Designation: E 779 – 03

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

This standard is issued under the fixed designation E 779; 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 covers a standardized technique for measuring 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 conditions. For tests conducted in the field, it must be recognized that field conditions may be less than ideal. Nevertheless, strong winds and large indoor-outdoor temperature differentials should be avoided.

1.3 This test method is intended to produce a measure of air tightness of a building envelope. This test method does not measure air leakage rates under normal conditions of weather and building operation. To measure air-change rate directly, use the tracer gas dilution method (see Test Method E 741).

1.4 This test method is intended for the measurement of the airtightness 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 *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 741 Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution.

E 1258 Test Method for Airflow Calibration of Fan Pressurization Devices

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *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, ACT–.

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

3.1.3 *air-leakage rate*, *n*—the volume of air movement/unit time across the building envelope.

3.1.3.1 *Discussion*—This movement includes flow through joints, cracks, and porous surfaces, or a combination thereof. The driving force for such an air leakage, in service can be either mechanical pressurization and de-pressurization, natural wind pressures, or air temperature differentials between the building interior and the outdoors, or a combination thereof.

3.1.4 *building envelope*, *n*—the boundary or barrier separating the interior volume of a building from the outside environment.

3.1.4.1 *Discussion*—For the purpose of this test method, the interior volume is the deliberately conditioned space within a building, generally not including attics, basements, and attached structures, for example, garages, unless such spaces are connected to the heating and air conditioning system, such as a crawl space plenum.

3.1.5 *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.

3.1.5.1 *Discussion*—A multi-room space that is interconnected within itself with door-sized openings through any partitions or floors is likely to satisfy this criterion if the fan airflow rate is less than 3 m^3/s 6 × 10^3 ft^3/min).

3.1.6 *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).

3.2 *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

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventilation.

Current edition approved Oct. 1, 2003. Published November 2003. Originally approved in 1981. Last previous edition approved in 1999 as E 779 – 99.

[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]

and pressure differences, the air leakage characteristics of a building envelope can be evaluated.

5. Significance and Use

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

5.2 In most commercial or industrial buildings, outdoor air often is introduced by design; however, air leakage can be 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 can be 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 can be 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 is permitted.

6.2 *Major Components*:

6.2.1 *Air-Moving Equipment*—A fan, blower, 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. Where applicable, the HVAC system of the building may be used in place of the fan or blower.

6.2.2 *Pressure-Measuring Device*—A manometer or pressure indicator to measure pressure difference with an accuracy of ±5 % of measured pressure.

6.2.3 *Airflow Measuring System*—A 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 E 1258

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

6.2.5 *Wind Speed-Measuring Device (Optional)*—A device to give an accuracy within ±0.25 m/s (0.56 mph) at 2.5 m/s (5.6 mph). Perform wind speed measurements at a distance three to five building heights away from the buildings, where practical. List the height above ground at which wind speed is measured.

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 in operation. 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 To create a single zone for this test procedure, all interconnecting doors, except for closets, which should be closed, in the conditioned space should be opened such that a uniform pressure will be maintained within the conditioned space to within ±10 % of the measured inside/outside pressure difference. Verify this condition by differential pressure measurements at the highest pressure used in the test. Make these measurements at the highest and lowest level of the building and on the windward and leeward sides.

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

8.3 Make general observations of the condition of the building. Take notes on 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 so that their average values can be estimated. 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), do not perform the test, because the pressure difference induced by the stack effect is too large to allow accurate interpretation of the results.

8.5 If the wind speed is to be part of the measurement record, use a wind-measuring device or obtain readings from a nearby weather bureau. Preferred test conditions are wind speed of 0 to 2 m/s (0 to 4 mph) and an outside temperature from 5 to 35°C (41 to 95°F).

8.6 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 leakage at these points.

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

8.8 *Installing the Envelope Pressure Sensor(s)*—Install the pressure measuring device across the building envelope. It is good practice to use more than one location across the building envelope for pressure measurement, for example, one across each facade. Fig. 1 illustrates preferred locations for exterior pressure measurement locations that avoid extremes of exterior pressures (at exterior corners). A good location avoids exterior corners and complex architectural features and should be close to the middle of the exterior wall. In addition, buildings more than three stories, or 7.5 m (25.5 ft), high shall have exterior pressures measured at more than one height on the exterior walls. The pressures from each location should be averaged, typically using a manifold. Average the pressures over at least a 10-s time period.

8.9 Measure zero flow pressures with the fan opening blocked. These zero flow envelope pressures are measured before and after the flow measurements. These zero flow pressures are to be subtracted from the envelope pressures measured during pressurization and depressurization.

