Designation: E779 – 10

Standard Test Method for Determining Air Leakage Rate by Fan Pressurization[1]

This standard is issued under the fixed designation E779; 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 This test method measures air-leakage rates through a building envelope under controlled pressurization and de-pressurization.

1.2 This test method is applicable to small temperature differentials and low-wind pressure differential, therefore strong winds and large indoor-outdoor temperature differentials shall be avoided.

1.3 This test method is intended to quantify the air tightness of a building envelope. This test method does not measure air change rate or air leakage rate under normal weather conditions and building operation.

NOTE 1—See Test Method E741 to directly measure air-change rates using the tracer gas dilution method

1.4 This test method is intended to be used for measuring the air tightness of building envelopes of single-zone buildings. For the purpose of this test method, many multi-zone buildings can be treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones.

1.5 Only metric SI units of measurement are used in this standard. If a value for measurement is followed by a value in other units in parentheses, the second value may be approximate. The first stated value is the requirement.

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]

E631 Terminology of Building Constructions

E741 Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution

E1258 Test Method for Airflow Calibration of Fan Pressurization Devices

3. Terminology

3.1 For definitions of terms used in this test method, refer to Terminology E631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air-change rate*, *n*—air-leakage rate in volume units/h divided by the building space volume with identical volume units, normally expressed as air changes/h, ACH.

3.2.2 *air-leakage*, *n*—the movement/flow of air through the building envelope, which is driven by either or both positive (infiltration) and negative (exfiltration) pressure differences across the envelope.

3.2.3 *air-leakage graph*, *n*—the graph that shows the relationship of measured airflow rates to the corresponding measured pressure differences, plotted on a log-log scale.

3.2.4 *air-leakage rate*, *n*—the volume of air movement/unit time across the building envelope including airflow through joints, cracks, and porous surfaces, or a combination thereof driven by mechanical pressurization and de-pressurization, natural wind pressures, or air temperature differentials between the building interior and the outdoors, or a combination thereof.

3.2.5 *building envelope*, *n*—the boundary or barrier separating different environmental conditions within a building and from the outside environment.

3.2.6 *effective leakage area*, *n*—the area of a hole, with a discharge coefficient of 1.0, which, with a 4 Pa pressure difference, leaks the same as the building, also known as the sum of the unintentional openings in the structure

3.2.7 *height, building*, *n*—the vertical distance from grade plane to the average height of the highest ceiling surface.

3.2.8 *interior volume*, *n*—deliberately conditioned space within a building, generally not including attics and attached structures, for example, garages, unless such spaces are connected to the heating and air conditioning system, such as a crawl space plenum.

3.2.9 *single zone*, *n*—a space in which the pressure differences between any two places, differ by no more than 5 % of the inside to outside pressure difference including multi-room

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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.

TABLE 1 Symbols and Units

Symbol	Quantity	Unit
E	Elevation above sea level	m [ft]
Q	Measured airflow rate	m^3/s [cfm]
Q_o	Air leakage rate	m^3/s [cfm]
C	Air leakage coefficient	$m^3/(s \cdot Pa^n)$ [cfm/Pa^n]
ρ	Air density	kg/m^3[lb/ft^3]
T	Temperature	° C [°F]
n	Pressure exponent	. . .
P	Pressure	Pa [lb/ft^2]
dP	Induced pressure difference	Pa [lb/ft^2]
dP_r	Reference pressure difference	Pa [lb/ft^2]
μ	Dynamic air viscosity	kg/(m·s) [lb/(ft·h)]
A	Area	m^2[ft^2]

space that is interconnected within itself with door-sized openings through any partitions or floors where the fan airflow rate is less than 3 m^3/s (6 × 10^3 ft^3/min).

3.2.10 *test pressure difference*, *n*—the measured pressure difference across the building envelope, expressed in Pascals (in. of water or pounds-force/ft^2 or in. of mercury).

3.3 *Symbols and Units*—See Table 1.

4. Summary of Test Method

4.1 This test method consists of mechanical pressurization or de-pressurization of a building and measurements of the resulting airflow rates at given indoor-outdoor static pressure differences. From the relationship between the airflow rates and pressure differences, the air leakage characteristics of a building envelope are determined.

5. Significance and Use

5.1 Air leakage accounts for a significant portion of the thermal space conditioning load. In addition, it affects occupant comfort and indoor air quality.

5.2 In most commercial or industrial buildings, outdoor air is often introduced by design; however, air leakage is a significant addition to the designed outdoor airflow. In most residential buildings, indoor-outdoor air exchange is attributable primarily to air leakage through cracks and construction joints and is induced by pressure differences due to temperature differences, wind, operation of auxiliary fans (for example, kitchen and bathroom exhausts), and the operation of combustion equipment in the building.

5.3 The fan-pressurization method is simpler than tracer gas measurements and is intended to characterize the air tightness of the building envelope. It is used to compare the relative air tightness of several similar buildings to identify the leakage sources and rates of leakage from different components of the same building envelope, and to determine the air leakage reduction for individual retrofit measures applied incrementally to an existing building, and to determine ventilation rates when combined with weather and leak location information.

6. Apparatus

6.1 The following is a general description of the required apparatus. Any arrangement of equipment using the same principles and capable of performing the test procedure within the allowable tolerances shall be permitted.

6.2 *Major Components*:

6.2.1 *Air-Moving Equipment*—Fan, blower, HVAC air movement component or blower door assembly that is capable of moving air into and out of the conditioned space at required flow rates under a range of test pressure differences. The system shall provide constant airflow at each incremental pressure difference at fixed pressure for the period required to obtain readings of airflow rate.

6.2.2 *Pressure-Measuring Device*—Manometer or pressure indicator to measure pressure difference with an accuracy of ± 5 % of the measured pressure or 0.25 Pa (0.001 in. H_2O), whichever is greater.

6.2.3 *Airflow Measuring System*—Device to measure airflow with an accuracy of ± 5 % of the measured flow. The airflow measuring system shall be calibrated in accordance with Test Method E1258.

6.2.4 *Temperature-Measuring Device*—Instrument to measure temperature with an accuracy of ± 1°C (2°F).

7. Hazards

7.1 *Eye Protection*—Glass breakage at the building pressure differences normally applied to the test structure is uncommon; however, for added safety, adequate precautions, such as the use of eye protection shall 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*—Exposure to the noise level generated by fans can be hazardous to the hearing of involved personnel and hearing protection is required.

7.5 *Debris and Fumes*—The blower or fan forces a large volume of air into or out of a building while in operation. Care shall be exercised to not to damage plants, pets, occupants, or internal furnishings due to influx of cold or warm air. Caution shall be exercised against sucking debris or exhaust gases from fireplaces and flues into the interior of the building. Active combustion devices shall be shut off or the safety determined of conducting the test by a properly trained technician before conducting the test.

