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

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 (e) 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 Pressuriza-
tion 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. H2O), 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 (m3/s,
ft3/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 incorpo-
rating a controllable fan and instruments for airflow measure-
ment and building pressure difference measurement that
mounts securely in a door or other opening.

3.1.5 building pressure difference, \( P \), \( n \)—the pressure differ-
ence across the test zone envelope (Pa, in. H2O).

3.1.6 fan airflow rate, \( Q_{fan} \), \( n \)—the volume of airflow
through the blower door per unit of time (m3/s, ft3/min).

3 Available from American National Standards Institute (ANSI), 25 W. 43rd St.,

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.
3.1.7 **nominal airflow rate,** \(Q_{\text{nom}}\), \(n\)—the flow rate indicated by the blower door using the manufacturer’s calibration coefficients (m³/s, ft³/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. H₂O).

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. H₂O) during fan pressurization at a building pressure difference of 50 Pa (0.2 in. H₂O) 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 m³/s (6 × 10³ ft³/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:

\[ P_{\text{zero}} = \text{zero-airflow pressure before test, } \text{Pa (in. H}_2\text{O)} \]
\[ P_{\text{zero}}\text{2} = \text{zero-airflow pressure after test, } \text{Pa (in. H}_2\text{O)} \]
\[ Q_{\text{env}} = \text{the air leakage rate, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ Q_{\text{env1}} = \text{average air leakage rate, } \bar{Q}_{\text{env1}} \text{ at the primary pressure station, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ Q_{\text{env2}} = \text{average air leakage rate, } \bar{Q}_{\text{env2}} \text{ at the secondary pressure station, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ Q_{\text{fan}} = \text{fan airflow rate (see 3.1.6)} \]
\[ Q_{\text{nom}} = \text{nominal airflow rate (see 3.1.7)} \]
\[ T = \text{temperature, °C (°F)} \]
\[ t = \text{value from a two-tailed student } t\text{ table for the 95 % confidence level} \]
\[ \delta n = \text{measurement uncertainty of the envelope flow exponent (dimensionless)} \]
\[ \delta Q_{\text{env}} = \text{measurement uncertainty of the average air leakage rate, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta Q_{\text{50}} = \text{the measurement uncertainty of } Q_{\text{50}}, \text{ m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta Q_{\text{bias}} = \text{estimated bias of the flow rate, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta Q_{\text{bias1}} = \text{estimated bias of the flow rate at the primary pressure station, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta Q_{\text{bias2}} = \text{estimated bias of the flow rate at the secondary pressure station, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta Q_{\text{precision}} = \text{precision index of the average measured flow rate, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta Q_{\text{p1}} = \text{precision index of the average measured flow rate at the primary pressure station, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta Q_{\text{p2}} = \text{precision index of the average measured flow rate at the secondary pressure station, } \text{m}^3/\text{s (ft}^3/\text{min)} \]
\[ \delta P = \text{measurement uncertainty of the average measured pressure differential across the building envelope, } \text{Pa (in. H}_2\text{O)} \]
\[ \delta P_{\text{bias1}} = \text{estimated bias of the pressure differential across the building envelope, } \text{Pa (in. H}_2\text{O)} \]
\[ \delta P_{\text{bias2}} = \text{estimated bias of the pressure differential across the building envelope at the primary pressure station, } \text{Pa (in. H}_2\text{O)} \]
\[ \delta P_{\text{precision}} = \text{precision index of the average measured pressure differential across the building envelope at the secondary pressure station, } \text{Pa (in. H}_2\text{O)} \]
\[ \delta P_{\text{p1}} = \text{precision index of the average measured pressure differential across the building envelope at the primary pressure station, } \text{Pa (in. H}_2\text{O)} \]
\[ \delta P_{\text{p2}} = \text{precision index of the average measured pressure differential across the building envelope at the secondary pressure station, } \text{Pa (in. H}_2\text{O)} \]