NOTE 1—Some equipment may perform this step, or an equivalent step, automatically. Follow the manufacturer's instructions accordingly.

8.10 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-handling equipment. Because the capacity of the air handling equipment, the tightness of 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 2—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.

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

8.12 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 should be used.

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

8.14 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 pressure and the temperatures of the air flowing through the flowmeter during the test, these readings must be converted using information obtained from the manufacturer for the change in calibration with these parameters.

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, due to elevation changes only, of the outside air for depressurization tests or of the inside air for pressurization tests (see Appendix X1). To convert the airflow rate to air leakage rate for depressurization, use the following equation:

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

where:

ρ_{in} = the indoor air density, in kg/m^3 (lb/ft^3), and

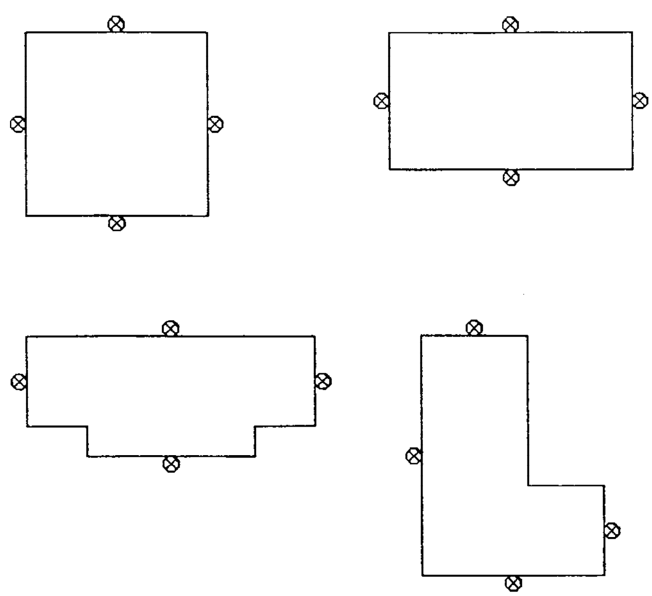

FIG. 1 Recommended Locations for Exterior Pressures (Plan Views of Buildings—"X" Within Circles Mark Pressure Tap Locations)

p_{out} = the outdoor air density, in kg/m^3 (lb/ft^3).

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 such 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 a log-linearized linear regression technique, where *Q* is the airflow rate, in m^3/s (ft^3/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* should be calculated. *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 should be repeated.

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/m^3(lb/ft^3).

9.6.1 The unsubscripted quantities refer to the values under the conditions of the test (indoor air for pressurization and outdoor air for pressurization), 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.

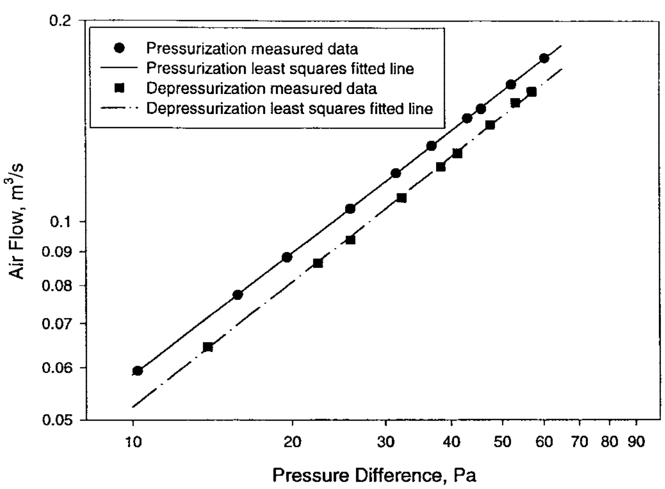

FIG. 2 Example Air Leakage Graph

9.6.2 The leakage area A_L, in m^2, can 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 and leakage area for use in other calculations, the pressurization and depressurization envelope flows (corrected using Eq 1 and 2) and pressure differences, with their offsets removed, may be combined together. This combined data set then is used in the same way as each individual data set to obtain *C*, *n*, and A_L for the combined data. If the flow at a specified pressure difference, such as 50 Pa, is desired, it should be determined from Eq 3 using the derived *C* and *n* and the specified pressure difference.

9.7 Determine confidence limits for the derived values from the data used to determine Eq 3 using Appendix X2.

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 (optional) 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 Optional data, including wind speed/direction and whether wind speed is estimated to exceed 0 to 2 m/s (0 to 4 mph).

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 area. Also, 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 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.

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 (1bm/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 IP 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.

