),
δP_{prec1}	=	precision index of the average measured pressure differential across the building envelope at the primary pressure station, Pa (in. H_2O),
δP_{prec2}	=	precision index of the average measured pressure differential across the building envelope at the secondary pressure station, Pa (in. H_2O),

δV_{zone} = measurement uncertainty of the zone volume, $m^3(ft^3)$,
μ = dynamic viscosity, kg/m·s (lbm/ft·hr),
ρ = air density, $kg/m^3(lbm/ft^3)$, and
ρ_{cal} = air density at which the calibration values are valid, $kg/m^3(lbm/ft^3)$.

4. Summary of Test Methods

4.1 *Pressure versus Flow*—These test methods consist of mechanical depressurization or pressurization of a building zone during which measurements of fan airflow rates are made at one or more pressure stations. The air leakage characteristics of a building envelope are evaluated from the relationship between the building pressure differences and the resulting airflow rates. Two alternative measurement and analysis procedures are specified in this standard, the single-point method and the two-point method.

4.1.1 *Single-Point Method*—This method provides air leakage estimates by making multiple flow measurements near $P_1 = 50$ Pa (0.2 in. H_2O) and assuming a building flow exponent of $n = 0.65$.

4.1.2 *Two-Point Method*—This method provides air leakage estimates by making multiple flow measurements near $P_1 = 50$ Pa (0.2 in. H_2O) and near $P_2 = 12.5$ Pa (0.05 in. H_2O) that permit estimates of the building flow coefficient and flow exponent.

5. Significance and Use

5.1 *Airtightness*—Building airtightness is one factor that affects building air change rates under normal conditions of weather and building operation. These air change rates account for a significant portion of the space-conditioning load and affect occupant comfort, indoor air quality, and building durability. These test methods produce results that characterize the airtightness of the building envelope. These results can be used to compare the relative airtightness of similar buildings, determine airtightness improvements from retrofit measures applied to an existing building, and predict air leakage. Use of this standard in conjunction Practice E 1186 permits the identification of leakage sources and rates of leakage from different components of the same building envelope. These test methods evolved from Test Method E 779 to apply to orifice blower doors.

5.1.1 *Applicability to Natural Conditions*—Pressures across building envelopes under normal conditions of weather and building operation vary substantially among various locations on the envelope and are generally much lower than the pressures during the test. Therefore, airtightness measurements using these test methods cannot be interpreted as direct measurements of natural infiltration or air change rates that would occur under natural conditions. However, airtightness measurements can be used to provide air leakage parameters for models of natural infiltration. Such models can estimate average annual ventilation rates and the associated energy costs. Test Methods E 741 measure natural air exchange rates using tracer gas dilution techniques.

5.1.2 *Relation to Test Method E 779*—These test methods are specific adaptations of Test Method E 779 to orifice blower doors. For nonorifice blower doors or for buildings too large to use blower doors, use Test Method E 779.

5.2 *Single-Point Method*—Use this method to provide air leakage estimates for assessing improvements in airtightness.

5.3 *Two-Point Method*—Use this method to provide air leakage parameters for use as inputs to natural ventilation models. The two-point method uses more complex data analysis techniques and requires more accurate measurements (Tables X1.1 and X1.2) than the single-point method. It can be used to estimate the building leakage characteristics at building pressure differences as low as 4 Pa (0.016 in. H_2O). A variety of reference pressures for building envelope leaks has been used or suggested for characterizing building airtightness. These pressures include 4 Pa (0.016 in. H_2O), 10 Pa (0.04 in. H_2O), 30 Pa (0.12 in. H_2O), and 50 Pa (0.2 in. H_2O). The ASHRAE *Handbook of Fundamentals* uses 4 Pa.

5.4 *Depressurization versus Pressurization*—Depending on the goals of the test method, the user may choose depressurization or pressurization or both. This standard permits both depressurization and pressurization measurements to compensate for asymmetric flow in the two directions. Depressurization is appropriate for testing the building envelope tightness to include the tightness of such items as backdraft dampers that inhibit infiltration but open during a pressurization test. Combining the results of depressurization and pressurization measurements can minimize wind and stack-pressure effects on calculating airtightness but may overestimate air leakage due to backdraft dampers that open only under pressurization.

5.5 *Effects of Wind and Temperature Differences*—Calm winds and moderate temperatures during the test improve precision and bias. Pressure gradients over the envelope caused by inside-outside temperature differences and wind cause bias in the measurement by changing the building pressure differences over the test envelope from what would occur in the absence of these factors. Wind also causes pressure fluctuations that affect measurement precision and cause the data to be autocorrelated.

6. Apparatus

6.1 *Blower Door*—An orifice blower door (see Fig. 1).

6.2 *Measurement Precision and Bias*—Appendix X1 lists recommended values for the precision and bias of the measurements of airflow, pressure difference, wind speed, and temperature to obtain the precision and bias for test results described in 11.2 for the single-point method and 11.3 for the two-point method.

6.2.1 *Fan with Controllable Flow*—The fan shall have sufficient capacity to generate at least a 40 Pa (0.20 in. H_2O) building pressure difference in the zone tested and be controllable over a calibrated range sufficient to generate the building pressure differences required by this standard.

NOTE 5—For testing most single family houses, a range of airflows from 0.1 to 3 m^3/s (200 to 6000 ft^3/min) is usually adequate.

6.2.2 *Airflow Measurement*—The procedure for calibrating the airflow measurement device shall be provided with the instrument together with estimates of the precision and bias of

[4] Historically, a variety of other units have been used.

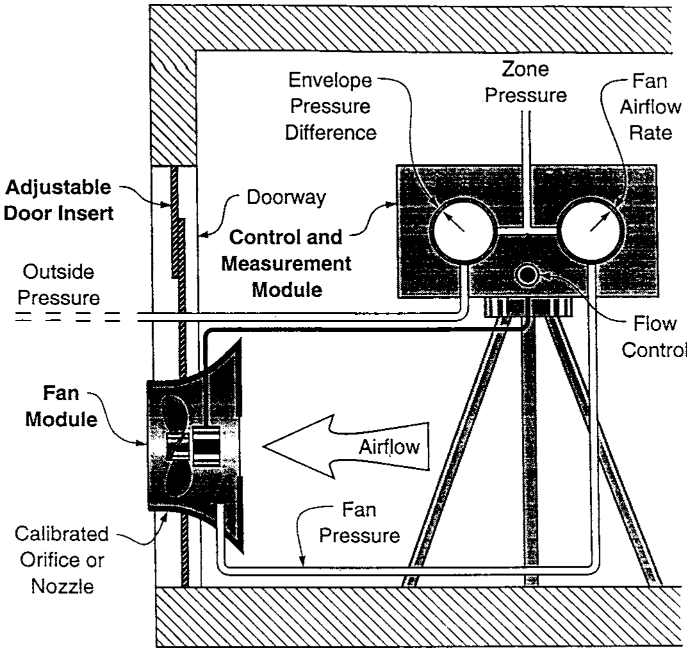

FIG. 1 Blower Door Assembly

the instrument. The air density (ρ_{cal}) for which any calibration equations or tables were calculated shall be reported. If the instrument automatically compensates for changes in air density, the instructions shall note this fact.