\[ Alt = \text{altitude at site, m (ft)} \]
\[ C = \text{flow coefficient at standard conditions, } \text{m}^3/\text{s (Pa}^n) \text{ ft}^3/\text{min (in. H}_2\text{O}^n) \]
\[ L = \text{effective leakage area at standard conditions, } \text{m}^2 \text{(in.}^2) \]
\[ n = \text{envelope flow exponent (dimensionless)} \]
\[ P = \text{building pressure difference (see 3.1.5)} \]
\[ P_1 = \text{average pressure, } P_{\text{stat}} \text{ at the primary pressure station, } \text{Pa (in. H}_2\text{O)} \]
\[ P_2 = \text{average pressure, } P_{\text{stat}} \text{ at the secondary pressure station, } \text{Pa (in. H}_2\text{O)} \]
\[ P_{\text{ref}} = \text{the reference pressure differential across the building envelope, } \text{Pa (in. H}_2\text{O)} \]
\[ P_{\text{stat}} = \text{station pressure, } \text{Pa (in. H}_2\text{O)} \]
\[ P_{\text{test}} = \text{test pressure, } \text{Pa (in. H}_2\text{O)} \]
\[ \delta V_{\text{zone}} = \text{measurement uncertainty of the zone volume, } m^3(\text{ft}^3) \]
\[ \mu = \text{dynamic viscosity, } kg/m\cdot s(\text{lbf/ft} \cdot \text{hr}) \]
\[ \rho = \text{air density, } kg/m^3(\text{lbf/ft}^3) \]
\[ \rho_{\text{cal}} = \text{air density at which the calibration values are valid, } kg/m^3(\text{lbf/ft}^3) \]

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 \( P_1 = 50 \text{ Pa} \) (0.2 in. H\(_2\)O) 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 \( P_1 = 50 \text{ Pa} \) (0.2 in. H\(_2\)O) and near \( P_2 = 12.5 \text{ Pa} \) (0.05 in. H\(_2\)O) 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 non-orifice 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\(_2\)O). 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\(_2\)O), 10 Pa (0.04 in. H\(_2\)O), 30 Pa (0.12 in. H\(_2\)O), and 50 Pa (0.2 in. H\(_2\)O). 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\(_2\)O) 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...
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 8.1.1.1.1.

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

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

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. H₂O) 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. H₂O). 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. H₂O). 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 \( P_1 (P_2 \leq \frac{1}{3} P_1) \).

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. H₂O).

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. H₂O). 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:

\[
P_{sta} = P_{test} - \left( \frac{P_{zero1} + P_{zero2}}{2} \right)
\]

where:

- \( P_{sta} \) = station pressure, Pa (in. H₂O),
- \( P_{test} \) = test pressure, Pa (in. H₂O),
- \( P_{zero1} \) = zero-airflow pressure before replicate measurement, Pa (in. H₂O), and
- \( P_{zero2} \) = zero-airflow pressure after replicate measurement, Pa (in. H₂O).

9.1.2 Station Pressure Averages—For all replicates at a station pressure, calculate the average \( P_{sta} \), 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.)

\[ \rho_{in} = 1.2041 \left( \frac{1 - 0.00656 \cdot Alt}{293} \right)^{5.255} \left( \frac{T_{in}}{T_{in} + 273} \right) \]  
\[ \rho_{out} = 1.2041 \left( \frac{1 - 0.00656 \cdot Alt}{293} \right)^{5.255} \left( \frac{T_{out}}{T_{out} + 273} \right) \]

where:
- \( Alt \) = altitude at site, m,
- \( \rho \) = 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:

\[ Q_{fan} = Q_{nom} \left( \frac{\rho_{cal}}{\rho_{in}} \right)^{0.5} \]
\[ Q_{fan} = Q_{nom} \left( \frac{\rho_{cal}}{\rho_{out}} \right)^{0.5} \]

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
- \( \rho_{cal} \) = 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:

\[ Q_{env} = Q_{fan} \left( \frac{\rho_{in}}{\rho_{cal}} \right) \]
\[ Q_{env} = Q_{fan} \left( \frac{\rho_{out}}{\rho_{cal}} \right) \]

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\(_2\)O)—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\(_2\)O) using Eq 8 for depressurization and Eq 9 for pressurization. (For inch-pound units, use Eq A4.3 or Eq A4.4.)

\[ Q_{50} = Q_{env} \left( \frac{50 Pa}{P_1} \right)^{0.65} \left( \frac{\rho_{out}}{1.2041} \right)^{0.35} \left( \frac{\mu_{out}}{0.00001813} \right)^{0.3} \]

where:
- \( P_1 \) = average pressure, \( \bar{P}_{sta} \), at the primary pressure station, Pa, and
- \( Q_{env} \) = 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.)

\[ ACH_{50} = \left( \frac{3600 \cdot Q_{env}}{V_{zone}} \right) \]

