Government of Canada
Gouvernement du Canada

Canadian General Standards Board
Office des normes générales du Canada

CAN/CGSB-149.10-2024

Supersedes CAN/CGSB-149.10-2019

NATIONAL STANDARD OF CANADA
STANDARDS COUNCIL OF CANADA
CONSEIL CANADIEN DES NORMES
NORME NATIONALE DU CANADA

Determination of the airtightness of building envelopes by the fan depressurization method

Canadian General Standards Board CGSB

SCC CCN

Canada

Experience and excellence
Expérience et excellence
CGSB ONGC

Canadian General Standards Board statement

The CANADIAN GENERAL STANDARDS BOARD (CGSB), under whose auspices this standard has been developed, is a government directorate within Public Services and Procurement Canada. CGSB is engaged in the production of voluntary standards in a wide range of subject areas through the media of standards committees and the consensus process. The standards committees are composed of representatives of relevant interests including producers, consumers and other users, retailers, governments, educational institutions, technical, professional and trade societies, and research and testing organizations. Any given standard is developed on the consensus of views expressed by such representatives.

CGSB has been accredited by the Standards Council of Canada as a national Standards Development Organization. The standards that CGSB develops and offers as National Standards of Canada conform to the requirements and guidance established for this purpose by the Standards Council of Canada. In addition to standards it publishes as National Standards of Canada, CGSB may produce other deliverables that meet particular needs, in response to requests from a variety of sources in both the public and private sectors. CGSB standards and CGSB's National Standards are developed in conformance with the policies described in the CGSB Policy and Procedures Manual for the Development and Maintenance of Standards.

CGSB's standards are subject to review and revision to ensure that they keep abreast of technological progress. CGSB will review and publish this standard on a schedule not to exceed five years from the date of publication. Suggestions for their improvement, which are always welcome, should be brought to the notice of the standards committees concerned. Changes to standards may be issued as amendments or as new editions of standards.

An up-to-date listing of CGSB's standards, including details on latest issues and amendments, is found in the CGSB Catalogue at the following Web site, http://www.tpsgc-pwgsc.gc.ca/ongc-cgsb/index-eng.html, along with more information about CGSB products and services.

Although the intended primary application of this standard is stated in its scope, it is important to note that it remains the responsibility of the users of the standard to judge its suitability for their particular purpose.

The testing and evaluation of a product or service against this standard may require the use of materials and/or equipment that could be hazardous. This standard does not purport to address all the safety aspects associated with its use. Anyone using this standard has the responsibility to consult the appropriate authorities and to establish appropriate health and safety practices in conjunction with any applicable regulatory requirements prior to its use. CGSB neither assumes nor accepts any responsibility for any injury or damage that may occur during or as the result of tests, wherever performed.

Attention is drawn to the possibility that some of the elements of this standard may be the subject of patent rights. CGSB shall not be held responsible for identifying any or all such patent rights. Users of this standard are expressly advised that determination of the validity of any such patent rights is entirely their own responsibility.

For enforcement purposes, standards shall be considered published the final day of the month of their publication date.

Contact the Canadian General Standards Board

To obtain information on CGSB, its services and standards or to obtain CGSB publications, please contact us:

web — http://www.tpsgc-pwgsc.gc.ca/ongc-cgsb/index-eng.html

e-mail — ncr.cgsb-ongc@tpsgc-pwgsc.gc.ca

telephone — 1-800-665-2472

mail — Canadian General Standards Board
140 O'Connor Street, Tower East
Ottawa, Ontario Canada K1A 0S5

Standards Council of Canada statement

A National Standard of Canada is a standard developed by a Standards Council of Canada (SCC) accredited Standards Development Organization, in compliance with requirements and guidance set out by SCC. More information on National Standards of Canada can be found at www.scc.ca.

SCC is a Crown corporation within the portfolio of Innovation, Science and Economic Development (ISED) Canada. With the goal of enhancing Canada's economic competitiveness and social well-being, SCC leads and facilitates the development and use of national and international standards. SCC also coordinates Canadian participation in standards development, and identifies strategies to advance Canadian standardization efforts.

Accreditation services are provided by SCC to various customers, including product certifiers, testing laboratories, and standards development organizations. A list of SCC programs and accredited bodies is publicly available at www.scc.ca.

NATIONAL STANDARD OF CANADA

CAN/CGSB-149.10-2024

Supersedes CAN/CGSB-149.10-2019

Determination of the airtightness of building envelopes by the fan depressurization method

CETTE NORME NATIONALE DU CANADA EST DISPONIBLE EN VERSIONS FRANÇAISE ET ANGLAISE.

ICS 91.120.10

Published June 2024 by the
Canadian General Standards Board
Ottawa, Ontario K1A 0S5

Canadian General Standards Board

Committee on airtightness and air leakage testing of buildings

(Voting membership at date of ballot)

Chair	
John Harris	DSG Building Diagnostics (General interest)
General interest category	
Laverne Dalgleish	Building Professional Quality Institute
Salvatore Ciarlo	Owens Corning Canada
Producer category	
Janette Hooper	Retrotec
Regulator category	
Adam Willis	National Research Council - Construction Research Centre
Ekaterina Bellehumeur	Natural Resources Canada - Office of Energy Efficiency
User category	
John Godden	Canadian Residential Energy Services Network
Mark Rosen	Building Knowledge Canada Inc.
Niels Anthonsen	Enerlytics Building Performance Ltd.
Committee Manager (non-voting)	
Mark Schuessler	Canadian General Standards Board

Translation of this National Standard of Canada was conducted by the Government of Canada.

Preface

This National Standard of Canada CAN/CGSB-149.10-2024 supersedes the 2019 edition. It was originally announced as a reaffirmation, however minor technical and editorial changes were done as a new edition. The Scope and content have not changed. This standard is used in a conformity assessment program.

Changes since the previous edition

- Some uses of the term pressure were clarified to pressure difference.
- Standardizing the format use of the $ACH50$, $NLR50$, $ELA10$, $NLA10$ and $Q50$ to not use subscripts.
- Correcting typo in B.1.3.