X2. Recommended Procedure For Estimating Errors In Derived Quantities

X2.1 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 error in such quantities. The following method is recommended: 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.

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

where:

N = the total number of test readings.

X2.1.1 Eq 3 then transforms into the following:

$$y = \ln(C) + n \cdot x \quad (X2.1)$$

X2.1.2 Compute the following quantities:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \quad (X2.2)$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \tag{X2.3}$$

$$S_x^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2 \tag{X2.4}$$

$$S_y^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i - \bar{y})^2 \tag{X2.5}$$

$$S_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y}) \tag{X2.6}$$

X2.1.2.1 Then the best estimate of n and ln (C) is given by the following:

$$n = \frac{S_{xy}}{S_x^2} \tag{X2.7}$$

$$\ln(C) = \bar{y} - n \cdot \bar{x} \tag{X2.8}$$

$$C = \exp^{[\bar{y} - n \cdot \bar{x}]} \tag{X2.9}$$

X2.1.2.2 The 95 % confidence limits for C and n can be determined in the following equation. The variance of n is given by the estimate:

$$S_n = \frac{1}{S_x}\left(\frac{S_y^2 - n \cdot S_{xy}}{N-2}\right)^{\frac{1}{2}} \tag{X2.10}$$

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

$$S_{\ln(C)} = S_n\left(\frac{\sum_{i=1}^{N} x_i^2}{N}\right)^{\frac{1}{2}} \tag{X2.11}$$

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

$$I_{\ln(C)} = S_{\ln(C)}\, T\,(95\,\%, N-2) \tag{X2.12}$$

$$I_n = S_n\, T\,(95\,\%, N-2) \tag{X2.13}$$

Where the values of the two-sided student distribution (T (95 %, $N - 2$)) are given in Table X2.1.

X2.1.2.3 This means that the probability is 95 % that the pressure exponent n lies in the interval ($n - I_n$, $n + I_n$) and the air leakage coefficient C lies in the interval:

$$(C \cdot exp^{-I_{\ln(C)}}, C \cdot exp^{I_{\ln(C)}}) \tag{X2.14}$$

X2.1.2.4 The estimate of the variance around the regression line Eq X2.1 at the value x is:

$$S_y(x) = S_n\left(\frac{N-1}{N}S_x^2 + (x - \bar{x})^2\right)^{\frac{1}{2}} \tag{X2.15}$$

and the confidence interval in the estimate of y using Eq X2.1 at any x is

$$I_y(x) = S_y(x)\, T\,(95\,\%, N-2) \tag{X2.16}$$

X2.1.2.5 The airflow rate Q, predicted by Eq 3 at any pressure difference dP, therefore, lies in the interval:

$$(Q \cdot exp^{-I_{y(\ln(dP))}}, Q \cdot exp^{I_{y(\ln(dP))}}) \tag{X2.17}$$

with a probability of 95 %.

X2.1.2.6 It is this interval that should 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 50 Pa. For example, the confidence interval of the estimate of the leakage area A_L using Eq 5 is as follows:

$$(A_L \cdot exp^{-I_{y(\ln(dP))}}, A_L \cdot exp^{I_{y(\ln(dP))}}) \tag{X2.18}$$

with a probability of 95 %.

X2.1.3 In practice, the above error analysis can be carried out using standard statistical computer programs.

TABLE X2.1 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

X3. EXAMPLE CALCULATIONS

X3.1 Introduction

X3.1.1 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.

X3.2 Site Data

X3.2.1 Single-story house with a ceiling to floor height of 2.5 m. The house is located at 600 m above seal level (E).

X3.3 Checking Test Limits

X3.3.1 *Section* 8.4—The product of indoor-outdoor temperature difference and building height must 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.

X3.3.2 The average windspeed is 1 m/s, and the outdoor temperature is 8°C, thus meeting the specifications of 8.5.

X3.3.3 Ten pressure difference and flow measurements are made between 10 and 60 Pa, thus meeting the requirements of 8.10.

X3.4 Pressurization Data

X3.4.1 *Measured Pressurization Data*—See Table X3.1.