8. Procedure

8.1 To create a single zone for this test procedure, all interconnecting doors in the conditioned space shall be open such that a uniform pressure shall be maintained within the conditioned space to within ±10 % of the measured inside/outside pressure difference. This condition shall be verified by differential pressure measurements at the highest pressure used in the test. These measurements shall be taken at the highest ceiling elevation and lowest floor elevation of the building and on the windward and leeward sides.

8.2 HVAC balancing dampers and registers shall not be adjusted. Fireplace and other operable dampers shall be closed unless they are used to pass air to pressurize or de-pressurize the building.

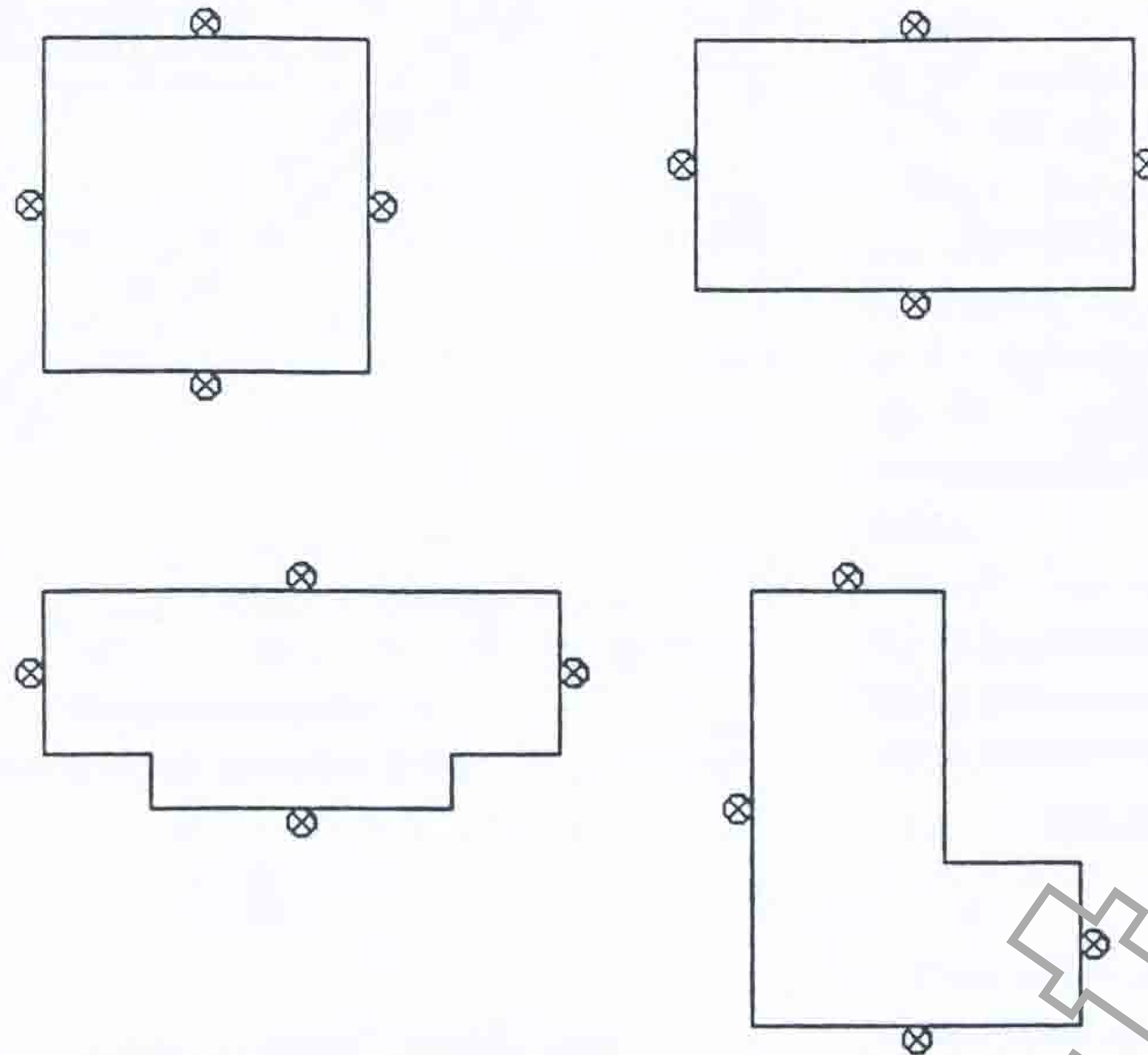

FIG. 1 Recommended Locations for Exterior Pressures (Plan Views of Buildings—"X" Within Circles Mark Pressure Tap Locations)

8.3 General observations of the condition of the building shall be recorded, including appropriate observations of the windows, doors, opaque walls, roof, and floor.

8.4 Measure and record the indoor and outdoor temperatures at the beginning and the end of the test and average the values. If the product of the absolute value of the indoor/outdoor air temperature difference multiplied by the building height, gives a result greater than 200 m °C (1180 ft °F), the test shall not be performed, because the pressure difference induced by the stack effect is too large to allow accurate interpretation of the results.

8.5 Connect the air duct or blower door assembly to the building envelope, using a window, door, or vent opening. Seal or tape openings to avoid air leakage at these points.

8.6 If a damper is used to control airflow, it shall be in a fully closed position for the zero flow pressure measurements.

8.7 *Installing the Envelope Pressure Sensor(s)*—Install the pressure measuring device across the building envelope. Where possible, locate the pressure tap at the bottom of the leeward wall. When wind causes adverse pressure fluctuations it may be advantageous to average the pressures measured at multiple locations, for example, one across each facade. Fig. 1 illustrates preferred locations that avoid extremes of exterior pressures. A good location avoids exterior corners and should be close to the middle (horizontally) of the exterior wall. Beware of direct sunlight hitting pressure tubing, especially vertical sections.

8.8 Measure zero flow pressures with the fan opening blocked. These zero flow envelope pressures shall be measured before and after the flow measurements. The average over at least a 10-s interval shall be used. These zero flow pressures shall be subtracted from the envelope pressures measured during pressurization and depressurization.

NOTE 2—Some equipment may perform this step, or an equivalent step, automatically. Follow the manufacturer's instructions accordingly.

8.9 The range of the induced pressure difference shall be from 10 to 60 Pa (0.04 to 0.24 in. H_2O), depending on the capacity of the air-moving equipment. Because the capacity of the air-moving equipment, the lack of tightness in the building, and the weather conditions affect leakage measurements, the full range of the higher values may not be achievable. In such cases, substitute a partial range encompassing at least five data points.