6.2.3 *Pressure Measurement*—The procedure for calibrating the pressure measurement device shall be provided with the instrument together with estimates of the precision and bias of the instrument.

6.3 *Wind Speed Measurement (two-point method only)*—A device to measure the site wind speed.

6.4 *Air Temperature Measurement*—A thermometer or electronic sensor with readout.

6.5 *Barometer (optional)*—A device to measure the site barometric pressure.

6.6 *Data Acquisition (optional)*—Automated data acquisition equipment to record (in machine readable form) data on airflow and building pressure differences within 10 s of each other and (optionally) temperature, wind speed, and barometric pressure.

6.7 *Pressure and Flow Measurement System (two-point method only)*—The flow and pressure measurement system shall measure flow and pressure differentials within 20 s of each other.

6.8 *Wind Pressure Averaging System (optional)*—A system to reduce the effect of pressure variations from static probes outside the building envelope and of pressure fluctuations over time. It shall have a manifold that accepts multiple tubes of equal lengths sufficient to reach representative surfaces of the building.

7. Hazards

7.1 *Eye Protection*—Glass should not break at the building pressure differences normally applied to the test structure. However, for added safety, adequate precautions such as the use of eye protection should be taken to protect the personnel.

7.2 *Safety Clothing*—Use safety equipment required for general field work, including safety shoes and hard hats.

7.3 *Equipment Guards*—The air-moving equipment shall have a proper guard or cage to house the fan or blower and to prevent accidental access to any moving parts of the equipment.

7.4 *Noise Protection*—Make hearing protection available for personnel who must be close to the noise that may be generated by the fan.

7.5 *Debris and Fumes*—The blower or fan forces a large volume of air into or out of a building while operating. Exercise care not to damage plants, pets, occupants, or internal furnishings due to influx of cold or warm air. Exercise similar cautions against sucking debris or exhaust gases from fireplaces and flues into the interior of the building. Active combustion devices require a properly trained technician to shut them off or to determine the safety of conducting the test.

8. Procedure

8.1 *Establish Test Objectives*—Determine the configuration of the building envelope to be tested. The most common objectives are to evaluate the effect of construction quality on leaks in the building envelope (hereafter called closed) or to assess the envelope's impact on natural air change rates (hereafter called occupied). Choose the envelope condition appropriate to the objective.

8.1.1 *Residential Construction*—Use Table 1 to determine the recommended test envelope conditions for residential construction.

8.1.1.1 *Closed*—Close all operable openings and seal other intentional openings to evaluate envelope airtightness without including intentional openings.

8.1.1.2 *Occupied (default)*—Leave all operable openings in the conditions typical of occupancy to assess the envelope's effect on natural air change rates. This shall be the default option if no compelling reason exists to choose 8.1.1.1.

8.2 *Ancillary Measurements*:

8.2.1 *Environmental Measurements*—Measure and record the wind speed 2 m (6 ft) above the ground and 10 m (30 ft) upwind from the building, when practical, outside temperature, and inside temperature at the beginning of each fan pressurization test. Circle or otherwise emphasize the readings if wind speed is greater than 2 m/s (4 mph) or outside temperature is outside the bounds of 5 to 35°C (41 to 95°F).

8.2.2 *Determine Site Altitude*—Determine the altitude of the measurement site, *Alt* in m or ft, above mean sea level within 100 m (3×10^2 ft).

8.3 *Building Preparation*:

8.3.1 *Establish Test Zone Envelope*—Define the test zone envelope appropriate for the goals of the test. Open all doors, windows, and other openings that connect portions of the building outside the test zone envelope with the outdoors.

NOTE 6—For example, if the first floor is to be the lower boundary of the test zone envelope, open basement doors and windows. If the floor and the basement are part of the test zone envelope, close those doors and windows.

8.3.2 *Establish Test Zone*—All interior building doors in the test zone shall be open to create a uniform inside pressure. If

TABLE 1 Recommended Test Envelope Conditions

Building Component	Envelope Conditions	
	Occupied (Default)	Closed
Vented combustion appliance	Off	Off
Pilot light	As found	As found
Flue to nonwood combustion appliance	Sealed	No preparation
Flues for fireplaces and wood stoves with dampers	Closed	Closed
Flues for fireplaces and wood stoves without dampers	Ashes removed	Ashes removed
Fireplace and wood stove doors and air inlet dampers	Closed	Closed
Fireplace without firebox doors	No preparation	No preparation
Furnace room door for furnace outside test zone	Closed	Closed
Combustion air intake damper for wood stove or fireplace	Closed	Closed
Make up air intake damper for furnace inside test zone	Sealed	Closed
Make up air intake for furnace inside test zone without damper	Sealed	No preparation
Exhaust and supply fans	Off	Off
Fan inlet grills with motorized damper	Closed	Closed
Fan inlet grills without motorized damper	Sealed	No preparation
Ventilators designed for continuous use	Sealed	Sealed
Supply and exhaust ventilator dampers	Sealed	Held closed
Clothes dryer	Off	Off
Clothes dryer vent	No preparation	No preparation
Ventilation to other zones	Sealed	Sealed
Windows and exterior doors	Latched	Latched
Window air conditioners	Sealed	No preparation
Openings leading to outside the test zone	Closed	Closed
Openings within the test zone	Open	Open
Floor drains and plumbing traps	Filled	Filled

door-sized openings are not present within the test zone, perform measurements to confirm that the single-zone criterion referred to in 3.1.11 has been met.

8.3.3 *Building Components*—To follow the recommended preparation of a residential building, choose the column in Table 1 appropriate for the purpose of the test. Adjust all building components in accordance with the appropriate entry in Table 1.

8.4 *Blower Door Measurements*:

8.4.1 *Installation*—Install the blower door in an entry with minimal obstructions of airflow to and from the rest of the building. Orient the blower door appropriately for depressurization or pressurization as required.

8.4.2 *Zero the Pressure Sensor*—Connect the inside-outside pressure sensor ports together and zero the pressure difference sensor. Reconnect the inside-outside pressure sensor to measure the pressure difference across the envelope.

NOTE 7—Some blower doors may perform this or an equivalent step automatically. Follow the manufacturer's instructions accordingly. When mechanical pressure gauges are used, obtaining a reproducible gauge zero may require running the gauges over their full scale several times until a reproducible zero can be demonstrated. The gauges should return to within 1 Pa (0.004 in. H_2O) of zero after a measurement.