X3.4.2 *Calculations*:

X3.4.2.1 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.

$$\rho_{in} = 1.2041\left(1 - \frac{0.0065 \cdot E}{293}\right)^{5.2553}\left(\frac{293}{T_{in} + 273}\right) \tag{X3.1}$$

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

TABLE X3.1 Measured Pressurization Data Points

Point	Pressure Difference Across Building Envelope, (Pa)	Measured Flow Through Flowmeter, (m^2/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 = −0.3 Pa
Average pressure offset (dP_{off}) = ½ (−0.43 − 0.3) = −0.36 Pa
Outdoor temperature (T_{out}) = 8°C
Indoor temperature (T_{in}) = 21°C
Wind speed = 1 m/s

$$\rho_{in} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{21 + 273}\right) = 1.119 \text{ kg/m}^3 \quad \text{(X3.2)}$$

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

$$\rho_{out} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{8 + 273}\right) = 1.170 \text{ kg/m}^3 \quad \text{(X3.3)}$$

X3.4.2.2 Each Flow in Table X3.1 is multiplied by the ratio of ρ_{out}/ρ_{in}, for example, for point number 1:

$$Q_o = Q\left(\frac{\rho_{out}}{\rho_{in}}\right) = 0.0568\left(\frac{1.170}{1.119}\right) = 0.0593\frac{m^3}{s} \quad \text{(X3.4)}$$

X3.4.2.3 Each pressure difference has the pressure offset of −0.36 Pa subtracted from it, for example, for point number 1:

$$9.9 - (-0.36) = 10.2\ Pa \quad \text{(X3.5)}$$

X3.4.2.4 This results in the corrected data shown in Table X3.2 for pressure and flow.

X3.4.2.5 The data in Table X3.2 are plotted in Fig. 2. Following the method outlined in Appendix X2 the flow coefficient, C, pressure exponent, n, are determined as follows:

X3.4.3 *Logarithmic Transformation*—Table X3.3 shows the natural logarithms of the pressures and flows from Table X3.2.

X3.4.3.1 The variance of the log of pressure is calculated using Eq X2.4:

TABLE X3.2 Corrected Pressurization Data Points

Point	Pressure Difference Across Building Envelope, (Pa)	Flow Through Building Envelope, (m^3/ s)
1	10.2	0.0593
2	15.8	0.0774
3	19.6	0.0881
4	25.8	0.1044
5	31.5	0.1183
6	36.8	0.1301
7	43.0	0.1431
8	45.7	0.1478
9	52.1	0.1607
10	60.2	0.1762

TABLE X3.3 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	2.3239	−2.8251
2	2.7616	−2.5592
3	2.9743	−2.4291
4	3.2486	−2.2595
5	3.4495	−2.1346
6	3.6062	−2.0395
7	3.7620	−1.9439
8	3.8231	−1.9116
9	3.9540	−1.8283
10	4.0984	−1.7359

[A] The number of observations (N) is 10. The average of the log of pressure using Eq X2.2 is 3.4002. The average of the log of flow using Eq X2.3 is −2.1667.

$$S^2_{\ln(dP)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})^2 = \quad \text{(X3.6)}$$

$$\frac{1}{10-1}((2.3239 - 3.4002)^2 + (2.7616 - 3.4002)^2 + ... + (4.0894 - 3.4002)^2) = 0.32397$$

X3.4.3.2 The variance of the log of flow is calculated using Eq X2.5:

$$S^2_{\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(Q)_i - \overline{\ln(Q)})^2 = \quad \text{(X3.7)}$$

$$\frac{1}{10-1}((-2.8251 + 2.1667)^2 + (-2.5592 + 2.1667)^2 + ... (-1.7359 + 2.1667)^2) = 0.121884$$

X3.4.3.3 The covariance of the log of pressure and the log of flow is calculated using Eq X2.6:

$$S_{\ln(dP)\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})(\ln(Q)_i - \overline{\ln(Q)}) = \quad \text{(X3.8)}$$

$$\frac{1}{10-1}((2.3239 - 3.4002)(-2.8251 + 2.1667) + ... + (4.0894 - 3.4002)(-1.7359 + 2.1667)) = 0.198841$$

X3.4.3.4 Then n and ln (C) are given by Eq X2.7 and X2.9:

$$n = \frac{S_{\ln(dP)\ln(Q)}}{S^2_{\ln(dP)}} = \frac{0.198841}{0.32397} = 0.613 \quad \text{(X3.9)}$$

$$C = \exp(^{\bar{y} - n\bar{x}}) = \exp(-2.1667 - 0.613 \times 3.4002) = 0.0143\frac{m^3}{sPa^n} \quad \text{(X3.10)}$$

X3.4.3.5 To make the corrections to standard conditions the density and viscosity at both the standard and measurement conditions must be calculated as follows:

X3.4.3.6 The indoor density (ρ) was calculated above to be 1.119 kg/m³.

The reference density (ρ_o) is 1.2041 kg/m³.