The following definitions apply in understanding how to implement this National Standard of Canada:

- "shall" indicates a **requirement**;
- "should" indicates a **recommendation**;
- "may" is used to indicate that something is **permitted**;
- "can" is used to indicate that something is **possible**, for example, that an organization is able to do something.

Notes accompanying clauses do not include requirements or alternative requirements. The purpose of a note accompanying a clause is to separate explanatory or informative material from the text. Annexes are designated normative (mandatory) or informative (non-mandatory) to define their application.

Table of contents

Page

<u>Figures</u>

<u>Tables</u>

Determination of the airtightness of building envelopes by the fan depressurization method

1 Scope and field of application

1.1 Scope

This is a standard method of tests (SMOTs) for the determination of the airtightness of building envelopes. This standard contains three test options, two types of assessments and, for attached zones, two pressure boundary set-ups. The test options are the multi-point test, the two-point test and the single-point test. The types of assessments are as-operated and closed-up. The pressure boundary set-ups are guarded and unguarded.

Each test can be used to determine the airtightness characteristics including combined area of leaks in the building envelope. It is the responsibility of the user, specifically the referencing code, standard or program, to specify what test and results are required.

These tests are not intended for determining the actual air leakage that occurs through a building envelope under the natural influences of wind and buoyancy pressures, or as a result of pressures produced by the operation of mechanical systems.

Units of measure – Quantities and dimensions in this standard are given in SI units.

1.2 Applicability

These test methods are applicable to buildings or portions of buildings that are suitable for testing as a single zone (e.g. detached houses, townhouses, apartments with self-contained heating and ventilation systems, and commercial buildings) and are generally limited to three storeys above grade.

1.3 Choice of standard method of test

The choice of one test option over another is based on the consideration of the following factors: time commitment and, therefore, cost for the user in the field, repeatability, accuracy and the measurement of airtightness descriptors that are required versus the pressure differential(s) at which the test is performed.

Uncertainty analysis is only available with the multi-point test option, and the ability to extrapolate the results to different pressures is not available with the single-point test option without using an assumed n value.

The choice of assessment type is based on ease of testing, safety, and what elements of the building envelope are to be assessed.

The pressure boundary set-up is chosen based on ease of testing and availability of multiple test fan systems, access to adjacent zones and whether leakage through the common surfaces of adjacent zones is of importance.

Any code, standard or program that references CAN/CGSB-149.10 should be assumed to be referring to a depressurization test using the multi-point test option, the as-operated assessment type and an unguarded pressure boundary set-up unless it specifies otherwise.

The possible choices are summarized in Table 1 below:

Table 1 – Setup Options

Type of assessment	Pressure boundary set-ups	Test options
As-operated	Unguarded	• Multi-point • Two-point • Single-point
	Guarded	• Multi-point • Two-point • Single-point
Closed-up	Unguarded	• Multi-point • Two-point • Single-point
	Guarded	• Multi-point • Two-point • Single-point

It is further assumed that building measurements are taken from the inside surfaces and that the reference pressure for the results is 50 Pa for flow and 10 Pa for leakage area unless otherwise specified by the referencing code, standard or program.

1.4 Combustion spillage

This standard does not predict the risk of combustion spillage. Users are advised to refer to standards written specifically for that purpose.

1.5 Wind condition uncertainty

This standard is applicable to small indoor-outdoor temperature differentials and low wind conditions. The uncertainty of the test results increases with increasing wind speeds and temperature differentials. Annex F contains recommendations to mitigate wind effects.

1.6 Uncertainty

The testing and evaluation of a product against this standard may require the use of materials and equipment that could be hazardous. This standard does not purport to address all the safety aspects associated with its use. Anyone using this standard has the responsibility to consult the appropriate authorities and to establish appropriate health and safety practices in conjunction with any applicable regulatory requirements prior to its use.

2 Principle

2.1 Test fan use

A fan (or a combination of fans) is used to exhaust air from (or supply air to) the building at rates required to maintain specified pressure differences across the building envelope. The intention is to subject the complete building envelope to a simultaneous and similarly directed air pressure. The flows are corrected to the reference temperature and pressure. The relationship between flow and pressure difference is used to calculate the equivalent leakage area of the building envelope.

2.2 Test direction

The test can be done as either a depressurization test or a pressurization test, which can provide some insight into the behaviour of components such as dampers and weatherstripping that behave differently when subjected to positive or negative pressures. The referencing code, standard or program may specify depressurization, pressurization or both. This standard is written on the assumption of a depressurization test.

3 Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this National Standard of Canada. The referenced documents may be obtained from the sources noted below.

Note: The contact information provided below was valid at the date of publication of this standard.

A reference to a regulation is always to the latest issue.

An undated reference is to the latest edition or revision of the reference or document in question, unless otherwise specified by the authority applying this standard. A dated reference is to the specified revision or edition of the reference or document in question.

3.1 ASTM International

ASTM E1258-88 (2018) — *Standard Test Method for Airflow Calibration of Fan Pressurization Devices*

3.1.1 Contact information

The above may be obtained from ASTM International. Telephone: 1-877-909-2786. Web site: https://www.astm.org/. They can also be obtained from Standards Store by Accuris. Telephone: 1-800-447-2273. Web site: https://global.ihs.com/.

4 Terminology and symbols

4.1 Terminology

For the purposes of this standard, the following terms and definitions apply.

air changes per hour at 50 Pa ($ACH50$)
ratio of the airflow per hour at a pressure difference of 50 Pa to the enclosed volume of the building.

airtightness
degree to which openings in the building envelope, intentional or unintentional, have been avoided.

building envelope
portion of the conditioned structure that separates conditioned from unconditioned space (air, soil or water).

building volume (V)
volume of the building that is subject to a pressure difference for the purpose of the test, enclosing the conditioned space and measured to the interior surfaces or exterior as specified by the referencing code, standard or program. It is enclosed by the total building envelope area and includes the volume of interior partitions and space between floors.

equivalent leakage area ($ELA10$)
area of a sharp-edged orifice that has the same airflow rate as the combined leaks in the tested building when both are subjected to a pressure difference of 10 Pa[1]. It is assumed to be roughly equivalent to the sum of all the openings in the building envelope.