8.4.3 *Primary Pressure Station*—The target primary station for induced building pressure difference shall be $P_1 = 50$ Pa (0.20 in. H_2O). A minimum of five replicate measurements of pressure and airflow at the primary pressure station are required. For the single-point method, only primary-station pressures are required. If 50 Pa is not achieved, use the highest sustainable pressure obtained.

8.4.4 *Secondary Pressure Station (two-point method)*—When using the two-point method, the secondary target pressure station shall be $P_2 = 12.5$ Pa (0.05 in. H_2O). A minimum of five replicate measurements of pressure and airflow at the secondary pressure station are required. In all cases P_2 shall be less than or equal to one third of $P_1 (P_1 \geq 3\ P_2)$.

8.4.5 *Determining the Zero-Flow Pressure Difference*—Before and after each measurement at a pressure station, seal the fan opening in the blower door. Measure and record the inside-outside pressure differential at zero airflow in Pa (in. H_2O).

8.4.6 *Pressure and Flow Measurements*—For each replicate measurement, measure and record the airflow rate in cubic metres per second (cubic feet per minute). Record the measured value for pressure each time in Pa (in. H_2O). Pressure and flow measurements must occur within 20 s of each other.

8.4.7 *Pressurization and Depressurization*—When performing both pressurization and depressurization measurements, record the pressurization and depressurization data separately and perform separate calculations.

9. Data Analysis and Calculations

9.1 *Station Pressure Calculation*:

9.1.1 *Test Station Pressure*—Calculate the station pressure for each replicate measurement, using Eq 1:

$$P_{sta} = P_{test} - \left(\frac{P_{zero1} + P_{zero2}}{2} \right) \tag{1}$$

where:

P_{sta} = station pressure, Pa (in. H_2O),
P_{test} = test pressure, Pa (in. H_2O),
P_{zero1} = zero-airflow pressure before replicate measurement, Pa (in. H_2O), and
P_{zero2} = zero-airflow pressure after replicate measurement, Pa (in. H_2O).

9.1.2 *Station Pressure Averages*—For all replicates at a station pressure, calculate the average P_{sta}, $\bar{P}_{sta}$, and standard deviation of the values of P_{sta}.

9.2 *Flow Calculation*:

9.2.1 *Calculate Air Densities*—Use Eq 2 to calculate inside air density or Eq 3 to calculate outside air density. (Use Eq A4.1 and A4.2 for inch-pound units.)

$$\rho_{in} = 1.2041\left(\frac{1-0.0065\cdot Alt}{293}\right)^{5.2553}\left(\frac{293}{T_{in}+273}\right) \quad (2)$$

$$\rho_{out} = 1.2041\left(\frac{1-0.0065\cdot Alt}{293}\right)^{5.2553}\left(\frac{293}{T_{out}+273}\right) \quad (3)$$

where:
Alt = altitude at site, m,
ρ = air density, kg/m^3, and
T = temperature,° C.

NOTE 8—The standard conditions used in calculations in this standard are 20°C (68°F) for temperature, 1.2041 kg/m^3(0.07517 lbm/ft^3) for air density, and mean sea level for altitude.

9.2.2 *Calculate Dynamic Viscosities*—Calculate the dynamic viscosities for inside ($\mu_{in} = \mu$, when $T = T_{in}$) and outside ($\mu_{out} = \mu$, when $T = T_{out}$) air at the site using Eq A5.1 or Eq A5.2.

9.2.3 *Nominal Airflow Rate*—Use the manufacturer's calibration coefficient values to convert all measurements to nominal airflow, Q_{nom}. Include raw data for flow calculations in the test report.

9.2.4 *Fan Airflow Rate*—Calculate fan airflow rate for depressurization if the apparatus does not provide an automatic calculation. Use Eq 4 for depressurization or Eq 5 for pressurization, as follows:

$$Q_{fan} = Q_{nom}\left(\frac{\rho_{cal}}{\rho_{in}}\right)^{0.5} \quad (4)$$

$$Q_{fan} = Q_{nom}\left(\frac{\rho_{cal}}{\rho_{out}}\right)^{0.5} \quad (5)$$

where:
Q_{fan} = the fan airflow rate, m^3/s (ft^3/min),
Q_{nom} = the fan airflow rate uncorrected for air density and dynamic viscosity, m^3/s (ft^3/min), and
ρ_{cal} = air density at which the calibration values are valid, kg/m^3(lbm/ft^3).

9.2.5 *Calculate Air Leakage Rate*—Convert all the fan airflow rates to air leakage rates, the air leakage passing through the test zone envelope. Use Eq 6 for depressurization and Eq 7 for pressurization:

$$Q_{env} = Q_{fan}\left(\frac{\rho_{in}}{\rho_{out}}\right) \quad (6)$$

$$Q_{env} = Q_{fan}\left(\frac{\rho_{out}}{\rho_{in}}\right) \quad (7)$$

where:
Q_{env} = the air leakage rate, m^3/s (ft^3/min).

9.3 *Single-Point Method*:

9.3.1 *Air Leakage at 50 Pa (0.2 in. H_2O)*—Calculate the average of the values of Q_{env}, $\bar{Q}_{env}$, and the standard deviation of the values of Q_{env}. Estimate the standard air leakage rate at 50 Pa (0.2 in. H_2O) using Eq 8 for depressurization and Eq 9 for pressurization. (For inch-pound units, use Eq A4.3 or Eq A4.4.)

$$Q_{50} = Q_{env1}\left(\frac{50\ \text{Pa}}{P_1}\right)^{0.65}\left(\frac{\rho_{out}}{1.2041}\right)^{0.35}\left(\frac{\mu_{out}}{0.00001813}\right)^{0.3} \quad (8)$$

$$Q_{50} = Q_{env1}\left(\frac{50\ \text{Pa}}{P_1}\right)^{0.65}\left(\frac{\rho_{in}}{1.2041}\right)^{0.35}\left(\frac{\mu_{in}}{0.00001813}\right)^{0.3} \quad (9)$$

where:
P_1 = average pressure, $\bar{P}_{sta}$, at the primary pressure station, Pa, and
Q_{env1} = average air leakage rate, $\bar{Q}_{env}$, at the primary pressure station, m^3/s.

9.3.2 ACH_{50}—As an option, calculate ACH_{50} using Eq 10. (For inch-pound units, use Eq A4.5.)

$$ACH_{50} = \left(\frac{3600\cdot Q_{50}}{V_{zone}}\right) \quad (10)$$

where:
V_{zone} = volume of the test zone, m^3.

9.3.3 *Calculation of Uncertainty*—Calculate the uncertainty of $\bar{Q}_{env}$ using A3.2. As an option, calculate the uncertainty of ACH_{50} using A3.2.

9.4 *Two-Point Method*:

9.4.1 *Calculation of Flow Exponent, Flow Coefficient, and Effective Leakage Area*—Calculate the average and standard deviation of Q_{env1}, Q_{env2}, P_1, and P_2 at the primary and secondary pressure stations,

where:
Q_{env1} = average air leakage rate, $\bar{Q}_{env}$, at the primary pressure station, m^3/s (ft^3/min),
Q_{env2} = average air leakage rate, $\bar{Q}_{env}$, at the secondary pressure station, m^3/s (ft^3/min),
P_1 = average primary station pressure, Pa (in. H_2O), and
P_2 = average secondary station pressure, Pa (in. H_2O).