NOTE 3—It is advisable to check that the condition of the building envelope has not changed after each pressure reading, for example, that sealed openings have not become unsealed or that doors, windows, or dampers have not been forced open by the induced pressure.

8.10 Use increments of 5 to 10 Pa (0.02 to 0.04 in. H_2O) for the full range of induced pressure differences.

8.11 At each pressure difference, measure the airflow rate and the pressure differences across the envelope. After the fan and instrumentation have stabilized, the average over at least a 10-s interval shall be used.

8.12 For each test, collect data for both pressurization and de-pressurization.

8.13 Determine the elevation of the measurement site, E (m or ft), above mean sea level within 100 m (330 ft).

9. Data Analysis and Calculations

9.1 Unless the airflow measuring system gives volumetric flows at the barometric pressure and the temperatures of the air flowing through the flowmeter during the test, these readings shall be converted using information obtained from the manufacturer for the change in calibration with these parameters. The barometric pressure or air density, if used in the conversions, may be calculated using equations from Appendix X1.

9.2 Convert the readings of the airflow measuring system (corrected as in 9.1, if necessary) to volumetric air flows at the temperature and barometric pressure of the outside air for depressurization tests or of the inside air for pressurization tests (see Appendix X1, Eq X1.1 through X1.4 for determining indoor and outdoor air densities). To convert the airflow rate to air leakage rate for depressurization, use the following equation:

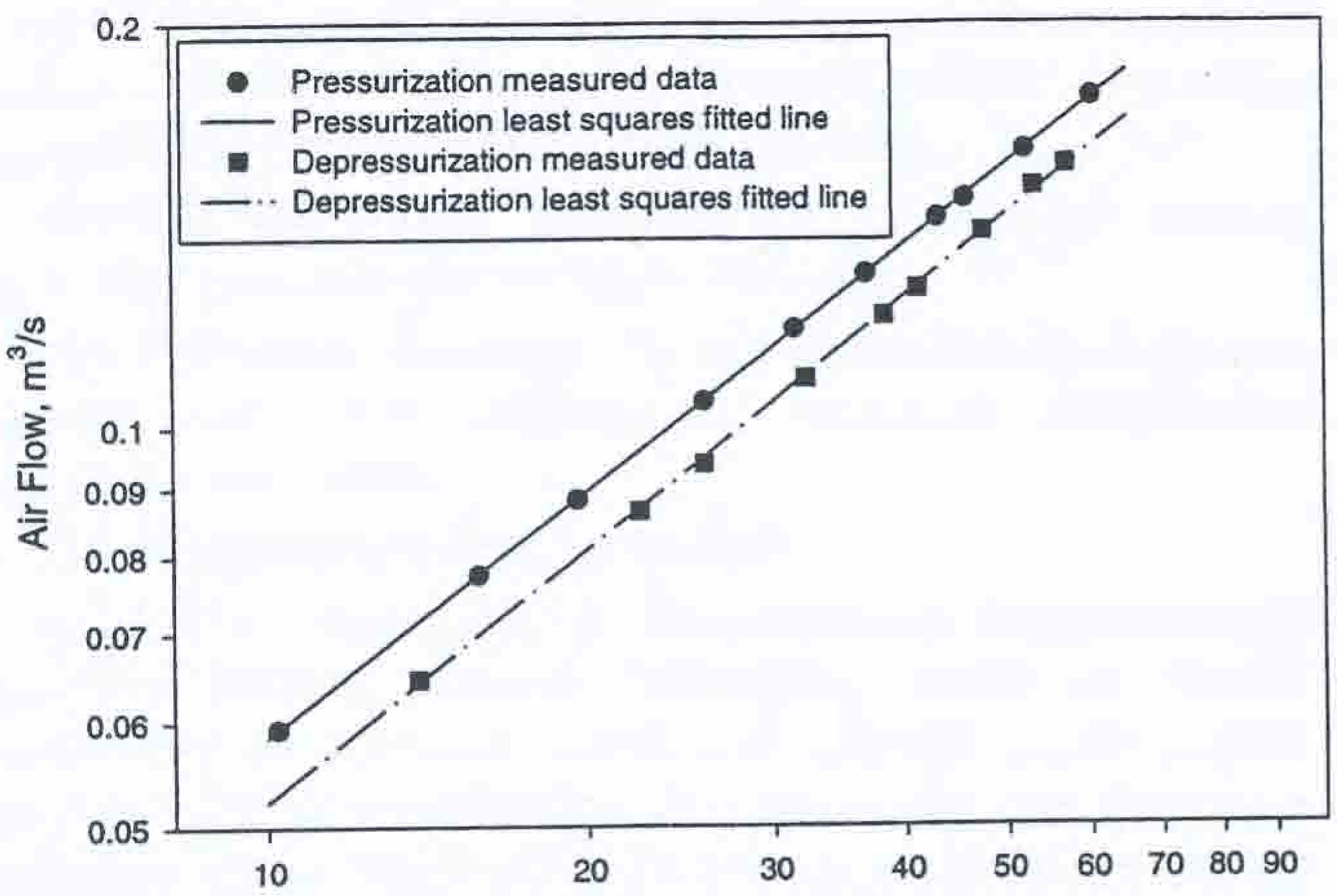

FIG. 2 Example Air Leakage Graph

$$Q_o = Q\left(\frac{\rho_{in}}{\rho_{out}}\right) \quad (1)$$

where:
ρ_{in} = the indoor air density, in kg/m³ (lb/ft³), and
ρ_{out} = the outdoor air density, in kg/m³ (lb/ft³).

9.2.1 To convert the airflow rate to air leakage rate for pressurization, use the following equation:

$$Q_o = Q\left(\frac{\rho_{out}}{\rho_{in}}\right) \quad (2)$$

9.3 Average the zero flow envelope pressures measured before and after the flow measurements. Subtract the average from the measured envelope pressures at each pressure station to determine the corrected envelope pressures.

9.4 Plot the measured air leakage against the corrected pressure differences on a log-log plot to complete the air leakage graph for both pressurization and de-pressurization (for an example, see Fig. 2).

9.5 Use the data to determine the air leakage coefficient, *C*, and pressure exponent, *n*, in Eq 3 separately for pressurization and depressurization:

$$Q = C(dP)^n \quad (3)$$

9.5.1 Use an unweighted log-linearized linear regression technique, where *Q* is the airflow rate, in m³/s (ft³/min), and *dP* is the differential pressure in Pa. In determining the fit of the above equation, the confidence intervals of the derived air leakage coefficient *C* and pressure exponent n shall be calculated according to Annex A1. *C* and *n* shall be calculated separately for pressurization and depressurization. If the pressure exponent is less than 0.5 or greater than 1, then the test is invalid and shall be repeated.