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

9.3.3 Calculate Uncertainty—Calculate the uncertainty of \( Q_{env} \) using A3.2. As an option, calculate the uncertainty of \( ACH_{eq} \) 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, as follows:

\[ Q_{env1} = \text{average air leakage rate, } \bar{Q}_{env}, \text{ at the primary pressure station, m}^3/\text{s (ft}^3/\text{min)} \]
\[ Q_{env2} = \text{average air leakage rate, } \bar{Q}_{env}, \text{ at the secondary pressure station, m}^3/\text{s (ft}^3/\text{min)} \]
\[ P_1 = \text{average primary station pressure, Pa (in. H}2\text{O)} \]
\[ P_2 = \text{average secondary station pressure, Pa (in. H2O).} \]

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):

\[ Q_{env} (P, p, \mu) = C \cdot P^n \left( \frac{1.2041}{\rho} \right)^{1-s} \left( \frac{0.00001813}{\mu} \right)^{2n-1} \]

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:

\[ n = \frac{\ln \left( \frac{Q_{env1}}{Q_{env2}} \right)}{\ln \left( \frac{P_1}{P_2} \right)} \]

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 \( n \):
9.4.1.4 Effective Leakage Area—To estimate the effective leakage area in SI units at standard conditions, use the formula:

\[
C = \frac{Q_{env}}{\left(\frac{P}{T}\right)^n} \left(\frac{\rho_{out}}{0.00001813}\right)^{2n-1}
\]

Equation 13

\[
C = \frac{Q_{env}}{\left(\frac{P}{T}\right)^n} \left(\frac{\rho_{in}}{0.00001813}\right)^{2n-1}
\]

Equation 14

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 \(\rho_{cal}\).

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

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

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 \(P_{stu}\) (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 \(n = 0.65, P_1 = 50\text{ Pa}\) (0.2 in. \(H_2O\)), and \(P_2 = 12.5\text{ Pa}\) (0.05 in. \(H_2O\)), the uncertainty of extrapolating to measured flow at 4 Pa

(0.016 in. H₂O) 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/m³ (lbm/ft³), 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. H₂O) over the range of 10 to 60 Pa (0.04 to 0.24 in. H₂O).

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/m³ (lbm/ft³) 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. For a more thorough discussion of the precision and bias calculations in this standard, refer to Sherman and Palmiter.

A3.2 One-Point Analysis:
The precision index for \( \bar{Q}_{env} \) is given by:

\[
\delta Q_{\text{env prec}} = \sqrt{\delta Q_{\text{precision}}^2 + \frac{\delta \bar{Q}_{\text{fan}}^2}{Q_{\text{fan}}^2} + n \left( \frac{\delta P_{\text{precision}}^2}{P_{\text{1}}} \right)} \quad (A3.1)
\]

where:

\( \delta Q_{\text{env prec}} \) is the precision index for \( \bar{Q}_{\text{env}} \) measured.

\( \delta Q_{\text{precision}} \) is the precision error.

\( \delta \bar{Q}_{\text{fan}} \) is the precision error for the airflow measurement.

\( \delta P_{\text{precision}} \) is the precision error for the pressure measurement.

\( n \) is the number of measurements.

\( P_{\text{1}} \) is the reference pressure.

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

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Recommended Condition</th>
<th>Ideal Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow—percentage of flow at 50 Pa (0.2 in H₂O)</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Pressure difference—Pa (in. H₂O)</td>
<td>1.0 (0.004)</td>
<td>0.1 (0.0004)</td>
</tr>
<tr>
<td>Uncertainty of flow exponent for exponent single-point method, ( \delta n )—unitless</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Temperature—°C (°F)</td>
<td>0.5 (0.9)</td>
<td></td>
</tr>
</tbody>
</table>

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A3.5 Substitute the result of Eq A3.4 in place of Eq A3.2 in Eq A3.3:

\[
\frac{\delta Q_{bias_env}}{Q_{env}} = \frac{\delta Q_{bias}}{Q_{fan}} + \frac{\delta Q_{precision}}{Q_{env}} + \frac{\delta P_{precision}}{P_1}
\]

(A3.2)

where:

\[\delta Q_{bias} = \text{estimated bias of the flow rate, m}^3/\text{s (ft}^3/\text{min)},\]

\[\delta P_{bias} = \text{estimated bias of the pressure differential across the building envelope, Pa (in. H}_2\text{O)}\]

A3.2.1 The measurement uncertainty for \(Q_{env}\) is given by:

\[
\frac{\delta Q_{env}}{Q_{env}} = \sqrt{\left(\frac{\delta Q_{bias}}{Q_{env}}\right)^2 + \left(\frac{\delta Q_{precision}}{Q_{env}}\right)^2 + \left(\frac{\delta P_{bias}}{P_1}\right)^2}
\]