The viscosity is calculated by substituting these values into Eq X1.5:

For indoor temperature of 21°C:

$$\mu = \frac{1.458 \times 10^{-6}(21 + 273)^{0.5}}{1 + \dfrac{110.4}{21 + 273}} = 1.817 \times 10^{-5} \quad \text{(X3.11)}$$

For the reference temperature of 20°C:

$$\mu = \frac{1.458 \times 10^{-6}\,(20+273)^{0.5}}{1 + \dfrac{110.4}{20+273}} = 1.813 \times 10^{-5} \qquad \text{(X3.12)}$$

X3.4.3.7 The air leakage coefficient is corrected to standard conditions with Eq 4.

$$C_o = C\left(\frac{\mu}{\mu_o}\right)^{2n-1}\left(\frac{\rho}{\rho_o}\right)^{1-n}$$
$$= 0.143\left(\frac{1.817 \times 10^{-5}}{1.813 \times 10^{-5}}\right)^{(2\times0.613-1)}\left(\frac{1.047}{1.204}\right)^{(1-0.613)}$$
$$= 0.135\,\frac{m^3}{s \cdot Pa^n} \qquad \text{(X3.13)}$$

X3.4.3.8 The leakage area is calculated using Eq 5, using a reference pressure (dP) of 4 Pa:

$$A_L = C_o\left(\frac{\rho_o}{2}\right)^{\frac{1}{2}}(dP_r)^{\left(n-\frac{1}{2}\right)}$$
$$= 0.0135\left(\frac{1.204}{2}\right)^{\frac{1}{2}}(4)^{(0.613-0.5)}$$
$$= 0.01226_4 m^2$$
$$= 122.6_4 cm^2 \qquad \text{(X3.14)}$$

X3.5 Depressurization Data

X3.5.1 *Measured Depressurization Data*—See Table X3.4.

X3.5.2 *Calculations*:

X3.5.2.1 Using E = 600 m and T_{in} = 24°C:

$$\rho_{in} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{24+273}\right) = 1.038\ kg/m^3 \qquad \text{(X3.15)}$$

X3.5.2.2 Using E = 600 m and T_{out} = 17°C:

$$\rho_{out} = 1.2041\left(1 - \frac{0.0065 \cdot 600}{293}\right)^{5.2553}\left(\frac{293}{17+273}\right) = 1.061\ kg/m^3 \qquad \text{(X3.16)}$$

X3.5.2.3 Each flow in Table X3.4 is multiplied by the ratio of ρ_{in}/ρ_{out}, for example, for point number 1:

$$Q_o = Q\left(\frac{\rho_{in}}{\rho_{out}}\right) = 0.0503\left(\frac{1.038}{1.061}\right) = 0.0492 \qquad \text{(X3.17)}$$

X3.5.2.4 Each pressure difference has the pressure offset of 0.3 Pa subtracted from it, for example, for point number 1:

$$9.3 - 0.3 = 9\ Pa \qquad \text{(X3.18)}$$

X3.5.2.5 This results in the corrected depressurization data for pressure and flow shown in Table X3.5. The data in Table X3.5 are plotted in Fig. 2. Following the method outlined in Appendix X2 and shown above for pressurization data, the flow coefficient, C, and pressure exponent, n, are determined as follows:

X3.5.3 *Logarithmic Transformation*—Table X3.6 shows the natural logarithms of the pressures and flows from Table X3.5.

X3.5.3.1 The variance of the log of pressure is calculated using Eq X2.4:

$$S^2_{\ln(dP)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})^2 = \qquad \text{(X3.19)}$$

$$\frac{1}{10-1}((2.1978 - 3.39)^2 + (2.6294 - 3.39)^2 + ... + (4.0433 - 3.39)^2)$$
$$= 0.36330$$

X3.5.3.2 The variance of the log of flow is calculated using Eq X2.5:

$$S^2_{\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(Q)_i - \overline{\ln(Q)})^2 = \qquad \text{(X3.20)}$$

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

X3.5.3.3 The convariance of the log of pressure and the log of flow is calculated using Eq X2.6:

$$S_{\ln(dP)\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}\left(\ln(dP)_i - \overline{\ln(dP)}\right)(\ln(Q)_i - \overline{\ln(Q)}) = \qquad \text{(X3.21)}$$

$$\frac{1}{10-1}((2.1978 - 3.39)(-3.0119 + 2.2675) + ... + (4.0433 - 3.39)$$
$$(-1.8516 + 2.2675))$$
$$= 0.22848$$

X3.5.3.4 Then n and ln (C) are given by Eq X2.7 and Eq X2.9:

$$n = \frac{S_{\ln(dP)\ln(Q)}}{S^2_{\ln(dP)}} = \frac{0.22848}{0.36330} = 0.629 \qquad \text{(X3.22)}$$

TABLE X3.4 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) = 0.3 Pa
Outdoor temperature (T_{out}) = 17°C
Indoor temperature (T_{in}) = 24°C
Wind speed = 1 m/s.