NOTE 4—Check the following before repeating the test:
(1) Equipment for proper calibration,
(2) Weather conditions against the temperature and pressure used in the calculations,
(3) Connection of the pressurizing fan to the enclosure for leaks,
(4) Connection between sections of the building, and
(5) All windows, doors, and other potential building openings are closed, etc.

9.6 Correct the air leakage coefficient *C* to standard conditions [20°C and sea level *E* = 0 m (68°F, *E* = 0 ft)] with Eq 4.

$$C_o = C\left(\frac{\mu}{\mu_o}\right)^{2n-1}\left(\frac{\rho}{\rho_o}\right)^{1-n} \quad (4)$$

where:
μ = the dynamic viscosity of air, kg/m·s (lb/ft/h), and
ρ = the air density, kg/m³(lb/ft³).

9.6.1 The unsubscripted quantities refer to the values under the conditions of the test (indoor air for pressurization and outdoor air for depressurization), and the subscripted quantities to the values under the standard reference conditions. Appendix X1 contains the appropriate tables and equations for the temperature and barometric pressure (elevation) variation of ρ and μ.

9.6.2 The leakage area A_L, in m², shall be calculated from the corrected air leakage coefficient and the pressure exponent using a reference pressure (dP_r) in Eq 5. Calculate the leakage areas separately for pressurization and depressurization:

$$A_L = C_o\left(\frac{\rho_o}{2}\right)^{\frac{1}{2}}(dP_r)^{\left(n-\frac{1}{2}\right)} \quad (5)$$

9.6.3 The conventional reference pressure is 4 Pa, but other values may be used if the value is included in the test report.

9.6.4 To obtain a single value for flow coefficient, pressure exponent, leakage area or flow at a particular pressure for use in other calculations, the average of the values obtained for pressurization and depressurization shall be used.

9.7 Determine confidence limits for the derived values from the data used to determine Eq 3 using Annex A1. To obtain the confidence limits of a combined pressurization and depressurization result use the combined result (which is the simple average of the pressurization and depressurization values) plus and minus the quantity calculated using equation Eq 6.

$$PE95(x_{combined}) = \left(\frac{1}{2}\right)\cdot sqrt(PE95(x_{depress})^2 + PE95x_{press}()^2) \quad (6)$$

where:
$PE95(x_{depress})$ = half the width of the 95 % confidence interval (from 9.7) in the depressurization result, and
$PE95(x_{press})$ = half the width of the 95 % confidence interval (from 9.7) in the pressurization result.

10. Report

10.1 Report the following information:

10.1.1 Building description, including location, address (street, city, state or province, zip or postal code, country, and elevation [above mean sea level in m (ft)].

10.1.2 Construction, including date built (estimate if unknown), floor areas for conditioned space, attic, basement, and crawl space, and volumes for conditioned spaces, attic, basement, and crawl space.

10.1.3 Condition of openings in building envelope including:

10.1.3.1 Doors, closed, locked or unlocked;

10.1.3.2 Windows, closed, latched or unlatched;

10.1.3.3 Ventilation openings, dampers closed or open;

10.1.3.4 Chimneys, dampers closed or open; and a

10.1.3.5 Statement whether the test zone is interconnected with at least door-sized openings. If not, the results of pressure measurements between portions of the zone.

10.1.4 HVAC system, including the location and sizes of ducts that penetrate the test zone envelope.

10.2 Procedure, including the test equipment used (manufacturer, model, serial number), and calibration records of all measuring equipment.

10.3 Measurement data, including:

10.3.1 Fan pressurization measurements (inside-outside zero flow building pressure differences); inside and outside temperature (at start and end of test) and the product of the absolute value of the indoor/outdoor air temperature difference multiplied by the building height; 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 deviations from standard procedure.

10.3.2 Wind speed/direction and whether wind speed is estimated or measured on site. When measured on site, record the height above the ground at which wind speed was measured.

10.4 Calculations, including:

10.4.1 The leakage coefficient and pressure exponent for both pressurization and de-pressurization in accordance with 9.6;

10.4.2 The effective leakage areas for pressurization, de-pressurization, and combined. Report if a reference pressure other than 4 Pa is used; and

10.4.3 An estimate of the confidence limits in accordance with 9.7.

11. Precision and Bias

11.1 The confidence limits calculated in 9.7 give an estimate of the precision uncertainty of the test results. The specific precision and bias of this test method is dependent largely on the instrumentation and apparatus used and on the ambient conditions under which the data are taken.[3]

12. Keywords

12.1 air leakage; air-leakage rates; blower-door test; building envelope; depressurization; energy conservation; fan pressurization testing; infiltration; pressurization; ventilation

[3] Murphy, W.E., Colliver, D.G., and Piercy, L.R., "Repeatability and Reproducibility of Fan Pressurization Devices in Measuring Building Air Leakage," *ASHRAE Trans*, Vol 97, Part 2, 1990.

ANNEX

(Mandatory Information)

A1. PROCEDURE FOR ESTIMATING PRECISION ERRORS IN DERIVED QUANTITIES

A1.1 This test method contains several derived quantities, which often are used to summarize the air tightness of the building or component tested. It is important to report an estimate of the precision error in such quantities. The following method shall be used: all derived quantities depend on the estimation of the air leakage coefficient C and air pressure exponent n of Eq 3. To determine C and n, make a log transformation of the variables Q and dP for each reading.

$$x_i = \ln(dP_i) \quad \text{for } i = 1..N$$
$$y_i = \ln(Q_i)$$

where:
N = the total number of test readings.

A1.1.1 Eq 3 then transforms into the following:

$$y = \ln(C) + n \cdot x \tag{A1.1}$$

A1.1.2 Compute the following quantities:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{A1.2}$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \tag{A1.3}$$

$$S_x^2 = \frac{1}{N-1}\sum_{i=1}^{N} (x_i - \bar{x})^2 \tag{A1.4}$$

$$S_y^2 = \frac{1}{N-1}\sum_{i=1}^{N} (y_i - \bar{y})^2 \tag{A1.5}$$

$$S_{xy} = \frac{1}{N-1}\sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y}) \tag{A1.6}$$

A1.1.2.1 Then the best estimate of n and ln (C) is given by the following:

$$n = \frac{S_{xy}}{S_x^2} \tag{A1.7}$$

$$\ln(C) = \bar{y} - n \cdot \bar{x} \tag{A1.8}$$

$$C = \exp^{[\bar{y} - n \cdot \bar{x}]} \tag{A1.9}$$

A1.1.2.2 The 95 % confidence limits for C and n can be determined by the following equations. The variance of n is given in the estimate:

$$S_n = \frac{1}{S_x}\left(\frac{S_y^2 - n \cdot S_{xy}}{N-2}\right)^{\frac{1}{2}} \tag{A1.10}$$

and the estimate of the variance of ln (C) is given by:

$$S_{\ln(C)} = S_n \left(\frac{\sum_{i=1}^{N} x_i^2}{N}\right)^{\frac{1}{2}} \tag{A1.11}$$

The confidence limits for ln (C) and n are respectively:

$$I_{\ln(C)} = S_{\ln(C)}\, T(95\,\%, N-2) \tag{A1.12}$$

$$I_n = S_n\, T(95\,\%, N-2) \tag{A1.13}$$

Where the values of the two-sided student distribution (T (95 %, N – 2)) are given in Table A1.1.