(A3.3)

where:

\[t = \text{value from a two-tailed student } t \text{ table for the 95 % confidence level.}\]

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\(_2\)O) or greater than 55 Pa (0.22 in. H\(_2\)O). To calculate the uncertainty of \(Q_{50}\), substitute the result of Eq A3.4 in place of Eq A3.2 in Eq A3.3:

\[
\frac{\delta Q_{bias_env}}{Q_{env}} = \sqrt{\left(\frac{\delta Q_{bias}}{Q_{fan}}\right)^2 + \left(\frac{\delta Q_{precision}}{Q_{env}}\right)^2 + \left(\frac{\delta P_{bias}}{P_1}\right)^2 + \ln^2 \left(\frac{50}{P_1}\right) \delta n}
\]

(A3.4)

where:

\[\delta n = \text{measurement uncertainty of the envelope flow exponent (dimensionless)}\]

\[P_1 = \text{average pressure, } P_{\text{stat,}} \text{ at the primary pressure station in Pa only.}\]

A3.2.3 To calculate the uncertainty of \(ACH_{50}\), estimate the uncertainty of the volume measurement, \(\delta V_{cone}\), and use Eq A3.5:

\[
\frac{\delta ACH_{50}}{ACH_{50}} = \sqrt{\left(\frac{\delta Q_{50}}{Q_{50}}\right)^2 + \left(\frac{\delta V_{cone}}{V}\right)^2}
\]

(A3.5)

where:

\[\delta Q_{50} = \text{the measurement uncertainty of } Q_{50}, \text{ m}^3/\text{s (ft}^3/\text{min)},\]

\[\delta V = \text{the uncertainty of } V, \text{ m}^3/\text{ft}^3.\]

A3.3 Two-Point Analysis:

A3.3.1 Uncertainty of \(Q_{ref}\)

The precision index for any \(Q_{ref}\) including \(Q_{env}\) is given by:

\[
\frac{\delta Q_{precision}}{Q_{ref}} = \frac{1}{\ln \left(\frac{P_1}{P_2}\right)^2} \left[\ln^2 \left(\frac{P_{\text{ref}}}{P_1}\right) \left(\frac{\delta Q_{bias}}{Q_{ref}}\right)^2 + \ln^2 \left(\frac{\delta Q_{bias}}{Q_{ref}}\right)^2 + \frac{\delta P_{bias}^2}{P_1^2}\right]^{1/2}
\]

(A3.6)

\[\delta n_{precision} = \frac{1}{\ln \left(\frac{P_1}{P_2}\right)^2}
\]

A3.3.2 Uncertainty of \(n\)—The precision index for \(n\) is given by:

\[
\frac{\delta n_{bias}}{P_1} = \frac{1}{\ln \left(\frac{P_1}{P_2}\right)^2}
\]

(A3.10)

A3.3.2.1 The bias for \(n\) is given by:

\[
\frac{\delta Q_{bias}}{Q_{ref}} = \frac{1}{\ln \left(\frac{P_1}{P_2}\right)^2} \left[\ln^2 \left(\frac{P_{\text{ref}}}{P_1}\right) \left(\frac{\delta Q_{bias}}{Q_{ref}}\right)^2 + \ln^2 \left(\frac{\delta Q_{bias}}{Q_{ref}}\right)^2 + \frac{\delta P_{bias}^2}{P_1^2}\right]^{1/2}
\]

(A3.7)

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:
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:

\[
\begin{align*}
\rho_{in} &= 0.07517 \left( 1 - \frac{0.003566-Alt}{528} \right)^{5.255/10} \left( \frac{528}{T_{in} + 460} \right)^{0.3} \\
\rho_{out} &= 0.07517 \left( 1 - \frac{0.003566-Alt}{528} \right)^{5.255/10} \left( \frac{528}{T_{out} + 460} \right)^{0.3}
\end{align*}
\]  

(A4.1)  

(A4.2)

where:

Alt = altitude at site, ft,
\( \rho \) = 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:

\[
\begin{align*}
Q_{50} &= Q_{env} \left( \frac{0.2 \text{ in. } H_{2}O}{P_{1}} \right)^{0.65} \left( \frac{\rho_{in}}{0.07517} \right)^{0.35} \left( \frac{\rho_{out}}{0.04387} \right)^{0.3} \\
Q_{50} &= Q_{env} \left( \frac{0.2 \text{ in. } H_{2}O}{P_{1}} \right)^{0.65} \left( \frac{\rho_{in}}{0.07517} \right)^{0.35} \left( \frac{\rho_{out}}{0.04387} \right)^{0.3}
\end{align*}
\]  