exposed building envelope area (A_e)
exposed surface area of the building envelope that separates conditioned space from unconditioned space, measured on the interior or exterior as specified by the referencing code, standard or program.

guarded test
test that is performed with the attached zones being simultaneously pressurized/depressurized. This ensures that the common surfaces are not subject to a pressure difference. Hence the test will be assessing only exterior to interior leakage of the exposed building envelope.

normalized leakage area ($NLA10$)
ratio of the equivalent leakage area to the area of the building envelope.

normalized leakage rate ($NLR50$)
ratio of the airflow at 50 Pa to the area of the building envelope.

reference pressure
pressure at which the results are reported.

total building envelope area (A_t)
exposed building envelope area in addition to the common surface area subject to a pressure difference for the purpose of the test, such as party walls between attached units, measured on the interior or exterior as specified by the referencing code, standard or program.

unguarded test
test that is performed where the attached zones are not pressurized/depressurized and are at ambient pressure. In this case the common surfaces are subjected to the pressure difference. Hence the test will include leakage from the interior of the attached zones to the interior of the tested zone, as well as from the exterior to the interior of the tested zone.

zone
part or all of the conditioned space in a building that is sufficiently open to the location where testing equipment is to be installed to provide enough airflow such that the entire zone is at the same pressure.[2]

---

[1] Equivalent leakage area is similar to the effective leakage area. The effective leakage area is defined as the area of a nozzle-shaped hole (similar to the inlet of a blower door fan) that has the same airflow rate as the combined leaks in the tested building when both are subjected to a pressure difference of 4 Pa. It is the typical measure of leakage in US standards.

[2] It is generally accepted that a variation of not more than 5 Pa throughout the tested zone when the test equipment is set to 50 Pa is acceptable. Typically, openings the size of an attic hatch or larger that connect spaces within a zone will permit enough airflow to achieve this requirement, provided most of the zone volume is on the fan side of the opening.

4.2 Symbols

Although the definition of each quantity symbol is usually included in the paragraph in which it appears, Table 2 provides a list of quantity definitions for those quantity symbols which are included in the body of the Standard.

Table 2 – Symbols

Quantity symbol	Quantity definition	SI Unit	Unit symbol
A_e	Area of the exposed building envelope	square meters	m^2
A_t	Total area of the building envelope	square meters	m^2
ACH	Air changes per hour	1/hour	1/h
$ACH50$	Air changes per hour at 50 Pa	1/hour	1/h
C_r	Flow coefficient for the power law equation $Q = C_r \Delta P^n$	litres/(second·pascal^n)	L/(s·Pa^n)
ELA	Equivalent leakage area	square centimetre	cm^2
NLA	Normalized leakage area	square centimetre/ square metre	cm^2/m^2
NLR	Normalized leakage rate	litre/ (second·square metre)	L/(s·m^2)
n	Pressure exponent for the power law equation $Q = C_r \Delta P^n$	—	—
P_o	Ambient atmospheric pressure outside the building	kilopascals	kPa
$\Delta P_{m,s}$	Starting pressure difference across the building envelope with the test fan(s) not operating and sealed	pascals	Pa
$\Delta P_{m,f}$	Final pressure difference across the building envelope with the test fan(s) not operating and sealed	pascals	Pa
ΔP_m	Measured pressure difference across the building envelope	pascals	Pa
ΔP	Corrected pressure difference across the building envelope	pascals	Pa
$Q50$	The estimated flow calculated at 50 Pa	litres/second	L/s

Quantity symbol	Quantity definition	SI Unit	Unit symbol
Q_m	The indicated flow through the flow measuring device. For currently available commercial test fans, it is not the actual volumetric flow.	litres/second	L/s
Q_i	Actual volumetric flow of air going through the test fan. For currently available test fans, it is found by adjusting Q_m for the actual air density of the air going through the test fan.	litres/second	L/s
Q_r	Airflow rate through the building envelope corrected to standard conditions.	litres/second	L/s
$\hat{Q}_i$	The flow calculated from the fitted power law at a pressure P_i. This is calculated at each of the corrected building pressures and compared to the corrected flows (Q_r).	litres/second	L/s
r	Correlation coefficient of the fitted data (as specified in Annex B)	—	—
R	Gas constant for air [0.287055 kJ/(kg·K)]	kilojoules/kilogram Kelvin	kJ/(kg·K)
T_i	Intake air temperature at the test fan	degrees Celsius	ºC
T_o	Outdoor air temperature	degrees Celsius	ºC
T_r	Reference temperature of outside ambient air (20 ºC)	degrees Celsius	ºC
V	Volume of the building envelope	cubic meters	m^3
ρ_r	Density of air at reference conditions (1.204 kg/m^3)	kilograms/cubic metre	kg/m^3
ε_p	Relative standard error of $\hat{Q}$ at pressure	—	—
ε_{Qi}	Relative standard error of the estimated flow at each measured ΔP	—	—

5 Test fan system

The blower door system includes: the test fan(s), pressure and temperature measuring devices, sealing devices, and ancillary equipment such as tubing.

5.1 Test fan

The test fan shall have the following characteristics.

5.1.1 Airflow capacity

The test fan shall have a total airflow capacity capable of producing the pressure differences required for the type of test to be performed and the building being assessed.[3]

5.1.2 Control system

The test fan shall have a variable flow rate control system.

5.1.3 Calibration

The test fan shall be calibrated in airflow units. See 5.5.

5.1.4 Airflow measurement accuracy

The accuracy of airflow measurement shall be ±5% of the measured flow rate over the entire range.

5.2 Pressure measuring device

The pressure-measuring device shall be capable of measuring pressure differences across the building envelope over the range required by the test performed, typically 0 to 60 Pa. The pressure-measuring device shall be accurate to within ±1 Pa or 1% of reading, whichever is greater, and shall only be operated within its calibration range.

The pressure averaging and dampening devices and techniques described in Annex F can be used to mitigate wind and temperature induced fluctuations and offsets.

5.3 Thermometer

This device shall be used to measure temperature in degrees Celsius, and shall have an accuracy of ±1 ºC.