9.4.1.1 *Power Law*—The envelope leakage is assumed to follow a power law equation that relates the blower-door induced building pressure difference to the air leakage rate (Eq A4.6 in inch-pound units):

$$Q_{env}(P, \rho, \mu) = C\cdot P^n\left(\frac{1.2041}{\rho}\right)^{1-n}\left(\frac{0.00001813}{\mu}\right)^{2n-1} \quad (11)$$

where:
C = flow coefficient, $m^3/s\ (Pa)^n$,
n = flow exponent (dimensionless), and
P = blower-door induced building pressure difference, Pa.

Once C and n have been determined, subject to precision and accuracy constraints, use Eq 11 to determine what the test zone envelope airflow would be for any uniform building pressure difference, air density, and air temperature.

9.4.1.2 *Flow Exponent*—Estimate the flow exponent, n, derived from the power law equation:

$$n = \frac{\ln\left(\frac{Q_{env1}}{Q_{env2}}\right)}{\ln\left(\frac{P_1}{P_2}\right)} \quad (12)$$

9.4.1.3 *Flow Coefficient*—To estimate effective leakage area at the site elevation, calculate the flow coefficient C using Eq 13 for depressurization and Eq 14 for pressurization derived from the power law and the estimated value of n:

$$C = \frac{Q_{env1}}{(P_1)^n}\left(\frac{\rho_{out}}{1.2041}\right)^{1-n}\left(\frac{\mu_{out}}{0.00001813}\right)^{2n-1} \quad (13)$$

$$C = \frac{Q_{env1}}{(P_1)^n}\left(\frac{\rho_{in}}{1.2041}\right)^{1-n}\left(\frac{\mu_{in}}{0.00001813}\right)^{2n-1} \quad (14)$$

9.4.1.4 *Effective Leakage Area*—To estimate the effective leakage area in SI units at standard conditions, use C, the exponent, n, and the standard air density, $\rho_e = 1.204097$ kg/m^3 in Eq 15 to calculate L. Choose a reference pressure, P_{ref}, as required:

$$L = C \cdot P_{ref}^{(n-0.5)} \cdot (\rho_e/2)^{0.5} \quad (15)$$

where:
L = effective leakage area, m^2.

(Use Eq A4.9 for inch-pound units. If both depressurization and pressurization tests were performed, calculate and report an L separately for each.)

NOTE 9—Effective leakage area, L, in this standard differs from a similar measure of airtightness,[5] the equivalent leakage area, *ELA*, at the same reference pressure by several factors, including differing corrections for a discharge coefficient and dynamic viscosity.

9.4.1.5 Average the effective leakage areas computed by pressurization and depressurization if both types of pressurization were performed.

9.4.2 *Calculation of Uncertainty*—Calculate the uncertainty of Q, L, n, and C using A3.3.

10. Report

10.1 Report the following information:

10.2 *Building Description*:

10.2.1 *Location*—Street, city, state or province, zip or postal code, country.

10.2.1.1 *Elevation*—Above mean sea level in m (ft).

10.2.2 *Construction*:

10.2.2.1 Date built (estimate if unknown),

10.2.2.2 Floor areas for conditioned space, attic, basement, and crawl space,

10.2.2.3 Surface area of the building envelope, and

10.2.2.4 Volumes for conditioned spaces, attic, basement, and crawl space.

10.2.3 *Condition of Openings in Building Envelope*:

10.2.3.1 Type of test selected in 8.1.3, closed or occupied,

10.2.3.2 Condition of all building elements described in Table 1, and

10.2.3.3 Statement whether the test zone was interconnected with at least a door-sized opening; if not, the results of pressure measurements between portions of the zone.

10.2.4 *HVAC System*:

10.2.4.1 Location and sizes of ducts that penetrate the test zone envelope.

10.3 *Procedure*:

10.3.1 Technique employed, single-point or two-point, depressurization or pressurization, or both,

10.3.2 Test equipment used, manufacturer, model, serial number,

10.3.3 Calibration date of fan pressurization device, and

10.3.4 ρ_{cal}.

10.4 *Measurement Data*:

10.4.1 Fan pressurization measurements.

10.4.1.1 Inside-outside zero flow building pressure differences, P_{zero},

10.4.1.2 Tabular list of all air leakage measurements and calculations: time, building pressure difference, air density, nominal airflow rate, fan airflow rate, and air leakage rate, and

10.4.1.3 Deviations from standard procedure.

10.4.2 Ancillary data.

10.4.2.1 Weather measurement apparatus,

10.4.2.2 Wind speed/direction (two-point method only), whether wind speed is estimated to exceed 0 to 2 m/s (0 to 4 mph), and

10.4.2.3 Inside and outside temperature (at start and end of test), whether outside temperature is outside 5 to 35°C (41 to 95°F).

10.5 *Calculations*:

10.5.1 Means and standard deviations of P_{sta} (9.1.2) and of Q_{env} (9.3.1) for all pressure stations,

10.5.2 *One-Point Method*—The air leakage rate at 50 Pa, Q_{50} (Eq 8, Eq 9, Eq A4.3, or Eq A4.4) and, optionally, ACH_{50} (Eq 10 or Eq A4.5),

10.5.3 *Two-Point Method*—Flow exponent, n, and flow coefficient, C (Eq 12 and Eq 13 or Eq 14), the effective leakage area, L (Eq 15 or Eq A4.9), and the chosen reference pressure, P_{ref}. The air leakage rate at 50 Pa, Q_{50} (Eq 8, Eq 9, Eq A4.3, or Eq A4.4),

10.5.4 Error calculations for measured and derived values, including the values for precision index, bias, and overall uncertainty (Eq A3.1-A3.11).

10.6 *Calibration Certificates*:

10.6.1 Statement of means of calibration of the blower door and its components,

10.6.2 Statements of precision and bias of instruments.

11. Precision and Bias

11.1 *Measurement Uncertainty*—The precision and bias of this standard depend on the instrumentation and apparatus used, the test zone envelope, and the ambient conditions under which the data are taken.[6] Refer to recommended maximum values for precision and bias in Tables X1.1 and X1.2. These recommendations achieve the following uncertainties when calculated in accordance with Annex A3.

11.2 *Single-Point Method*—The uncertainty of measured flow at 50 Pa is 10 % using the single-point measurement assumptions for precision and bias and 5 % using the two-point assumptions.

11.3 *Two-Point Method*—Assuming an exponent of $n = 0.65$, $P_1 = 50$ Pa (0.2 in. H_2O), and $P_2 = 12.5$ Pa (0.05 in. H_2O), the uncertainty of extrapolating to measured flow at 4 Pa

[5] CGSB, "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method," *National Standard of Canada*, CAN/CGSB-149.10-M86, Canadian General Standards Board, Ottawa, 1986.