(A4.3)  

(A4.4)

where:

\( Q_{50} \) = the estimated air leakage rate, ft\(^3\)/min, at 0.20 in. H\(_{2}\)O,
\( Q_{env} \) = average air leakage, \( \bar{Q}_{env} \), at the primary pressure station, ft\(^3\)/min, and
\( P_{1} \) = average pressure, \( P_{stat} \), at the primary pressure station, in. H\(_{2}\)O.

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

\[
\frac{\delta C_{bias}}{C} = \frac{1}{\ln\left( \frac{P_{1}}{P_{2}} \right)} \left[ \ln^{2}\left( \frac{\delta Q_{bias}}{Q_{2}} \right) + n^{2} \left( \frac{\delta P_{bias}}{P_{2}} \right)^{2} + n^{2} \left( \frac{\delta P_{bias}}{P_{1}} \right)^{2} \right]^{1/2}
\]

(A3.13)

\[
\frac{\delta C}{C} = \sqrt{\left( \frac{\delta C_{bias}}{C} \right)^{2} + \left( \frac{\delta C_{precision}}{C} \right)^{2}}
\]

(A3.14)

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

\[
\frac{C}{P_{stat}} = \frac{C}{V_{zone}}
\]

(A4.5)

where:

\( V_{zone} \) = volume of the test zone, ft\(^3\).

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

\[
\begin{align*}
\frac{C}{P_{stat}} &= \frac{Q_{env} \left( \frac{0.07517}{\rho} \right)^{1-n} \left( \frac{0.04387}{\mu} \right)^{2n-1}}{Q_{env} \left( \frac{0.07517}{\rho} \right)^{1-n} \left( \frac{0.04387}{\mu} \right)^{2n-1}} \\
\frac{C}{P_{stat}} &= \frac{Q_{env} \left( \frac{0.07517}{\rho} \right)^{1-n} \left( \frac{0.04387}{\mu} \right)^{2n-1}}{Q_{env} \left( \frac{0.07517}{\rho} \right)^{1-n} \left( \frac{0.04387}{\mu} \right)^{2n-1}}
\end{align*}
\]

(A4.7)  

(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\(^3\):

\[
L = 0.1855 C P_{ref}^{n-0.5} \left( \rho_{e}/2 \right)^{0.5}
\]

(A4.9)

where:

\( L \) = effective leakage area, in.\(^2\), and
\( \rho \) = air density in leaks, lbm/ft\(^3\).

A5. CALCULATION OF DYNAMIC VISCOSITY

A5.1 Dynamic Viscosity—Calculate the dynamic viscosity \( \mu \) (kg/m-s) at temperature, \( T \) (°C):

\[
\mu = \frac{(1.458 \times 10^{-5}) T + 273.15}{1 + \left( \frac{110.4}{T + 273.15} \right)}^{0.5}
\]

(A5.1)

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

\[
\mu = \frac{(2.629 \times 10^{-5}) T + 459.7}{1 + \left( \frac{198.7}{T + 459.7} \right)}^{0.5}
\]

(A5.2)
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

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Single-point</th>
<th>Two-point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow—percentage of flow at the test pressure</td>
<td>± 5</td>
<td>± 3</td>
</tr>
<tr>
<td>Pressure difference—Pa (in. H₂O)</td>
<td>± 10</td>
<td>± 1</td>
</tr>
<tr>
<td>Temperature—°C (°F)</td>
<td>± 2 (± 3.6)</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Single-point</th>
<th>Two-point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow—percentage of flow at the test pressure</td>
<td>± 5</td>
<td>± 3</td>
</tr>
<tr>
<td>Pressure difference—as a percentage of the mean value</td>
<td>± 10</td>
<td>± 1</td>
</tr>
<tr>
<td>Temperature—°C (°F)</td>
<td>± 2 (± 3.6)</td>
<td></td>
</tr>
</tbody>
</table>

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/m³ and outside air density 1.196 kg/m³. Calibration air density 1.142 kg/m³. Altitude 200 m. Volume 768 m³.

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, Qnom.