5.4 Sealing devices

This equipment, such as an adjustable door frame and covering, shall be used to seal the test fan into a window or a door opening.

5.5 Calibration of equipment

5.5.1 Original calibration

The pressure measuring device shall be calibrated originally by the manufacturer. The test fan shall be calibrated or characterized originally by the manufacturer. The calibration shall be verified according to the manufacturer's instructions when any major component is replaced or damaged/repaired.

5.5.2 Test fan system calibration

Where required by section 5.5.1, the test fan shall be recalibrated in accordance with the manufacturer's instructions or in accordance with ASTM E1258-88. The fan shall be maintained to manufacturer's instructions.

5.5.3 Gauge calibration

The pressure-measuring device shall be accompanied at all times by a sticker or report showing the serial number, date of last calibration, and any corrections required to the readings. The frequency of calibration shall be in accordance with the manufacturer's recommendations.

---

[3] Sufficient capacity will depend on the leakage area, which tends to vary greatly from one building to another based on size and leakiness. A new detached house in colder climates typically requires 200 L/s. Older detached houses may require ten times this amount. Most available door fans have capacity exceeding 2500 L/s.

5.5.4 System calibration check

To identify the magnitude of system error or the need for system calibration, the entire system may be tested periodically in accordance with Annex G.

6 Testing

6.1 Set-up procedures

The objectives specified by the referencing code, standard or program shall assist in the selection of the test option, type of assessment and pressure boundary set-up.

For example, when the purpose of the airtightness test is to show an increase in the airtightness of a building envelope as a result of sealing unintentional openings, perform the test as described both before and after the sealing work using the identical test option, type of assessment and pressure boundary set-up.

6.1.1 Outdoor temperature

The outdoor air temperature shall be measured and recorded either at the start of the test or be an average of measurements during testing. Alternatively, data from a local meteorological station located within 20 km of the tested building can be used if the difference in altitude between them is not more than 500 m.

6.1.2 Included rooms

In the test shall be included all rooms which are heated to more than 10 ºC, except rooms that are equipped with separate ventilation and are expected to be always closed off from the zone that will be tested (e.g. a mechanical room with a separate make up air system would not be included).

6.1.3 Combustion appliances and other HVAC equipment

All vented combustion appliances, exhaust fans, vented dryers and air conditioners shall be switched off, as detailed in Table 3. Pilot lights on combustion appliances may be left on[4].

6.1.4 Assessment type

The building shall be prepared for the closed-up or as-operated assessment type as detailed in Table 3.

6.1.4.1 Closed-up

This condition tests the airtightness of only the unintentional building envelope openings. Intentional openings such as flues and ventilation openings are sealed and are therefore excluded from the test.

6.1.4.2 As-operated

This condition provides an indication of the airtightness of the intentional and unintentional openings in the building envelope under normal occupancy conditions.

6.1.5 Fireplaces and chimneys

Fireplaces that lack doors shall have ashes covered or removed. Check chimneys and furnace flues for excessive soot and do not perform the test if soot is likely to enter the building.

[4] When performing an unguarded test on one zone in a multi-zone building, care must be taken to ensure safe operation of atmospheric appliances in adjacent zones. Either turn them off or open a window or door in the adjacent zones to minimize the potential of backdrafting.

6.1.6 Elevation

The elevation of the building above sea level shall be recorded of the building to the nearest 100 m if required for the airflow corrections in Annex A.

6.1.7 Install test fan system

6.1.7.1 Read, understand, and follow the equipment manufacturer's manual.

6.1.7.2 For a depressurization test, position the test fan such that air will be exhausted from the building. For a pressurization test, position the test fan such that air will be supplied into the building.

6.1.7.3 To eliminate the possibility of disturbance of the flow entering the test fan ensure that no obstructions are placed within the width of the door and closer than three-quarters of one fan diameter in front of the test fan as shown in Figure 1. The body of the person conducting the test shall also be considered a potential obstruction, and shall remain outside of the clearance zone during the test. Figure 2 shows the general arrangement of the blower door system during the test.

6.1.7.4 Attach the tubing from the exterior to the pressure-measuring device. Attach tubing from the test fan to the pressure-measuring device.

6.1.7.5 Protect the interior and exterior pressure taps from the influence of the test fan by locating the ends of tubes away from all turbulence. Avoid placing them in the sun. See Annex F for more details on tube placement.

6.1.7.6 Seal the opening of the test fan.

6.1.7.7 After setting up the test fan system, verify the installation:

a) Visually inspect for various physical defects.

b) Visually inspect for proper installation in accordance with manufacturer's specifications.

c) Visually inspect the sealing device to ensure that it is tightly fitted into the door or window opening.

d) Ensure that pressure tubing is not pinched or obstructed.

6.1.8 Pressure boundary set-up

Record whether the test is guarded or unguarded.

If a guarded test is performed, set up a test fan system in each zone adjacent to the tested zone. Use the test fan systems to ensure the pressure difference between the adjacent zones and the tested zone is as close to zero as possible, within 3 Pa. Setting up the adjacent zones using Table 3 will help to ensure that the required pressures can be reached.

If an unguarded test is performed the adjacent zones shall be open to outside such that their pressure is the same as outside.

6.2 Test procedure

These procedures shall be performed with an automated system or conducted manually. Data collected by an automated system is acceptable. Manually collected data should be recorded in a format that meets the requirements of section 8.

These procedures are written on the assumption that the entire total building envelope area and the building volume is one continuous zone with nothing separating the test fan from any portion of the building volume. However, some apartment buildings may have exterior access to the units rather than from a common corridor. If the objective of the test is to assess the total building envelope area, rather than just the tested unit (see 6.1.8 for the description of a guarded versus unguarded test) then a multi-zone test as described in Annex C shall be used. The test procedures described below still apply but the set up and calculations differ.

6.2.1 Time averaging

All pressure readings, including the initial and final offset pressure, shall be taken with a minimum of 10 second time averaging. If acceptable results cannot be achieved as indicated by any of the verification data in 7.5.2 or by fluctuating pressure differences, extend the time averaging and consider the wind mitigation strategies in Annex F.