TABLE A1.1 Two-Sided Confidence Limits *T* (95 %, *N*) for a Student Distribution

N – 2	3	4	5	6	7	8	9	10
T (95 %, N - 2)	3.182	2.776	2.571	2.447	2.365	2.306	2.262	2.228
N - 2	11	12	13	14	15	16	17	18
T (95 %, N - 2)	2.201	2.179	2.160	2.145	2.131	2.120	2.110	2.101

A1.1.2.3 This means that the probability is 95 % that the pressure exponent n lies in the interval $(n - I_n, n + I_n)$ and the probability is 95 % that the air leakage coefficient C lies in the interval:

$$(C \cdot exp^{-I_{\ln(C)}}, C \cdot exp^{I_{\ln(C)}}) \quad (A1.14)$$

A1.1.2.4 The estimate of the variance around the regression line Eq A1.1 at the value x is:

$$S_y(x) = S_n\left(\frac{N-1}{N}S_x^2 + (x - \bar{x})^2\right)^{\frac{1}{2}} \quad (A1.15)$$

and the confidence interval in the estimate of y using Eq A1.1 at any x is:

$$I_y(x) = S_y(x)\,T(95\ \%, N-2) \quad (A1.16)$$

A1.1.2.5 The airflow rate Q, predicted by Eq 3 at any pressure difference dP, therefore, lies in the interval:

$$(Q \cdot exp^{-I_{y(\ln(dP))}}, Q \cdot exp^{I_{y(\ln(dP))}}) \quad (A1.17)$$

with a probability of 95 %.

A1.1.2.6 It is this interval that shall be used to estimate the error in the leakage area or the airflow rate across the building envelope or building envelope component at a reference pressure, for example 75 Pa. For example, the confidence interval of the estimate of the leakage area A_L using Eq 5 is as follows:

$$(A_L \cdot exp^{-I_{y(\ln(dP))}}, A_L \cdot exp^{I_{y(\ln(dP))}}) \quad (A1.18)$$

with a probability of 95 %.

A1.1.3 In practice, the above error analysis shall be carried out using standard statistical computer programs.

APPENDIXES

(Nonmandatory Information)

X1. DEPENDENCE OF AIR DENSITY AND VISCOSITY ON TEMPERATURE AND BAROMETRIC PRESSURE (ELEVATION)

X1.1 Use Eq X1.1 to calculate inside air density. Use Eq X1.2 to calculate outside air density. Use Eq X1.3 and X1.4 for inch-pound units.

$$\rho_{in} = 1.2041\left(1 - \frac{0.0065 \cdot E}{293}\right)^{5.2553}\left(\frac{293}{T_{in} + 273}\right) \quad (X1.1)$$

$$\rho_{out} = 1.2041\left(1 - \frac{0.0065 \cdot E}{293}\right)^{5.2553}\left(\frac{293}{T_{out} + 273}\right) \quad (X1.2)$$

where:
E = elevation above sea level (m),
ρ = air density (kg/m^3), and
T = temperature (°C).

NOTE X1.1—The standard conditions used in calculations in this test method 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 elevation.

$$\rho_{in} = 0.07517\left(1 - \frac{0.0035666 \cdot E}{528}\right)^{5.2553}\left(\frac{528}{T_{in} + 460}\right) \quad (X1.3)$$

$$\rho_{in} = 0.07517\left(1 - \frac{0.0035666 \cdot E}{528}\right)^{5.2553}\left(\frac{528}{T_{out} + 460}\right) \quad (X1.4)$$

where:
E = elevation above sea level (ft),
ρ = air density (lbm/ft^3), and
T = temperature (°F).

X1.1.1 The dynamic viscosity μ, in kg/(m·s), at temperature T, in °C, can be obtained from Eq X1.5.

$$\mu = \frac{b(T + 273)^{0.5}}{1 + \frac{s}{T + 273}} \quad (X1.5)$$

where:
b = to 1.458 × 10^{-6}; in kg/(m·s·K$^{0.5}$);
s = to 110.4, in K.

X1.1.1.1 For inch-pound units the dynamic viscosity μ, in lb/(fthr), at temperature T, in °F, can be obtained from Eq X1.6:

$$\mu = \frac{b(T + 460)^{0.5}}{1 + \frac{s}{T + 460}} \quad (X1.6)$$

where:
b = to 2.629 × 10^{-3}; in lb/ (ft·h · °F$^{0.5}$);
s = to 198.7, in °F.

X1.1.1.2 The barometric pressure in kPa, as a function of elevation only is obtained from Eq X1.7. Use Eq X1.8 for inch-pound units.

$$P = 101.325 \cdot \left(\frac{1 - 0.0065 \cdot E}{293}\right)^{5.2553} \quad (X1.7)$$

$$P = 2116 \cdot \left(\frac{1 - 0.003567 \cdot E}{528}\right)^{5.2553} \quad (X1.8)$$

X2. EXAMPLE CALCULATIONS

TABLE X2.1 Measured Pressurization Data Points

Point	Pressure Difference Across Building Envelope, (Pa)	Measured Flow Through Flowmeter, (m^3/s)[A]
1	9.9	0.0568
2	15.5	0.0741
3	19.2	0.0844
4	25.4	0.1000
5	31.1	0.1133
6	36.5	0.1246
7	42.7	0.1371
8	45.4	0.1416
9	51.8	0.1539
10	59.9	0.1688

[A] This measured flow is corrected for the temperature and density of the air flowing through the flowmeter and is the volumetric flow at the measurement conditions.

Initial pressure offset = –0.42 Pa
Final pressure offset = –0.30 Pa
Average pressure offset (dP_{off}) = ½ (–0.42 – 0.30) = –0.36 Pa
Outdoor temperature (T_{out}) = 8°C
Indoor temperature (T_{in}) = 21°C
Wind speed = 1 m/s

X2.1 Introduction

X2.1.1 This test method is performed for both pressurization and depressurization. Detailed, step-by-step calculations are given for pressurization only, and the depressurization calculation procedure is summarized for brevity.

X2.2 Site Data

X2.2.1 Single-story house with a ceiling to floor height of 2.5 m. The house is located at 600 m above sea level (E).