[6] Murphy, W. E., Colliver, D. G., and Piercy, L. R., "Repeatability and Reproducibility of Fan Pressurization Devices in Measuring Building Air Leakage," *ASHRAE Transactions*, Vol 97, Part 2, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, 1991.

(0.016 in. H_2O) would be 13 % using the two-point assumptions for precision and bias. Estimates of C and n have uncertainties of 10 % and 0.05, respectively, for the two-point assumptions.

12. Keywords

12.1 air leakage; blower door; building envelope; field method; pressurization

ANNEXES

(Mandatory Information)

A1. CALIBRATION OF FLOW MEASUREMENT DEVICE

A1.1 *Calibration*—This blower door shall be calibrated by a procedure traceable to NIST standards or E 1258 every three years or whenever damage is suspected. The calibration shall encompass the flow and pressure ranges at which the blower door will be used.

A1.2 *Calibration Certificate*—The calibration certificate shall include, as a minimum, the air density in $kg/m^3(lbm/ft^3)$, temperature in °C (°F) at which the calibration is valid, and measurements of system accuracy for flow and pressure ranges at which the blower door will be used. A copy of the manufacturer's calibration or the most recent recalibration shall be included in the test report.

A1.3 *Range of Calibration*—The device shall be equipped with some means of preventing the user from inadvertently making measurements outside the calibrated range.

A2. CALIBRATION OF PRESSURE MEASUREMENT DEVICE

A2.1 *Calibration*—The air pressure measurement device shall be calibrated every year or whenever damage is suspected. The pressure measurement device shall be calibrated by a manometer or pressure indicator that has an error of less than ± 0.5 Pa (± 0.002 in. H_2O) over the range of 10 to 60 Pa (0.04 to 0.24 in. H_2O).

A2.2 *Calibration Certificate*—The calibration certificate shall include measurement of precision, calculated as a standard deviation, and a statement of bias including hysteresis error and zeroing error. It shall also include the range of air density in $kg/m^3(lbm/ft^3)$ and temperature in °C (°F) within which the calibration is valid. A copy of the manufacturer's calibration or the most recent recalibration shall be included in the test report.

A3. ANALYSIS OF PRECISION AND BIAS ERRORS

A3.1 Table A3.1 lists the minimum unknown biases due to the specimen and conditions of measurement to be assumed for error calculations, including the minimum assumed unknown biases for airflow, building pressure difference, wind speed, and temperature measurements for both recommended and ideal conditions. Recommended test conditions are a wind speed of 0 to 2 m/s (0 to 4 mph) or less, and a temperature difference between inside the test zone and outdoors of 15°C (59°F) or less. Ideal test conditions are a wind speed of 0 m/s (0 mph) and a temperature difference between inside the test zone and outdoors of 0°C (32°F).

NOTE A3.1—The unknown bias does not include known biases determined during calibration or interlaboratory tests. For a thorough discussion of uncertainty calculations refer to ANSI/ASME PTC 19.1–1985.[7] For a more thorough discussion of the precision and bias calculations in this standard, refer to Sherman and Palmiter.[8]

TABLE A3.1 Minimum Assumed Unknown Bias for Blower Door Measurements

Measurement	Recommended Condition	Ideal Condition
Airflow—percentage of flow at 50 Pa (0.2 in H_2O)	3	1
Pressure difference—Pa (in. H_2O)	1.0 (0.004)	0.1 (0.0004)
Uncertainty of flow exponent for exponent single-point method, δn—unitless	0.15	
Temperature—°C (°F)	0.5 (0.9)	

A3.2 *One-Point Analysis:*

The precision index for $\bar{Q}_{env}$ is given by:

$$\frac{\delta Q_{envprec}}{\bar{Q}_{env}} = \sqrt{\frac{\delta^2 Q_{precision}}{Q_{fan}^2} + n^2 \frac{\delta^2 P_{precision}}{P_1^2}} \quad (A3.1)$$

where:

[7] ANSI/ASME, "Measurement Uncertainty—Instruments and Apparatus," *ANSI/ASME PTC 19.1–1985*, American Society of Mechanical Engineers, New York, 1986.

[8] Sherman, M. and Palmiter, L., "Uncertainties in Fan Pressurization Measurements," *Airflow Performance of Building Envelopes, Components and Systems, ASTM STP 1255*, Mark P. Modera and Andrew K. Persily, Eds., American Society for Testing and Materials, Philadelphia, 1995, pp. 266–283.

Q_{fan} = flow rate through the fan, m^3/s (ft^3/min),
P_1 = average pressure, $\bar{P}_{sta}$, at the primary pressure station, Pa (in. H_2O),
$\delta Q_{precision}$ = precision index of the average of the measured flow rate, m^3/s (ft^3/min), and
$\delta P_{precision}$ = precision index of the average of the measured pressure differential across the building envelope, Pa (in. H_2O).

The bias for $\bar{Q}_{env}$, is given by:

$$\frac{\delta Q_{biasenv}}{\bar{Q}_{env}} = \sqrt{\frac{\delta^2 Q_{bias}}{Q_{fan}^2} + n^2\frac{\delta^2 P_{bias}}{P_1^2}} \quad (A3.2)$$

where:
δQ_{bias} = estimated bias of the flow rate, m^3/s (ft^3/min), and
δP_{bias} = estimated bias of the pressure differential across the building envelope, Pa (in. H_2O).

A3.2.1 The measurement uncertainty for $\bar{Q}_{env}$ is given by:

$$\frac{\delta Q_{env}}{\bar{Q}_{env}} = \sqrt{\left(\frac{\delta Q_{biasenv}}{\bar{Q}_{env}}\right)^2 + t^2\left(\frac{\delta Q_{precenv}}{\bar{Q}_{env}}\right)^2} \quad (A3.3)$$

where:
t = value from a two-tailed student t table for the 95 % confidence level.

A3.2.2 Use Eq A3.3 to calculate the uncertainty of Q_{50}, unless P_1 is lower than 45 Pa (0.18 in. H_2O) or greater than 55 Pa (0.22 in. H_2O). To calculate the uncertainty of Q_{50}, substitute the result of Eq A3.4 in place of Eq A3.2 in Eq A3.3:

$$\frac{\delta Q_{biasenv}}{\bar{Q}_{env}} = \sqrt{\frac{\delta^2 Q_{bias}}{Q_{fan}^2} + n^2\frac{\delta^2 P_{bias}}{P_1^2} + \ln^2\left(\frac{50}{P_1}\right)\delta^2 n} \quad (A3.4)$$

where:
δn = measurement uncertainty of the envelope flow exponent (dimensionless) and
P_1 = average pressure, $\bar{P}_{sta}$, at the primary pressure station in Pa only.[9]

A3.2.3 To calculate the uncertainty of ACH_{50}, estimate the uncertainty of the volume measurement, δV_{zone}, and use Eq A3.5:

$$\frac{\delta ACH_{50}}{ACH_{50}} = \sqrt{\left(\frac{\delta Q_{50}}{Q_{50}}\right)^2 + \left(\frac{\delta V_{zone}}{V_{zone}}\right)^2} \quad (A3.5)$$

where:
δQ_{50} = the measurement uncertainty of Q_{50}, m^3/s (ft^3/min), and
δV = the uncertainty of V, m^3(ft^3).