6.2.2 Flow measurements

Flow readings shall be determined using the test fan pressure reading converted to flow using the test fan manufacturer's formulas and coefficients, or can be taken directly from the pressure measuring device where it has the formulas and coefficients integrated.

6.2.2.1 If the required pressure difference cannot be achieved with a single test fan, the test may be done with multiple test fans. In this case, before completing the calculations described in section 7, the building pressure readings are to be averaged and the test fan flows are to be summed.

6.2.3 Starting offset pressure and temperature

6.2.3.1 Record the starting offset pressure difference across the building envelope, $\Delta P_{m,s}$, and the intake air temperature at the test fan, T_i. Target pressure differences specified in 6.2.4, 6.2.5, and 6.2.6 should all be adjusted for the initial offset pressure (for example if the initial offset pressure is –1 Pa and the target pressure is –50 Pa, the first measurement should be taken at –51 Pa).

6.2.3.2 Remove all seals on the test fan and adjust it to achieve the maximum desired pressure. Recheck the sealing device for tightness and stability at this time. Adjust the test fan to achieve the minimum desired test pressure. Ensure that the flow reading at the minimum and maximum pressure is within the acceptable range for the test fan.

6.2.4 Procedure for multi-point test

6.2.4.1 Adjust the airflow to produce a pressure difference of between 50 Pa to 60 Pa across the building envelope.

6.2.4.2 Measure and record the airflow rate, $Q_{m,1}$, and the pressure difference, $\Delta P_{m,1}$. It should be noted that Q_m is the indicated flow, but for most measuring devices, this is not the true volumetric flow Q_i (see Annex A). Where software or a digital manometer does the adjustments the adjusted air flow Q_i may be recorded instead of Q_m.

6.2.4.3 Repeat 6.2.4.2 taking a minimum of 5 additional readings. The lowest pressure difference shall not be greater than 20 Pa, nor shall it be less than 10 Pa. The highest pressure difference shall not be greater than 60 Pa, nor shall it be less than 45 Pa. The spacing between two readings shall not exceed 10 Pa.

6.2.4.4 Repeat the test if the conditions in 7.5.2 are not met.

6.2.5 Procedure for two-point test[5]

6.2.5.1 Adjust the airflow to produce a pressure difference of 50 ± 3 Pa across the building envelope. Measure and record the airflow rate, $Q_{m,1}$, and the pressure difference, $\Delta P_{m,1}$.

6.2.5.2 Adjust the airflow to produce a pressure difference of 20 ± 3 Pa across the building envelope. Measure and record the airflow rate, $Q_{m,2}$, and the pressure difference, $\Delta P_{m,2}$.

6.2.6 Procedure for single-point test[5]

6.2.6.1 Adjust the airflow to produce a pressure difference of 50 ± 3 Pa across the building envelope. Measure and record the airflow rate, Q_m, and the pressure difference, ΔP_m.

6.2.7 Final offset pressure difference

Turn the test fan off. Seal the opening of the test fan, and measure the final offset pressure difference, $\Delta P_{m,f}$.

If the difference between the initial (see 6.2.3.1) and final offset pressure differences is greater than 3 Pa then the test shall be redone after addressing the issues.

6.3 Completion of the test

6.3.1 Return building to pre-test conditions

Dismantle and pack up the airtightness testing system:

a) Remove all seals applied in accordance with Table 3.

b) Reopen dampers as necessary.

c) Readjust thermostats on furnaces, boilers, stoves and water heaters.

d) Return the building to its normal operating condition, including a check to ensure that pilot lights of atmospherically vented appliances are still lit.

[5] While these procedures require 10 second time averaging in general, the two-point test has been shown to have comparable accuracy to the multi-point test when done with longer time averaging (~ 20 s). Similarly a single-point test may require longer time averaging to meet the intent of the test (~ 30 s). The user or the referencing code, standard or program should consider requiring longer time averaging depending on the intended use of the test results.

Table 3 – Building Envelope Preparation

Building Component	Building Envelope Assessment Type		Set Up	Return
	Closed-up	As-operated		
Flue connected to furnace, water heater, boiler[a]	Seal	No preparation	☐	☐
Flue connected to stove or fireplace: • With damper • Without damper	 Close or seal Seal	 Close No preparation	 ☐ ☐	 ☐ ☐
Combustion air intake damper on fireplace or woodstove	Close	Close	☐	☐
Make-up air intake for furnace: • With damper • Without damper	 Seal Seal	 Close No preparation	 ☐ ☐	 ☐ ☐
Ventilation air intake: • With damper • Without damper	 Seal Seal	 Close No preparation	 ☐ ☐	 ☐ ☐
Combined supply and exhaust ventilators: • Designed for continuous operation • Designed for intermittent operation	 Seal Seal	 Switch off Switch off	 ☐ ☐	 ☐ ☐
Window air conditioners	Seal	Switch off, no preparation	☐	☐
Vented, fuel-fired appliance	Switch off or turn down thermostat		☐	☐
Pilot lights on gas-fired appliances	Leave as is, check after test		☐	☐
Fireplace: • With firebox doors • Without firebox doors	Not in use Close No preparation		☐ ☐ ☐	☐ ☐ ☐
Woodstove Doors and inlet dampers	Not in use Close		☐ ☐	☐ ☐
Enclosed mechanical room[b] door	Close		☐	☐
Exhaust and supply fans	Switch off		☐	☐
Radon mitigation fans	Shut off		☐	☐
Exhaust fan and supply fan/duct inlet grilles: • With motorized damper • Without motorized damper	 Seal Seal	 Close No preparation	 ☐ ☐	 ☐ ☐

Building Component	Building Envelope Assessment Type		Set Up	Return
	Closed-up	As-operated		
Clothes dryer	Switch off and close door		☐	☐
Clothes dryer vent	No preparation (seal the vent if a dryer is not installed)		☐	☐
Central vacuum system if vented to the exterior	Turn off		☐	☐
Ventilation systems connected to other zones	Seal		☐	☐
Windows	Latch		☐	☐
Exterior doors	Close		☐	☐
Interior doors:	Open		☐	☐
Crawl space vents to outdoors: • With functional dampers • Without functional dampers	 Close No preparation		 ☐ ☐	 ☐ ☐
Attic hatch	Close		☐	☐
Crawl space hatch	Close		☐	☐
Floor drains	Fill		☐	☐
Plumbing traps	Fill		☐	☐
Water heater	Turn off		☐	☐
Broken window	Seal		☐	☐

[a] Provincially regulated authorities do not permit sealing of flues connected to gas-fired furnaces, boilers and water heaters unless carried out by the homeowner or by a certified gas fitter.