X2.3 Checking Test Limits

X2.3.1 *Section* 8.4—The product of indoor-outdoor temperature difference and building height shall be less than 200 m °C. In this case, the building is a bungalow with a floor to ceiling height of 2.5 m. The indoor-outdoor temperature difference during the test is 13°C. Multiplied together, these temperature differences give 2.5 m × 13°C = 32.5 m °C; therefore, this test passed.

X2.3.2 The average windspeed is 1 m/s, and the outdoor temperature is 8°C, thus meeting the specifications of 8.5.

X2.3.3 Ten pressure difference and flow measurements are made between 10 and 60 Pa, thus meeting the requirements of 8.10.

X2.4 Pressurization Data

X2.4.1 *Measured Pressurization Data*—See Table X2.1.

X2.4.2 *Calculations*:

X2.4.2.1 Because this is a pressurization test, the measured air flow rates through the flowmeter are converted to flow rates through the building envelope using Eq 2. This conversion requires the indoor and outdoor air density, calculated using Eq X1.1 and X1.2.

$$\rho_{in} = 1.2041\left(1 - \frac{0.0065 \cdot E}{293}\right)^{5.2553}\left(\frac{293}{T_{in} + 273}\right) \quad \text{(X2.1)}$$

TABLE X2.2 Corrected Depressurization Data Points

Point	Pressure Difference Across Building Envelope, (Pa)	Flow Through Building Envelop, (m^3/ s)
1	10.26	0.0594
2	15.86	0.0775
3	19.56	0.0883
4	25.76	0.1046
5	31.46	0.1185
6	36.86	0.1304
7	43.06	0.1434
8	45.76	0.1482
9	52.16	0.1610
10	60.26	0.1766

Substituting E = 600 m and T_{in} = 21°C:

$$\rho_{in} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{21 + 273}\right) = 1.118 \text{ kg/m}^3 \quad \text{(X2.2)}$$

Substituting E = 600 m and T_{out} = 8°C:

$$\rho_{out} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{8 + 273}\right) = 1.170 \text{ kg/m}^3 \quad \text{(X2.3)}$$

X2.4.2.2 Each Flow in Table X2.1 is multiplied by the ratio of ρ_{out}/ρ_{in}, for example, for point number 1:

$$Q_o = Q\left(\frac{\rho_{out}}{\rho_{in}}\right) = 0.0568\left(\frac{1.170}{1.118}\right) = 0.0594\frac{m^3}{s} \quad \text{(X2.4)}$$

X2.4.2.3 Each pressure difference has the pressure offset of –0.36 Pa subtracted from it, for example, for point number 1:

$$9.9 - (-0.36) = 10.3\ Pa \quad \text{(X2.5)}$$

X2.4.2.4 This results in the corrected data shown in Table X2.2 for pressure and flow.

X2.4.2.5 The data in Table X2.2 are plotted in Fig. 2. Following the method outlined in Annex A1 the flow coefficient, C, pressure exponent, n, are determined as follows:

X2.4.3 *Logarithmic Transformation*—Table X2.3 shows the natural logarithms of the pressures and flows from Table X2.2.

X2.4.3.1 The variance of the log of pressure is calculated using Eq A1.4:

$$S^2_{\ln(dP)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})^2 = \quad \text{(X2.6)}$$

$$\frac{1}{10-1}((2.3239 - 3.4002)^2 + (2.7616 - 3.4002)^2 + \ldots$$
$$+ (4.0894 - 3.4002)^2)$$
$$= 0.32329$$

X2.4.3.2 The variance of the log of flow is calculated using Eq A1.5:

$$S^2_{\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(Q)_i - \overline{\ln(Q)})^2 = \quad \text{(X2.7)}$$

$$\frac{1}{10-1}((-2.8251 + 2.1667)^2 + (-2.5592 + 2.1667)^2 + \ldots$$
$$(-1.7359 + 2.1667)^2)$$
$$= 0.12885$$

X2.4.3.3 The covariance of the log of pressure and the log of flow is calculated using Eq A1.6:

TABLE X2.3 Logarithms of Pressure and Flow Data Points[A]

Point	Ln (Pressure Difference Across Building Envelope, (Pa))	Ln (Flow Through Building Envelope, (m^3/ s))
1	2.3283	−2.8230
2	2.7638	−2.5571
3	2.9735	−2.4270
4	3.2488	−2.2574
5	3.4487	−2.1325
6	3.6071	−2.0374
7	3.7626	−1.9418
8	3.8234	−1.9095
9	3.9543	−1.8262
10	4.0987	−1.7338

[A] The number of observations (*N*) is 10.

$$S_{\ln(dP)\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})(\ln(Q)_i - \overline{\ln(Q)}) = \quad (X2.8)$$

$$\frac{1}{10-1}((2.3239 - 3.4002)(-2.8251 + 2.1667) + ... + (4.0894 - 3.4002)(-1.7359 + 2.1667)) = 0.198500$$

X2.4.3.4 Then *n* and ln (*C*) are given by Eq A1.7 and A1.9:

$$n = \frac{S_{\ln(dP)\ln(Q)}}{S^2_{\ln(dP)}} = \frac{0.198841}{0.32397} = 0.6140 \quad (X2.9)$$

$$C = \exp(^{\bar{y}-n\bar{x}}) = \exp(-2.1667 - 0.613 \times 3.4002) = 0.0142\,\frac{m^3}{sPa^n} \quad (X2.10)$$

X2.4.3.5 To make the corrections to standard conditions the density and viscosity at both the standard and measurement conditions shall be calculated as follows:

X2.4.3.6 The viscosity is calculated using Eq X1.5:

For indoor temperature of 21°C:

$$\mu = \frac{1.458 \times 10^{-6}(21 + 273)^{0.5}}{1 + \frac{110.4}{21 + 273}} = 1.817 \times 10^{-5} \quad (X2.11)$$

For the reference temperature of 20°C:

$$\mu = \frac{1.458 \times 10^{-6}(20 + 273)^{0.5}}{1 + \frac{110.4}{20 + 273}} = 1.813 \times 10^{-5} \quad (X2.12)$$

X2.4.3.7 The air leakage coefficient is corrected to standard conditions with Eq 4.

$$C_o = C\left(\frac{\mu}{\mu_o}\right)^{2n-1}\left(\frac{\rho}{\rho_o}\right)^{1-n} = 0.143\left(\frac{1.817 \times 10^{-5}}{1.813 \times 10^{-5}}\right)^{(2\times0.613-1)}\left(\frac{1.047}{1.204}\right)^{(1-0.613)} = 0.138\,\frac{m^3}{s \cdot Pa^n} \quad (X2.13)$$