TABLE X3.5 Corrected Depressurization Data Points

Point	Pressure Difference Across Building Envelope, (Pa)	Flow Through Building Envelope, (m^3/ s)
1	9.0	0.0492
2	13.9	0.0646
3	22.4	0.0864
4	25.8	0.0937
5	32.3	0.1086
6	38.3	0.1211
7	41.2	0.1268
8	47.6	0.1398
9	53.2	0.1511
10	57.0	0.1570

TABLE X3.6 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	−3.0119
2	2.6294	−2.7402
3	3.1075	−2.4491
4	3.2490	−2.3676
5	3.4743	−2.2203
6	3.6456	−2.1112
7	3.7183	−2.0654
8	3.8619	−1.9677
9	3.9734	−1.8897
10	4.0433	−1.8516

[A] The number of observations (*N*) is 10. The average of the log of pressure is 3.3900. The average of the log of flow is −2.2675.

$$C = \exp^{(\bar{y} - n \cdot \bar{x})} = \exp(-2.265 - 0.629 \times 3.39) = 0.0123 \quad \text{(X3.23)}$$

X3.5.3.5 To make the corrections to standard conditions the density and viscosity at both the standard and measurement conditions must be calculated. For depressurization, the measurement conditions are the outdoor air conditions, which is the air flowing through the envelope.

X3.5.3.6 The outdoor density (ρ) was calculated above to be 1.134 k/g/m^3. The reference density (ρ_o) is 1.2041 kg/m^3. The viscosity is calculated by substituting these values into Eq X1.5:

For outdoor temperature of 17°C:

$$\mu = \frac{1.458 \times 10^{-6}\,(17 + 273)^{0.5}}{1 + \frac{110.4}{17 + 273}} = 1.798 \times 10^{-5} \quad \text{(X3.24)}$$

For the reference temperature of 20°C:

$$\mu_o = \frac{1.458 \times 10^{-6}\,(20 + 273)^{0.5}}{1 + \frac{110.4}{20 + 273}} = 1.813 \times 10^{-5} \quad \text{(X3.25)}$$

X3.5.3.7 The air leakage coefficient is corrected to standard conditions with Eq 4.

$$\begin{aligned} C_o &= C\left(\frac{\mu}{\mu_o}\right)^{2n-1}\left(\frac{\rho}{\rho_o}\right)^{1-n} \\ &= 0.123\left(\frac{1.798 \times 10^{-5}}{1.813 \times 10^{-5}}\right)^{(2\times0.629-1)}\left(\frac{1.061}{1.204}\right)^{(1-0.629)} \\ &= 0.117\,\frac{m^3}{s \cdot Pa^n} \end{aligned} \quad \text{(X3.26)}$$

X3.5.3.8 The leakage area is calculated using Eq 5, using a reference pressure (dP) of 4 Pa:

$$\begin{aligned} A_L &= C_o\left(\frac{\rho_o}{2}\right)^{\frac{1}{2}}(dP_r)^{\left(n-\frac{1}{2}\right)} \\ &= 0.0117\left(\frac{1.204}{2}\right)^{\frac{1}{2}}(4)^{(0.629-0.5)} \\ &= 0.01085\ m^2 \\ &= 108.5\ cm^2 \end{aligned} \quad \text{(X3.27)}$$

X3.6 Combined Pressurization and Depression Data

X3.6.1 *Measured Data*—The measured data is given in Tables X3.1 and X3.4.

X3.6.2 *Calculations*—Table X3.7 shows the natural logarithms of the pressures and flows for both pressurization and depressurization.

TABLE X3.7 Corrected Logarithmic Data Points[A]

Point	Ln (Pressure Difference Across Building Envelope, (Pa))	Ln (Flow Through Building Envelope, (m^3/ s))
1	2.3239	−2.8251
2	2.7616	−2.5592
3	2.9743	−2.4291
4	3.2486	−2.2595
5	3.4495	−2.1346
6	3.6062	−2.0395
7	3.7620	−1.9439
8	3.8231	−1.9116
9	3.9540	−1.8283
10	4.0984	−1.7359
11	2.1978	−3.0119
12	2.6294	−2.7402
13	3.1075	−2.4491
14	3.2490	−2.3676
15	3.4743	−2.2203
16	3.6456	−2.1112
17	3.7183	−2.0654
18	3.8619	−1.9677
19	3.9734	−1.8897
20	4.0433	−1.8516

[A] The number of observations (*N*) is 20. The average of the log of pressure is 3.3951. The average of the log of flow is −2.2171.