[b] An enclosed mechanical room is a room expressly built to contain a combustion appliance such as a furnace or boiler, with a combustion air intake to the outside of the building, and is designed to prevent airflow to and from the remainder of the building.

Figure 1 – Clearances for test fan system

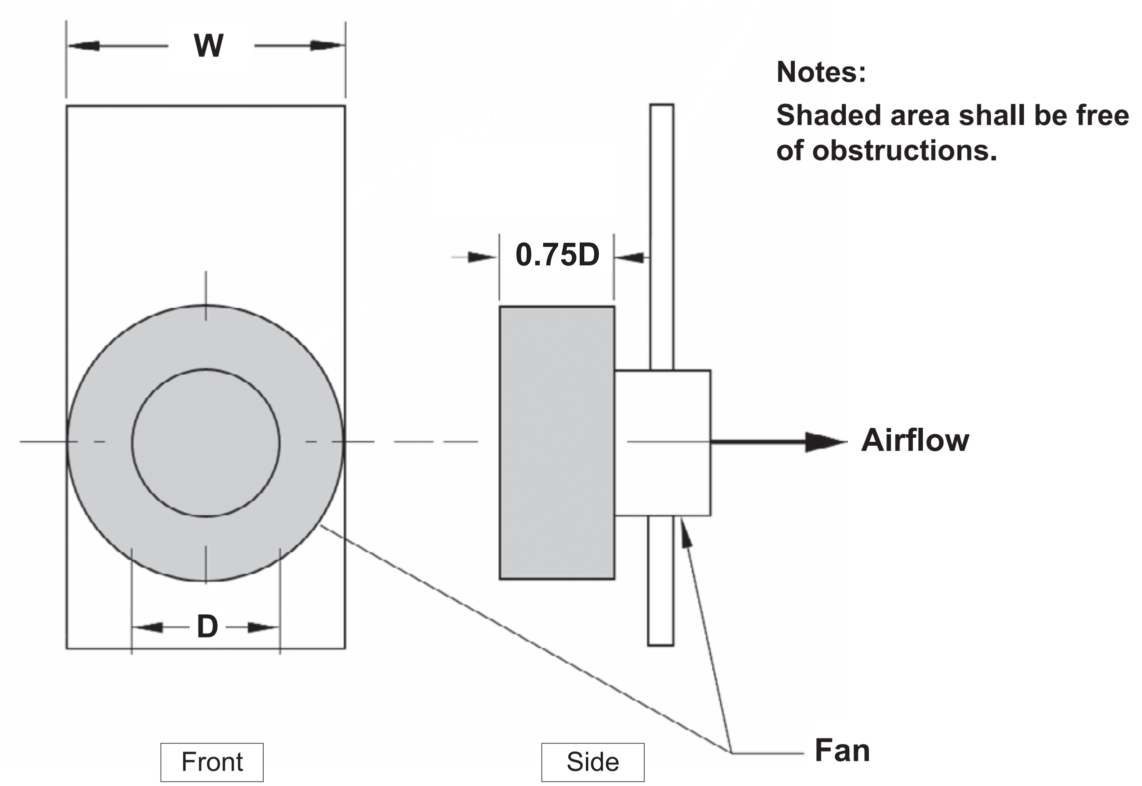
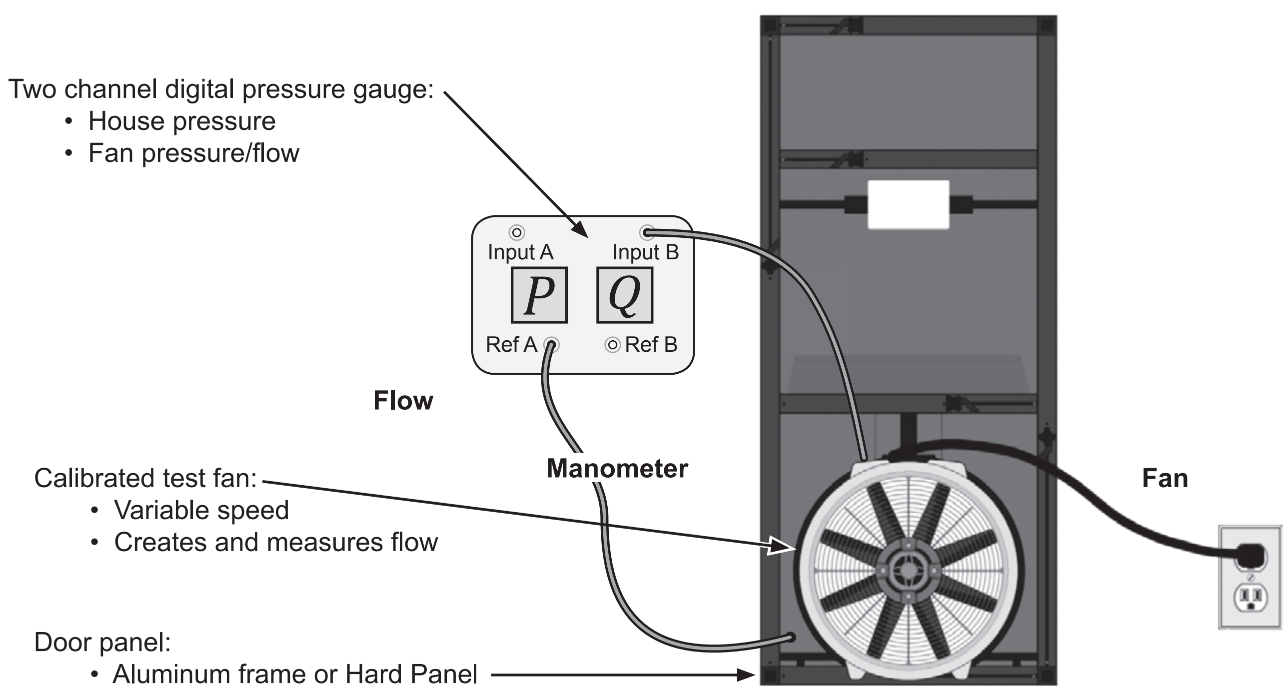


Figure 2 – General arrangement of the test fan system



7 Calculations

7.1 Determination of the area of the building envelope

7.1.1 Building envelope area

Measure the building envelope area if test results are to include the normalized leakage area (NLA) or normalized leakage rate (NLR).