X2.4.3.8 The leakage area is calculated using Eq 5, using a reference pressure (*dP*) of 4 Pa:

$$A_L = C_o\left(\frac{\rho_o}{2}\right)^{\frac{1}{2}}(dP_r)^{\left(n-\frac{1}{2}\right)} = 0.0135\left(\frac{1.204}{2}\right)^{\frac{1}{2}}(4)^{(0.613-0.5)} = 0.01257_4\text{m}^2 = 122.6_4\text{cm}^2 \quad (X2.14)$$

TABLE X2.4 Measured Depressurization Data Points

Point	Pressure Difference Across Building Envelope, (Pa)	Measured Flow Through Flowmeter, (m^3/ s)[A]
1	9.3	0.0503
2	14.2	0.0660
3	22.7	0.0883
4	26.1	0.0958
5	32.6	0.1110
6	38.6	0.1238
7	41.5	0.1296
8	47.9	0.1429
9	53.5	0.1545
10	57.3	0.1605

[A] This measured flow has been corrected for the temperature and density of the air flowing through the flowmeter and is the volumetric flow at the measurement conditions.

Initial pressure offset = −0.38 Pa
Final pressure offset = −0.21 Pa
Average pressure offset (dP_{off}) = ½ (−0.38 + (−0.21)) = −0.30 Pa
Outdoor temperature (T_{out}) = 17°C
Indoor temperature (T_{in}) = 24°C

X2.5 Depressurization Data

X2.5.1 *Measured Depressurization Data*—See Table X2.4.

X2.5.2 *Calculations*:

X2.5.2.1 Using E = 600 m and T_{in} = 24°C:

$$\rho_{in} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{24 + 273}\right) = 1.1071\ kg/m^3 \quad (X2.15)$$

X2.5.2.2 Using E = 600 m and T_{out} = 17°C:

$$\rho_{out} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{17 + 273}\right) = 1.1338\ kg/m^3 \quad (X2.16)$$

X2.5.2.3 Each flow in Table X2.4 is multiplied by the ratio of ρ_{in}/ρ_{out}, for example, for point number 1:

$$Q_o = Q\left(\frac{\rho_{in}}{\rho_{out}}\right) = 0.0503\left(\frac{1.038}{1.061}\right) = 0.0491 \quad (X2.17)$$

X2.5.2.4 Each pressure difference has the pressure offset of 0.3 Pa subtracted from it, for example, for point number 1:

$$-9.3 - (-0.3) = -9.0\ \text{Pa} \quad (X2.18)$$

X2.5.2.5 This results in the corrected depressurization data for pressure and flow shown in Table X2.5. The data in Table X2.5 are plotted in Fig. 2. Following the method outlined in Annex A1 and shown above for pressurization data, the flow coefficient, *C*, and pressure exponent, *n*, are determined as follows:

X2.5.3 *Logarithmic Transformation*—Table X2.6 shows the natural logarithms of the pressures and flows from Table X2.5.

X2.5.3.1 The variance of the log of pressure is calculated using Eq A1.4:

$$S^2_{\ln(dP)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})^2 = \quad (X2.19)$$

$$\frac{1}{10-1}((2.1978 - 3.39)^2 + (2.6294 - 3.39)^2 + ... + (4.0433 - 3.39)^2) = 0.36287$$

X2.5.3.2 The variance of the log of flow is calculated using Eq A1.5:

TABLE X2.5 Corrected Depressurization Data Points

Point	Pressure Difference Across Building Envelope, (Pa)	Flow Through Building Envelope, (m^3/ s)
1	−9.005	0.0491
2	−13.905	0.0644
3	−22.405	0.0862
4	−25.805	0.0935
5	−32.305	0.1084
6	−38.305	0.1209
7	−41.205	0.1295
8	−47.605	0.1395
9	−53.205	0.1509
10	−57.005	0.1567

TABLE X2.6 Logarithms of Pressure and Flow Data Points[A]

Point	Ln (Pressure Difference Across Building Envelope, (Pa))	Ln (Flow Through Building Envelope, (m^3/ s))
1	2.1978	−3.0136
2	2.6322	−2.7420
3	3.1093	−2.4509
4	3.2506	−2.3693
5	3.4752	−2.2221
6	3.6456	−2.1129
7	3.7186	−2.0672
8	3.8629	−1.9695
9	3.9742	−1.8914
10	4.0431	−1.8533

[A] The number of observations (*N*) is 10.

$$S^2_{\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(Q)_i - \overline{\ln(Q)})^2 = \qquad (X2.20)$$

$$\frac{1}{10-1}((-3.0119 + 2.2675)^2 + (-2.27402 + 2.2675)^2 + ...(-1.8516 + 2.2675)^2)$$
$$= 0.14374$$

X2.5.3.3 The covariance of the log of pressure and the log of flow is calculated using Eq A1.6:

$$S_{\ln(dP)\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}\left(\ln(dP)_i - \overline{\ln(dP)}\right)(\ln(Q)_i - \overline{\ln(Q)}) = \qquad (X2.21)$$

$$\frac{1}{10-1}((2.1978 - 3.39)(-3.0119 + 2.2675) + ... + (4.0433 - 3.39)(-1.8516 + 2.2675))$$
$$= 0.22834$$

X2.5.3.4 Then *n* and ln (*C*) are given by Eq A1.7 and Eq A1.9:

$$n = \frac{S_{\ln(dP)\ln(Q)}}{S^2_{\ln(dP)}} = \frac{0.22848}{0.36330} = 0.629 \qquad (X2.22)$$

$$C = \exp^{(\bar{y} - n \cdot \bar{x})} = \exp(-2.265 - 0.629 \times 3.39) = 0.0122 \qquad (X2.23)$$

X2.5.3.5 To make the corrections to standard conditions the density and viscosity at both the standard and measurement conditions shall be calculated. For depressurization, the measurement conditions shall be the outdoor air conditions, which is the air flowing through the envelope.