A3.3 *Two-Point Analysis:*

A3.3.1 *Uncertainty of* Q_{ref}

The precision index for any Q_{ref}, including $\bar{Q}_{env}$, is given by:

$$\frac{\delta Q_{precenv}}{Q_{ref}} = \frac{1}{\ln\left(\frac{P_1}{P_2}\right)}\left[\ln^2\left(\frac{P_{ref}}{P_1}\right)\left(\frac{(\delta Q_{prec2})^2}{Q_2^2} + n^2\frac{(\delta P_{prec2})^2}{P_2^2}\right) + \ln^2\left(\frac{P_{ref}}{P_2}\right)\left(\frac{(\delta Q_{prec1})^2}{Q_1^2} + n^2\frac{(\delta P_{prec1})^2}{P_1^2}\right)\right]^{1/2} \quad (A3.6)$$

where:
P_{ref} = the reference pressure differential across the building envelope, Pa (in. H_2O),
δQ_{prec1} = precision index of the average of the measured flow rate at the primary pressure station, m^3/s (ft^3/min),
δP_{prec1} = precision index of the average of the measured pressure differential across the building envelope at the primary pressure station, Pa (in. H_2O),
δQ_{prec2} = precision index of the average of the measured flow rate at the secondary pressure station, m^3/s (ft^3/min), and
δP_{prec2} = precision index of the average of the measured pressure differential across the building envelope at the secondary pressure station, Pa (in. H_2O).

A3.3.1.1 The bias for Q_{ref} is given by:

$$\frac{\delta Q_{biasenv}}{Q_{ref}} = \frac{1}{\ln\left(\frac{P_1}{P_2}\right)}\left[\ln^2\left(\frac{P_{ref}}{P_1}\right)\left(\frac{(\delta Q_{bias2})^2}{Q_2^2} + n^2\frac{(\delta P_{bias2})^2}{P_2^2}\right) + \ln^2\left(\frac{P_{ref}}{P_2}\right)\left(\frac{(\delta Q_{bias1})^2}{Q_1^2} + n^2\frac{(\delta P_{bias1})^2}{P_1^2}\right)\right]^{1/2} \quad (A3.7)$$

where:
δQ_{bias1} = estimated bias of the flow rate at the primary pressure station, m^3/s (ft^3/min),
δP_{bias1} = estimated bias of the pressure differential across the building envelope at the primary pressure station, Pa (in. H_2O),
δQ_{bias2} = estimated bias of the flow rate at the secondary pressure station, m^3/s (ft^3/min), and
δP_{bias2} = estimated bias of the pressure differential across the building envelope at the secondary pressure station, Pa (in. H_2O).

A3.3.1.2 The measurement uncertainty for Q_{ref} is given by substituting the values from Eq A3.6 and A3.7 into Eq A3.8. These equations also represent the precision index, bias, and measurement uncertainty of L at P_{ref}, as follows:

$$\frac{\delta Q_{env}}{Q_{ref}} = \sqrt{\left(\frac{\delta Q_{biasenv}}{Q_{ref}}\right)^2 + t^2\left(\frac{\delta Q_{precenv}}{Q_{ref}}\right)^2} \quad (A3.8)$$

A3.3.2 *Uncertainty of n*—The precision index for n is given by:

$$\delta n_{precision} = \frac{1}{\ln\left(\frac{P_1}{P_2}\right)} \sqrt{\left(\frac{(\delta Q_{prec2})^2}{Q_2^2} + n^2\frac{(\delta P_{prec2})^2}{P_2^2}\right) + \left(\frac{(\delta Q_{prec1})^2}{Q_1^2} + n^2\frac{(\delta P_{prec1})^2}{P_1^2}\right)} \quad (A3.9)$$

A3.3.2.1 The bias for n is given by:

$$\delta n_{bias} = \frac{1}{\ln\left(\frac{P_1}{P_2}\right)} \sqrt{\left(\frac{(\delta Q_{bias2})^2}{Q_2^2} + n^2\frac{(\delta P_{bias2})^2}{P_2^2}\right) + \left(\frac{(\delta Q_{bias1})^2}{Q_1^2} + n^2\frac{(\delta P_{bias1})^2}{P_1^2}\right)} \quad (A3.10)$$

A3.3.2.2 The measurement uncertainty for n is given by substituting the values from Eq A3.9 and A3.10 into Eq A3.11:

[9] To convert in. H_2O to Pa, multiply the value by 250.

$$\delta n = \sqrt{(\delta n_{bias})^2 + t^2 (\delta n_{precision})^2} \quad (A3.11)$$

A3.3.3 *Uncertainty of C*—The measurement uncertainty for C is given by:

$$\frac{\delta C_{precision}}{C} = \frac{1}{\ln\left(\frac{P_1}{P_2}\right)}\left[\ln^2(P_1)\left(\frac{(\delta Q_{prec2})^2}{Q_2^2} + n^2\frac{(\delta P_{prec2})^2}{P_2^2}\right) + \ln^2(P_2)\left(\frac{(\delta Q_{prec1})^2}{Q_1^2} + n^2\frac{(\delta P_{prec1})^2}{P_1^2}\right)\right]^{1/2} \quad (A3.12)$$

A3.3.3.1 The bias for C is given by:

$$\frac{\delta C_{bias}}{C} = \frac{1}{\ln\left(\frac{P_1}{P_2}\right)}\left[\ln^2(P_1)\left(\frac{(\delta Q_{bias2})^2}{Q_2^2} + n^2\frac{(\delta P_{bias2})^2}{P_2^2}\right) + \ln^2(P_2)\left(\frac{(\delta Q_{bias1})^2}{Q_1^2} + n^2\frac{(\delta P_{bias1})^2}{P_1^2}\right)\right]^{1/2} \quad (A3.13)$$

A3.3.3.2 The measurement uncertainty for C is given by substituting the values from Eq A3.12 and A3.13 intoEq A3.14:

$$\frac{\delta C}{C} = \sqrt{\left(\frac{\delta C_{bias}}{C}\right)^2 + t^2\left(\frac{\delta C_{precision}}{C}\right)^2} \quad (A3.14)$$

A4. EQUATIONS IN INCH-POUND UNITS

A4.1 Use the following equations as the inch-pound unit equivalents of their SI counterparts in the body of this standard.