7.1.2 Interior dimensions

Use the appropriate dimensions (interior or exterior as specified by the referencing code, standard or program) when determining the area of the building envelope. Accuracy of the linear measurements shall be ±0.05 m.[6]

7.1.3 Included areas

The building envelope area includes the exposed building envelope area for guarded tests, and the total building envelope area for unguarded tests.

The area of the building envelope shall be the total area of all portions of the envelope, including areas above and below grade. Portions of the building envelope include ceilings, floors, walls, windows, and doors.

For example a guarded test shall include:

a) Ceilings (flat or sloping) below unheated attics and roofs;

b) Floors over the ground (e.g. slabs on grade and basement floors);

c) Floors above the unheated portion of basements, cellars, crawl spaces, cold storage rooms and garages;

d) Floors exposed to the ambient environment such as floors above carports, bay windows, or overhangs; and

e) Exterior above-grade and below-grade walls and walls adjacent to unheated portions of basements, cellars, crawl spaces, cold storage rooms, unheated porches, garages and stairwells to basement entrances.

An unguarded test shall also include the above and below grade areas of common surfaces between adjacent zones, such as party walls and common ceilings and floors.

7.2 Determination of the interior volume enclosed by the building envelope

7.2.1 Volume

Some referencing codes, standards or programs may require an air leakage metric that is rationalized by volume such as air change per hour. If volume is calculated, include the total volume of all rooms and spaces enclosed by the building envelope specified in 7.1.3, including the volume of interior partitions and space between floors.

---

[6] Calculating building envelope areas has been shown to be a major source of error in airtightness test results. It is recommended to list every building envelope component prior to measuring and calculating the areas, to avoid errors or omission.

7.3 Correction of pressure difference readings

7.3.1 Corrected pressure difference

Correct each pressure difference reading $\Delta P_{m,i}$ using the following equation:

Equation 1

$$\Delta P_i = \Delta P_{m,i} - \frac{\Delta P_{m,s} + \Delta P_{m,f}}{2}$$

7.4 Correction of airflow readings

7.4.1 Airflow correction

Correct each airflow reading for differences in the indoor, outdoor, calibration and standard reference air temperatures and pressures in accordance with Annex A to obtain Q_r. The final correction shown in Annex A for reference conditions requires that the n value be determined as shown in 7.5.1 before completing density corrections. Therefore final correction is to C rather than Q.

7.5 Analysis of multi-point test data

The corrected data are used to generate the coefficients for a power law equation in the form $Q{=}C\Delta P^n$ which describes the leakage characteristics of the building envelope. This is done by using linear regression in the case of a multi-point test, slope and intercept equation for the two-point test, and an assumed n value for the single-point test. The required airtightness metrics, such as the equivalent leakage area, can then be determined from the power law equation and its coefficients. Sections 7.5, 7.6, and 7.7 cover the analysis for each of the three test options.

7.5.1 Regression analysis

Apply the procedure described in Annex B[7] to the corrected data, ΔP_i and $Q_{r,i}$, to fit a curve of the form:

Equation 2

$$Q = C_r \Delta P^n$$

Where:

- Q_r is the corrected airflow rate in units of L/s;
- C_r is the flow coefficient in units of L/(s·Pa^n);
- ΔP is the corrected pressure difference across the building envelope in units of Pa; and
- n is the pressure exponent which is dimensionless.

7.5.2 Verification of multi-point test data

In addition to the coefficients C_r and n, use the corrected data to determine the following in accordance with Annex B.

[7] The C_r, Q_i and $\hat{Q}_i$ values determined in accordance with Annex B are those under the reference conditions of 20 ºC and 101.325 kPa.

a) The correlation coefficient, r, for the fit of the data.

b) The relative error, εQ_i between the estimated airflow, $\hat{Q}_i$ and the corrected airflow, $Q_{r,i}$, at each corrected measured pressure difference, ΔP_i (optional).

c) The relative standard error of $\hat{Q}$ at $\Delta P = 10 \text{ Pa}$, which is also the relative standard error of the $ELA10$, ε_{10}.

7.5.2.1 Repeat the entire test if any of the following conditions is not met:

a) $0.50 \leq n \leq 1.00$;[8]

b) $r > 0.99$;

c) ε_{10} is less than 0.07.

Note: This standard is premised on determining the ELA at 10 Pa therefore the relative standard error is determined at 10 Pa (see Equation 47). The referencing code, standard or program should identify what reference pressure is important for their use and specify the relative standard error at that pressure as well (see Equation 46).

7.5.3 Calculation of $ELA10$

Assume that the density of air at reference conditions of 20 ºC and 101.325 kPa, ρ_r, is equal to 1.204 kg/m^3.

Calculate the equivalent leakage area using the following equation:

Equation 3

$$ELA10 = 11.57\sqrt{\rho_r} \cdot C_r \cdot 10^{n-0.5}$$

Where:

- $ELA10$ is in units of cm^2;
- ρ_r is the air density at reference conditions in units of kg/m^3;
- C_r is the flow coefficient in units of L/(s·Pa^n); and
- n is the pressure exponent as per 7.5.1.

7.6 Analysis of two-point test data

7.6.1 Pressure exponent

Determine the pressure exponent using the following equation:

[8] Practically speaking the range of n is much tighter, typically between 0.62 and 0.72. Variability due to wind can occasionally result in a value as low as 0.48. Values above 0.85 are uncommon. The referencing code, standard or program may choose to adopt different values based on experience.