X2.5.3.6 The outdoor viscosity is calculated using Eq X1.5: For outdoor temperature of 17°C:

$$\mu = \frac{1.458 \times 10^{-6}(17 + 273)^{0.5}}{1 + \frac{110.4}{17 + 273}} = 1.798 \times 10^{-5} \qquad (X2.24)$$

For the reference temperature of 20°C:

$$\mu_o = \frac{1.458 \times 10^{-6}(20 + 273)^{0.5}}{1 + \frac{110.4}{20 + 273}} = 1.813 \times 10^{-5} \qquad (X2.25)$$

X2.5.3.7 The air leakage coefficient is corrected to standard conditions with Eq 4.

$$C_o = C\left(\frac{\mu}{\mu_o}\right)^{2n-1}\left(\frac{\rho}{\rho_o}\right)^{1-n}$$
$$= 0.123\left(\frac{1.798 \times 10^{-5}}{1.813 \times 10^{-5}}\right)^{(2\times0.629-1)}\left(\frac{1.061}{1.204}\right)^{(1-0.629)}$$
$$= 0.119\,\frac{m^3}{s \cdot Pa^n} \qquad (X2.26)$$

X2.5.3.8 The leakage area is calculated using Eq 5, using a reference pressure (*dP*) of 4 Pa:

$$A_L = C_o\left(\frac{\rho_o}{2}\right)^{\frac{1}{2}}(dP_r)^{\left(n-\frac{1}{2}\right)}$$
$$= 0.0117\left(\frac{1.204}{2}\right)^{\frac{1}{2}}(4)^{(0.629-0.5)}$$
$$= 0.01109\ m^2$$
$$= 108.5\ cm^2 \qquad (X2.27)$$

X2.6 Combined Pressurization and Depressurization Data

X2.6.1 *Calculations*—The leakage coefficient $C_{0,\ combined}$ is the average of the C_0 values for pressurization and depressurization.

$$C_{0,\ combined} = 0.5\ 8\ (0.0138 + 0.0119) = 0.0129 \qquad (X2.28)$$

X2.6.1.1 The leakage exponent $n_{combined}$ is the average of the n values for pressurization and depressurization.

$$n_{combined} = 0.5 \cdot (0.6140 + 0.6293) = 0.6216 \qquad (X2.29)$$

X2.6.1.2 The leakage area $AL_{combined}$ is the average of the AL values for pressurization and depressurization.

$$AL_{combined} = 0.5 \cdot (0.01257 + 0.01109) = 0.01183 \qquad (X2.30)$$

X2.7 Estimates of Confidence Limits

X2.7.1 *Pressurization Confidence Limits*—The 95 % confidence limits for *C* and *n* are below. The variance of *n* is given by Eq A1.10:

$$S_n = \frac{1}{S_{\ln(dP)}}\left(\frac{S^2_{\ln(Q)} - n \cdot S_{\ln(dP)\ln(Q)}}{N-2}\right)^{\frac{1}{2}} \qquad (X2.31)$$

$$= \frac{1}{0.3244}\left(\frac{0.1218 - 0.613 \times 0.1988}{10-2}\right)^{\frac{1}{2}} = 0.001261$$

X2.7.1.1 The estimate of the variance of ln (*C*) is given by Eq A1.11:

$$S_{\ln(C)} = S_n\left(\frac{\sum_{i=1}^{N} dP_i^2}{N}\right)^{\frac{1}{2}} \qquad (X2.32)$$

$$= 0.001252\left(\frac{2.3239^2 + 2.7616^2 + ... + 4.0984^2}{10}\right)^{\frac{1}{2}} = 0.0043427$$

X2.7.1.2 The confidence limits for ln (*C*) and *n* require the values of the two-sided Student distribution (*T* (95 %, *N* – 2)) that are given in Table A1.1. In this case, (*T* (95 %, 8)) = 2.306.

X2.7.1.3 The 95 % confidence interval for *n* and ln (*C*) is then given by Eq A1.13:

$$I_n = S_n\, T\,(95\,\%, N-2) = 0.001252 \times 2.306 = 0.002908 \tag{X2.33}$$

$$I_{\ln(C)} = S_{\ln(C)}\, T\,(95\,\%, N-2) = 0.004310 \times 2.306 = 0.010014 \tag{X2.34}$$

X2.7.1.4 This means that the probability is 95 % that the pressure exponent *n* lies in the interval (0.611, 0.617), and the air leakage coefficient *C* lies in the interval:

$$(C \cdot \exp^{-I_{\ln(C)}}, C \cdot \exp^{I_{\ln(C)}}) = (0.0143\exp(-0.009939), 0.0143\exp(0.009939)) = (0.0141, 0.0144)\frac{m^3}{sPa^n} \tag{X2.35}$$

X2.7.1.5 To estimate the confidence limits for leakage area requires an estimate of the variance around the regression line (Eq A1.1) at the reference pressure difference (dP_r):

$$S_{\ln(Q)}(\ln(dP_r)) = S_n\left(\frac{N-1}{N}S^2_{\ln(dP)} + (\ln(dP_r) - \overline{\ln(dP)})^2\right)^{\frac{1}{2}} \tag{X2.36}$$

substituting the appropriate values gives:

$$S_{\ln(C)}(\ln(4)) = 0.001252\left(\frac{9}{10}0.342397 + (\ln(4) - 3.4002)^2\right)^{\frac{1}{2}} = 0.0026303 \tag{X2.37}$$

and the 95 % confidence interval in the estimate of ln (*Q*) using Eq A1.1 at the reference pressure, dP_r, is as follows:

$$I_{\ln(Q)}(\ln(dP_r)) = S_{\ln(C)}(\ln(dP_r))T(95\,\%, N-2) \tag{X2.38}$$

$$= 0.002610 \times 2.306 = 0.006065$$

X2.7.1.6 The 95 % confidence interval of the estimate of the leakage area A_L using then is given by the following:

$$A_L\exp(-I_{\ln(C)}(ln(dP_r))) = 0.0126exp(-0.006020) = 0.01254\ m^2 \tag{X2.39}$$

$$A_L\exp(I_{\ln(C)}(ln(dP_r))) = 0.0126exp(0.006020) = 0.0126\ m^2 \tag{X2.40}$$

$$A_L\exp(I_{\ln(C)}(\ln(dP_r))) = 0.01226\exp(0.05965) = 0.012334 \tag{X2.41}$$

Therefore the 95 % confidence limits for A_L (0.01257 m^2 or 125.7 cm^2) are (0.0125, 0.0126) m^2 or (125, 126) cm^2.

X2.7.2 *Depressurization Confidence Limits*—The depressurization confidence limits are calculated the same way as for pressurization, with the following results:

X2.7.2.1 The 95 % confidence interval for *n* is (0.620, 0.639).

X2.7.2.2 The 95 % confidence interval for *C* is (0.0118, 0.0126 m^3/sPa^n).

X2.7.2.3 The 95 % confidence interval for A_L is (0.0109, 0.0113) m^2 or (109, 113) cm^2.

X2.7.3 *Combined Pressurization and Depressurization Confidence Limits*—The combined pressurization and depressurization confidence limits are calculated with equation Eq 6, with the following results:

X2.7.3.1 The 95 % confidence interval for *n* is (0.617, 0.627).

X2.7.3.2 The 95 % confidence interval for *C* is (0.0127, 0.0131 m^3/sPa^n).

X2.7.3.3 The 95 % confidence interval for A_L is (0.0117, 0.0119) m^2 or (117, 119) cm^2.