X3.6.2.1 The variance of the log of pressure is calculated using Eq X3.7:

$$S^2_{\ln(dP)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})^2 = \quad \text{(X3.28)}$$

$$\begin{aligned} &\frac{1}{20-1}((2.3239 - 3.3951)^2 + (2.7616 - 3.3951)^2 + ... + (4.0433 \\ &\quad - 3.3951)^2) \\ &= 0.3258 \end{aligned}$$

X3.6.2.2 The variance of the log of flow is calculated using Eq X2.5:

$$S^2_{\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(Q)_i - \overline{\ln(Q)})^2 = \quad \text{(X3.29)}$$

$$\begin{aligned} &\frac{1}{20-1}((-2.8251 + 2.2171)^2 + (-2.5592 + 2.2171)^2 + ... (-1.8516 \\ &\quad + 2.2171)^2) \\ &= 0.12849 \end{aligned}$$

X3.6.2.3 The variance of the log of pressure and the log of flow is calculated using Eq X2.6:

$$S_{\ln(dP)\ln(Q)} = \frac{1}{N-1}\sum_{i=1}^{N}(\ln(dP)_i - \overline{\ln(dP)})(\ln(Q)_i - \overline{\ln(Q)}) = \quad \text{(X3.30)}$$

$$\begin{aligned} &\frac{1}{10-1}((2.3239 - 3.3951)(-2.8251 + 2.2171) + ... + (4.0433 \\ &\quad - 3.3951)(-1.8516 + 2.2171)) \\ &= 0.20268 \end{aligned}$$

X3.6.2.4 Then n and ln (C) are given by Eq X2.7 and X2.9:

$$n = \frac{S_{\ln(dP)\ln(Q)}}{S^2_{\ln(dP)}} = \frac{0.20268}{0.3258} = 0.622 \quad \text{(X3.31)}$$

$$C = \exp^{(\bar{y} - n \cdot \bar{x})} = \exp(-2.2171 - 0.622 \times 3.3951) = 0.0132 \quad \text{(X3.32)}$$

X3.6.2.5 To make the corrections to standard conditions the density and viscosity at both the standard and measurement conditions must be calculated. For the combined pressurization and depressurization calculations, the measurement conditions are the average of the depressurization outdoor air conditions and the pressurization indoor air conditions.

X3.6.2.6 The depressurization outdoor density (ρ) was calculated above to be 1.134 kg/m^3. The pressurization indoor density was calculated to be 1.119 kg/m^3. The average of these densities is 1.127 kg/m^3. The reference density (ρ_o) is 1.2041 kg/m^3.

X3.6.2.7 The depressurization outdoor viscosity was calculated to be 1.798 × 10^{-5} kg/m·s. The pressurization indoor viscosity was 1.817 × 10^{-5} kg/m·s. The average viscosity is 1.8075 × 10^{-5} kg/(m·s). For the reference temperature of 20°C, the viscosity is 1.813 × 10^{-5} kg/(m·s):

X3.6.2.8 The combined pressurization/depressurization air leakage coefficient is corrected to standard conditions with Eq 4.

$$C_o = C\left(\frac{\mu}{\mu_o}\right)^{2n-1}\left(\frac{\rho}{\rho_o}\right)^{1-n} = 0.0132\left(\frac{1.8075\times10^{-5}}{1.813\times10^{-5}}\right)^{(2\times0.622-1)}\left(\frac{1.127}{1.2041}\right)^{(1-0.622)} = 0.0129\,\frac{m^3}{sPa^n} \quad (X3.33)$$

X3.6.2.9 The leakage area is calculated using Eq 5, using a reference pressure (dP) of 4 Pa:

$$A_L = C_o\left(\frac{\rho_o}{2}\right)^{\frac{1}{2}}(dP_r)^{\left(n-\frac{1}{2}\right)} = 0.0129\left(\frac{1.2041}{2}\right)^{\frac{1}{2}}(4)^{(0.622-0.5)} = 0.0119\text{ m}^2 = 119\text{ cm}^2 \quad (X3.34)$$