A4.2 *Equations 2 and Equations 3*—In place of Eq 2 use Eq A4.1, in place of Eq 3 use Eq A4.2, as follows:

$$\rho_{in} = 0.07517\left(1 - \frac{0.003566 \cdot Alt}{528}\right)^{5.2553}\left(\frac{528}{T_{in} + 460}\right) \quad (A4.1)$$

$$\rho_{out} = 0.07517\left(1 - \frac{0.003566 \cdot Alt}{528}\right)^{5.2553}\left(\frac{528}{T_{out} + 460}\right) \quad (A4.2)$$

where:
Alt = altitude at site, ft,
ρ = air density, lbm/ft^3, and
T = temperature, °F.

A4.3 *Equations 8 and Equations 9*—In place of Eq 8 or Eq 9 use Eq A4.3 or Eq A4.4, as follows:

$$Q_{50} = Q_{env1}\left(\frac{0.2 \text{ in. } H_2O}{P_1}\right)^{0.65}\left(\frac{\rho_{out}}{0.07517}\right)^{0.35}\left(\frac{\mu_{out}}{0.04387}\right)^{0.3} \quad (A4.3)$$

$$Q_{50} = Q_{env1}\left(\frac{0.2 \text{ in. } H_2O}{P_1}\right)^{0.65}\left(\frac{\rho_{in}}{0.07517}\right)^{0.35}\left(\frac{\mu_{in}}{0.04387}\right)^{0.3} \quad (A4.4)$$

where:
Q_{50} = the estimated air leakage rate, ft^3/min, at 0.20 in. H_2O,
Q_{env1} = average air leakage, $\bar{Q}_{env}$, at the primary pressure station, ft^3/min, and
P_1 = average pressure, $\bar{P}_{sta}$, at the primary pressure station, in. H_2O.

A4.4 *Equation 10*—In place of Eq 10 use Eq A4.5:

$$ACH_{50} = \left(\frac{60 \cdot Q_{50}}{V_{zone}}\right) \quad (A4.5)$$

where:
V_{zone} = volume of the test zone, ft^3.

A4.5 *Equation 11*—In place of Eq 11 use Eq A4.6:

$$Q_{env}(P, \rho, \mu) = C \cdot P^n\left(\frac{0.07517}{\rho}\right)^{1-n}\left(\frac{0.04387}{\mu}\right)^{2n-1} \quad (A4.6)$$

where:
C = flow coefficient, ft^3/min(in. $H_2O)^n$,
n = flow exponent, dimensionless, and
P = blower-door induced building pressure difference, in. H_2O.

A4.6 *Equations 13 and Equations 14*—In place of Eq 13 and 14 use Eq A4.7 and A4.8:

$$C = \frac{Q_{env1}}{(P_1)^n}\left(\frac{\rho_{out}}{0.07517}\right)^{1-n}\left(\frac{\mu_{out}}{0.04387}\right)^{2n-1} \quad (A4.7)$$

$$C = \frac{Q_{env1}}{(P_1)^n}\left(\frac{\rho_{in}}{0.07517}\right)^{1-n}\left(\frac{\mu_{in}}{0.04387}\right)^{2n-1} \quad (A4.8)$$

A4.7 *Equation 15*—In place of Eq 15 use Eq A4.9 and the standard air density, $\rho_e = 0.07517$ lbm/ft^3:

$$L = 0.1855 \cdot C \cdot P_{ref}^{(n-0.5)} \cdot (\rho_e/2)^{0.5} \quad (A4.9)$$

where:
L = effective leakage area, in.^{2}, and
ρ = air density in leaks, lbm/ft^3.

A5. CALCULATION OF DYNAMIC VISCOSITY

A5.1 *Dynamic Viscosity*—Calculate the dynamic viscosity μ (kg/m·s) at temperature, T (°C):

$$\mu = \frac{(1.458 \times 10^{-6})\, T + 273.15)^{0.5}}{1 + \left(\frac{110.4}{T + 273.15}\right)} \quad (A5.1)$$

or μ for inch-pound units (lbm/ft·hr) at temperature, T (°F):

$$\mu = \frac{(2.629 \times 10^{-3})\, T + 459.7)^{0.5}}{1 + \left(\frac{198.7}{T + 459.7}\right)} \quad (A5.2)$$

APPENDIXES

(Nonmandatory Information)

X1. RECOMMENDED PRECISION AND BIAS

X1.1 *Measurement Bias*—Table X1.1 lists the recommended maximum bias for single- and two-point measurements of airflow, building pressure difference, wind speed, and temperature measurements.

X1.2 *Measurement Precision*—The recommended maximum imprecision (Table X1.2) for measurements has two levels of standard deviations, determined by calculation from a minimum of five sets of airflow, and building pressure difference measurement data.

TABLE X1.1 Recommended Maximum Bias for Blower Door Measurements

Measurement	Single-point	Two-point
Airflow—percentage of flow at the test pressure	5	2
Pressure difference—Pa (in. H_2O)	2.5 (0.01)	0.5 (0.002)
Temperature—°C (°F)	2.0 (3.6)	

TABLE X1.2 Recommended Maximum Imprecision for Blower Door Measurements (Standard Deviation of at Least 5 Data)

Measurement	Single-point	Two-point
Airflow—percentage of flow at the test pressure	± 5	± 3
Pressure difference—as a percentage of the mean value	± 10	± 1
Temperature—°C (°F)	± 2 (± 3.6)	

X2. SAMPLE CALCULATIONS

X2.1 *Assumptions*—Depressurization. Higher grade instrumentation. Try one-point and two-point methods. Inside temperature 20°C and outside temperature 15°C. Inside air density 1.176 kg/m^3 and outside air density 1.196 kg/m^3. Calibration air density 1.142 kg/m^3. Altitude 200 m. Volume 768 m^3.

X2.2 *Data Obtained*—Multiple measurements of airflow at 50 and 12.5 Pa yielded the results in Table X1.2. Assume that these values are corrected for zero offset using Eq 1 and for air density and dynamic viscosity using Eq 2.

X2.3 *Calculated Values*—Perform the calculations outlined in Eq 4 and Eq 6 to determine the air leakage rate, Q_{env}.

X2.3.1 *Conversion to Envelope Flow*—Convert all the measured airflows, Q_{nom}, to fan airflow rates in cubic metres per second using Eq 4, as shown in Eq X2.1:

$$Q_{fan} = Q_{nom}\left(\frac{1.142}{1.176}\right)^{0.5} = 0.986\ Q_{nom} \qquad \text{(X2.1)}$$

Then convert all fan airflows to air leakage rates, $Q_{envelope}$, using Eq 6, as shown in Eq X2.2.

$$Q_{env} = Q_{fan}\left(\frac{1.176}{1.196}\right) = 0.983\ Q_{fan} = 0.969\ Q_{nom} \qquad \text{(X2.2)}$$

where:

Q_{fan} = 1.74 m^3/s at 50.4 Pa and 0.70 m^3/s at 12.4 Pa.