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

\[
Q_{\text{fan}} = Q_{\text{nom}} \left( \frac{1.142}{1.196} \right)^{0.5} = 0.986 Q_{\text{nom}}
\]  

(X2.1)

Then convert all fan airflows to air leakage rates, Qenv, using Eq 6, as shown in Eq X2.2:

\[
Q_{\text{env}} = Q_{\text{fan}} \left( \frac{1.176}{1.196} \right) = 0.983 Q_{\text{fan}} = 0.969 Q_{\text{nom}}
\]  

(X2.2)

where:

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

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. H₂O)—Use Eq 8 to estimate the air leakage rate at 50 Pa (0.2 in. H₂O) as shown in Eq X2.3:

\[
Q_{50} = 1.744 \left( \frac{50}{50.4} \right)^{0.65} \left( \frac{1.196}{1.2041} \right)^{0.35} \left( \frac{0.0000179}{0.00001813} \right)^{0.5} = 1.724
\]  

(X2.3)

X2.3.2.2 ACH₅₀—Use Eq 9 to calculate ACH₅₀, as shown in Eq X2.4:

\[
ACH_{50} = \left( \frac{3600 \cdot 1.724}{768} \right) = 8.08
\]  

(X2.4)

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

\[
n = \frac{\ln \left( \frac{1.744}{0.697} \right)}{\ln \left( \frac{50.4 \text{ Pa}}{12.5 \text{ Pa}} \right)} = 0.65
\]  

(X2.5)

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

\[
C = \frac{1.74}{(50.4)^{0.65}} \left( \frac{1.1962}{1.2041} \right)^{0.35} \left( \frac{0.0000179}{0.00001813} \right)^{0.5} = 0.135
\]  

(X2.6)

X2.3.4 Effective Leakage Area—Estimate the effective leakage area at standard conditions in m² using Eq 15, as follows:

\[
L = (0.135 - (4)^{0.65 - 0.5}) (1.204/2)^{0.5} = 0.129
\]  

(X2.7)

X2.4 Calculated Uncertainty—The standard deviations obtained were 0 m³/s (0 % of mean) and 0.57 Pa (1 %) at the primary station and 0.016 m³/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 \( Q_{\text{bias}} = 0.018 \text{ m}^3/\text{s} \) and \( P_{\text{bias}} = 0.5 \text{ Pa} \). Calculate the precision index and bias for \( Q_{\text{ref}} = 50 \text{ Pa} \) separately using Eq A3.1 and A3.2, as shown in Eq X2.8 and X2.9:

\[
\delta Q_{\text{env, prec}} = \sqrt{\frac{0}{(1.77)^2} + (0.61)^2} = 0.33 \%
\]  

(X2.8)
where the assumptions about bias are adopted from Table 1.

X2.4.1.1 Five data points give 4\(^{\circ}\) 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.

\[
\delta Q_{\text{bias}} = (0.021)^2 + (2.776)^2 (0.0033)^2 = 2.3 \% \quad (X2.10)
\]

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

\[
\delta Q_{\text{precision}} = \frac{1}{\ln(50.4/12.4)} \left[ \ln^2 \left( \frac{0.016}{50.4} \right) \left( \frac{4}{0.65} \right)^2 + (0.65)^2 \left( \frac{0.25}{12.4} \right)^2 \right]
\]

\[
\delta Q_{\text{bias}} = \frac{1}{\ln(50.4/12.4)} \left[ \ln^2 \left( \frac{4}{50.4} \right) \left( \frac{0.0142}{0.65} \right)^2 + (0.65)^2 \left( \frac{0.5}{12.4} \right)^2 \right]^{1/2} = 2.1 \% \quad (X2.11)
\]

\[
\delta Q_{\text{env}} = \sqrt{(0.0620)^2 + (2.776)^2 (0.0211)^2} = 8.5 \% \quad (X2.13)
\]

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>
<thead>
<tr>
<th>(P_{\text{ref}}) (Pa)</th>
<th>(Q_{\text{ref}}) (m(^3)/s)</th>
<th>(P_{\text{ref}}) (Pa)</th>
<th>(Q_{\text{ref}}) (m(^3)/s)</th>
</tr>
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<td>50.4</td>
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<td>12.4</td>
<td>0.71</td>
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<td>0.70</td>
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<td>12.5</td>
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<td>12.2</td>
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<tr>
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<td>0.72</td>
</tr>
<tr>
<td>Standard Deviations</td>
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<td>0.25</td>
<td>0.016</td>
</tr>
</tbody>
</table>

TABLE X2.1 Measured Data at 50 and 12.5 Pa

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