X3.7 Estimates of Confidence Limits

X3.7.1 *Pressurization Confidence Limits*—The 95 % confidence limits for C and n are below. The variance of n is given by Eq X2.10:

$$S_n = \frac{1}{S_{\ln(dP)}}\left(\frac{S^2_{\ln(Q)} - n\cdot S_{\ln(dP)\ln(Q)}}{N-2}\right)^{\frac{1}{2}} \quad (X3.35)$$

$$= \frac{1}{0.3244}\left(\frac{0.1218 - 0.613\times0.1988}{10-2}\right)^{\frac{1}{2}} = 0.001252$$

X3.7.1.1 The estimate of the variance of ln (C) is given by Eq X2.11:

$$S_{\ln(C)} = S_n\left(\frac{\sum_{i=1}^{N} dP_i^{\,2}}{N}\right)^{\frac{1}{2}} \quad (X3.36)$$

$$= 0.001252\left(\frac{2.3239^2 + 2.7616^2 + ... + 4.0984^2}{10}\right)^{\frac{1}{2}} = 0.00310$$

X3.7.1.2 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 X2.1. In this case, (T (95 %, 8)) = 2.306.

X3.7.1.3 The 95 % confidence interval for n and ln (C) is then given by Eq X2.13:

$$I_n = S_n\,T(95\,\%, N-2) = 0.001252\times2.306 = 0.002887 \quad (X3.37)$$

$$I_{\ln(C)} = S_{\ln(C)}\,T(95\,\%, N-2) = 0.004310\times2.306 = 0.009939 \quad (X3.38)$$

X3.7.1.4 This means that the probability is 95 % that the pressure exponent n lies in the interval (0.610, 0.616), and the air leakage coefficient C lies in the interval:

$$(C\cdot\exp^{-I_{\ln(C)}}, C\cdot\exp^{I_{\ln(C)}}) = (0.0143\exp(-0.009939), 0.0143\exp(0.009939)) = (0.0142, 0.0144)\frac{m^3}{sPa^n} \quad (X3.39)$$

X3.7.1.5 To estimate the confidence limits for leakage area requires an estimate of the variance around the regression line (Eq X2.1) at the reference pressure difference (dP_r):

$$S_{\ln(C)}(\ln(dP_r)) = S_n\left(\frac{N-1}{N}S^2_{\ln(dP)} + (\ln(dP_r) - \overline{\ln(dP)})^2\right)^{\frac{1}{2}} \quad (X3.40)$$

substituting the appropriate values gives:

$$S_{\ln(C)}(\ln(4)) = 0.001252\left(\frac{9}{10}0.342397 + (\ln(4) - 3.4002)^2\right)^{\frac{1}{2}} = 0.002610 \quad (X3.41)$$

and the 95 % confidence interval in the estimate of ln (C) using Eq X2.1 at the reference pressure, dP_r, is as follows:

$$I_{\ln(C)}(\ln(dP_r)) = S_{\ln(C)}(\ln(dP_r))T(95\,\%, N-2) = 0.002610\times2.306 = 0.06020 \quad (X3.42)$$

X3.7.1.6 The 95 % confidence interval of the estimate of the leakage area A_L using then is given by the following:

$$A_L\exp(-I_{\ln(C)}(ln(dP_r))) = 0.0126exp(-0.006020) = 0.0125m^2 \quad (X3.43)$$

$$A_L\exp(I_{\ln(C)}(ln(dP_r))) = 0.0126exp(0.006020) = 0.0127m^2 \quad (X3.44)$$

$$A_L\exp(I_{\ln(C)}(\ln(dP_r))) = 0.01226\exp(0.05965) = 0.012334 \quad (X3.45)$$

Therefore the 95 % confidence limits for A_L (0.0126 m^2 or 126 cm^2) are (0.0125, 0.0127) m^2 or (125, 127) cm^2.

X3.7.2 *Depressurization Confidence Limits*—The depressurization confidence limits are calculated the same way as for pressurization, with the following results:

X3.7.2.1 The 95 % confidence interval for n is (0.619, 0.638).

X3.7.2.2 The 95 % confidence interval for C is (0.0119, 0.0127 m^3/sPa^n).

X3.7.2.3 The 95 % confidence interval for A_L is (0.0109, 0.0113) m^2 or (109, 113) cm^2.

X3.7.3 *Combined Pressurization and Depressurization Confidence Limits*—The combined pressurization and depressurization confidence limits are calculated the same way as for the individual tests, with the following results:

X3.7.3.1 The 95 % confidence interval for n is (0.580, 0.662).

X3.7.3.2 The 95 % confidence interval for C is (0.0119, 0.0146 m^3/sPa^n).

X3.7.3.3 The 95 % confidence interval for A_L is (0.0121, 0.0144) m^2 or (121, 144) cm^2.