X2.3.2 *Single-Point*—The single-point method assumes a value of n = 0.65 for the envelope flow exponent in Eq 11.

X2.3.2.1 *Air Leakage at 50 Pa (0.2 in. H_2O)*—Use Eq 8 to estimate the air leakage rate at 50 Pa (0.2 in. H_2O) as shown in Eq X2.3:

$$Q_{50} = 1.744\left(\frac{50}{50.4}\right)^{0.65}\left(\frac{1.1962}{1.2041}\right)^{0.35}\left(\frac{0.0000179}{0.00001813}\right)^{0.3} = 1.724 \qquad \text{(X2.3)}$$

X2.3.2.2 ACH_{50}—Use Eq 9 to calculate ACH_{50}, as shown in Eq X2.4:

$$ACH_{50} = \left(\frac{3600 \cdot 1.724}{768}\right) = 8.08 \qquad \text{(X2.4)}$$

X2.3.3 *Two-Point*—First estimate n using Eq 12, as shown in Eq X2.5:

$$n = \frac{\ln\left(\frac{1.744}{0.697}\right)}{\ln\left(\frac{50.4\ \text{Pa}}{12.5\ \text{Pa}}\right)} = 0.65 \qquad \text{(X2.5)}$$

Next use the value of n in Eq 13 to determine the flow coefficient, C, as shown in Eq X2.6:

$$C = \frac{1.74}{(50.4)^{0.65}}\left(\frac{1.1962}{1.2041}\right)^{0.35}\left(\frac{0.0000179}{0.00001813}\right)^{0.3} = 0.135 \qquad \text{(X2.6)}$$

X2.3.4 *Effective Leakage Area*—Estimate the effective leakage area at standard conditions in m^2 using Eq 15, as follows:

$$L = (0.135)\cdot (4)^{(0.65-0.5)}\cdot(1.204/2)^{0.5} = 0.129 \qquad \text{(X2.7)}$$

X2.4 *Calculated Uncertainty*—The standard deviations obtained were 0 m^3/s (0 % of mean) and 0.57 Pa (1 %) at the primary station and 0.016 m^3/s (2.2 %) and 0.25 Pa (2.0 %) at the secondary station. These values certainly meet the single-point measurement assumptions, but they require us to calculate uncertainty for the two-point assumptions.

X2.4.1 *One-Point Analysis*—Assume in our example that Q_{bias} = 0.018 m^3/s and P_{bias} = 0.5 Pa. Calculate the precision index and bias for Q_{ref} = 50 Pa separately using Eq A3.1 and A3.2, as shown in Eq X2.8 and X2.9:

$$\frac{\delta Q_{envprec}}{\bar{Q}_{env}} = \sqrt{\frac{\left(\frac{0}{\sqrt{5}}\right)^2}{(1.77)^2} + (0.65)^2\frac{\left(\frac{0.57}{\sqrt{5}}\right)^2}{(50.4)^2}} = 0.33\ \% \qquad \text{(X2.8)}$$

$$\frac{\delta Q_{envbias}}{\bar{Q}_{env}} = \sqrt{\frac{(0.018)^2}{(1.77)^2} + (0.65)^2\frac{(0.5)^2}{(50.4)^2}} = 1.2\ \% \quad \text{(X2.9)}$$

where the assumptions about bias are adopted from Table 1.

X2.4.1.1 Five data points give 4° of freedom and t = 2.776. Combine the bias (Eq X2.9) and precision index (Eq X2.8) in quadrature to obtain the measurement uncertainty (Eq X2.10) using Eq A3.3. This gives an uncertainty of 2.3 % at the 95 % confidence level.

$$\frac{\delta Q_{env}}{\bar{Q}_{env}} = \sqrt{(0.021)^2 + (2.776)^2\,(0.0033)^2} = 2.3\ \% \quad \text{(X2.10)}$$

X2.4.2 *Two-Point Analysis*—Calculate the precision index and bias for Q_{ref} = 4 Pa separately using Eq A3.6 and A3.7, as shown in Eq X2.11 and X2.12:

$$\frac{\delta Q_{precenv}}{Q_{ref}} = \frac{1}{\ln\left(\frac{50.4}{12.4}\right)}\left[\ln^2\left(\frac{4}{50.4}\right)\left(\frac{\left(\frac{0.016}{5}\right)^2}{(0.71)^2} + (0.65)^2\frac{\left(\frac{0.25}{5}\right)^2}{(12.4)^2}\right) + \ln^2\left(\frac{4}{12.4}\right)\left(\frac{\left(\frac{0}{5}\right)^2}{(1.77)^2} + (0.65)^2\frac{\left(\frac{0.57^2}{5}\right)^2}{(50.4)^2}\right)\right]^{1/2} = 2.1\ \% \quad \text{(X2.11)}$$

$$\frac{\delta Q_{biasenv}}{Q_{ref}} = \frac{1}{\ln\left(\frac{50.4}{12.4}\right)}\left[\ln^2\left(\frac{4}{50.4}\right)\left(\frac{(0.0142)^2}{(0.71)^2} + (0.65)^2\frac{(0.5)^2}{(12.4)^2}\right) + \ln^2\left(\frac{4}{12.4}\right)\left(\frac{(0.0355)^2}{(1.77)^2} + (0.65)^2\frac{(0.5)^2}{(50.4)^2}\right)\right]^{1/2} = 6.2\ \% \quad \text{(X2.12)}$$

X2.4.2.1 Five data points give 4° of freedom and t = 2.776. Combine the bias (Eq X2.12) and precision index (Eq X2.11) in quadrature to obtain the measurement uncertainty (Eq X2.13) using Eq A3.6. This gives an uncertainty of 8.5 % at the 95 % confidence level.

$$\frac{\delta Q_{env}}{Q_{ref}} = \sqrt{(0.0620)^2 + (2.776)^2\,(0.0211)^2} = 8.5\ \% \quad \text{(X2.13)}$$

X2.4.3 Using Eq A3.6-A3.8, obtain a precision index of 0.86 %, a bias of 2.8 %, and an uncertainty for n of 3.7 % at the 95 % confidence level. Similarly, using Eq A3.9-A3.11, obtain a precision index of 3.3 %, a bias of 10 %, and an uncertainty for C of 13.5 % at the 95 % confidence level.

TABLE X2.1 Measured Data at 50 and 12.5 Pa

50 Pa		12.5 Pa	
P_{sta} (Pa)	Q_{nom} (m^3/s)	P_{sta} (Pa)	Q_{nom} (m^3/s)
Data			
49.5	1.80	12.5	0.71
50.7	1.80	12.6	0.70
51.0	1.80	12.0	0.73
50.3	1.80	12.5	0.72
50.6	1.80	12.2	0.74
Means			
50.4	1.80	12.4	0.72
Standard Deviations			
0.57	0.00	0.25	0.016