Equation 4

$$n = \frac{ln\left(Q_{r,1}/Q_{r,2}\right)}{ln(\Delta P_1/\Delta P_2)}$$

Where:

- $Q_{r,1}$ is the corrected flow rate in units L/s at ΔP_1;
- ΔP_1 is the corrected test pressure difference of 50 ± 3 Pa;
- $Q_{r,2}$ is the corrected flow rate in units L/s at ΔP_2; and
- ΔP_2 is the corrected test pressure difference of 20 ± 3 Pa.

7.6.2 Flow coefficient

Determine the flow coefficient, C_r, using the following equation:

Equation 5

$$C_r = \frac{Q_{r,1}}{\Delta P_1^n}$$

Where:

- $Q_{r,1}$ is the corrected flow rate in L/s at ΔP_1;
- ΔP_1 is the corrected test pressure difference of 50 ± 3 Pa; and
- n is the pressure exponent which is dimensionless.

7.6.3 Equivalent leakage area

Calculate the $ELA10$ using Equation 3.

7.7 Analysis of single-point test method

7.7.1 Pressure exponent

An assumed n value of 0.68 is used for the single point test[9].

7.7.2 Flow coefficient

Calculate the flow coefficient using Equation 5 with the assumed n value of 0.68.

7.7.3 Equivalent leakage area

Calculate the equivalent leakage area using the assumed n value of 0.68 and Equation 6.

---

[9] This section uses an assumed n value of 0.68 based on the default value in the HOT2000 energy simulation software. It was originally determined by assessing the first 300 R-2000 houses, and since validated by assessing 43,000 new houses built between 2010 and 2018. In the United States a value of 0.65 is commonly used.

Equation 6

$$ELA10 = 19.21 \cdot \frac{Q_{r,1}}{\Delta P_1^{\;0.68}}$$

Where:

- $ELA10$ is in units of cm²;
- $Q_{r,1}$ is the corrected flow rate in units L/s at ΔP_1; and
- ΔP_1 is the corrected test pressure difference of 50 ± 3 Pa.

7.8 Calculation of normalized values

Use normalized values, calculated according to this section, when the purpose of the test is to compare the airtightness of the building envelope of different buildings.

7.8.1 Flow at 50 Pa

For the following sections the airflow at 50 Pa, $Q50$, is calculated using the following equation:

Equation 7

$$Q50 = C_r 50^n$$

Where:

- $Q50$ is in units of L/s;
- C_r is the flow coefficient in units of L/(s·Pa^n); and
- n is the pressure exponent which is dimensionless.

7.8.2 Normalized leakage area ($NLA10$)

To calculate $NLA10$ for an unguarded test, use the following equation:

Equation 8

$$NLA10 = \frac{ELA10}{A_t}$$

Where:

- NLA is in units of cm²/m²;
- ELA is in units of cm²; and
- A_t is the total building envelope area in units of m².

For guarded tests replace A_t with A_e, the exposed building envelope area.

7.8.3 Normalized leakage rate ($NLR50$)

To calculate $NLR50$ for an unguarded test, use the following equation:

Equation 9

$$NLR50 = \frac{Q50}{A_t}$$

Where:

- $NLR50$ is in units of L/s·m^2;
- $Q50$ is in units of L/s; and
- A_t is the total building envelope area in units of m^2.

For guarded tests replace A_t with A_e, the exposed building envelope area.

7.8.4 Air changes per hour at 50 Pa ($ACH50$)

To calculate $ACH50$, use the following equation:

Equation 10

$$ACH50 = \frac{3.6 \cdot Q50}{V}$$

Where:

- $ACH50$ is in units of 1/h;
- $Q50$ is in units of L/s; and
- V is the building volume in units of m^3.

8 Test report

The test report shall include the following information:

a) The name and address of the company or individual who conducted the test;

b) The address of the building under test;

c) The date of the test and the date of the report;

d) The make and model of the equipment used;

e) The date of calibration for the pressure measuring device (optional);

f) The outdoor temperature;

g) The outdoor pressure (optional);

h) The indoor initial and final temperatures;

i) A description of the building envelope (optional);

j) The area of the building envelope when used in the calculations;

k) The building volume when used in the calculations;

l) The test option: multi-point, two-point or single-point;

m) The type of assessment: closed-up or as-operated;

n) The pressure boundary set-up: unguarded or guarded;

o) Whether or not automated testing was performed;

p) The uncorrected pressure difference and flow data;

q) The units of measurement;

r) Location where the test fan system was installed for the test;

s) Any deviation from the test cited.

The following data shall be reported as required for the purpose of the test:

t) For the multi-point test:

   1) The corrected airflow rates at each corrected pressure differential;

   2) The values for C_r and n;

   3) The correlation coefficient, r;

   4) The $ELA10, ACH50, NLA10, NLR50;$

   5) The relative standard error of the $ELA10$ (if the $ELA10$ is reported);

   6) The corrected flow at 50 Pa ($Q50$);

   7) The relative standard error of the corrected flow at 50 Pa (if $Q50$ is reported).

u) For the two-point test:

   1) The corrected airflow rates at each corrected pressure differential;

   2) The values for C_r and n;

   3) The $ELA10, ACH50, NLA10, NLR50$;

   4) The corrected flow at 50 Pa ($Q50$).

v) For the single-point test:

1) The corrected airflow rate at the corrected pressure differential;

2) The values for C_r and n (if n is not assumed to be 0.68);

3) The $ELA10$, $ACH50$, $NLA10$, $NLR50$;

4) The corrected flow at 50 Pa ($Q50$).

A sample test report can be found in Annex D.

Annex A
(normative)

Airflow corrections

A.1 General theory

In order for the results of an airtightness test to be useful, they must be brought to a standard set of reference conditions of temperature and pressure so that tests can be compared even if performed under different conditions. Specifically, the indicated airflow rates need to be corrected for the differences in air density (ρ) and viscosity (μ) between calibration conditions, the actual conditions inside and outside the house, and the reference conditions. In the case of a depressurization test:

- the indicated airflow needs to be adjusted for the difference between the inside conditions and the calibration conditions to give the actual airflow;
- the actual airflow needs to be adjusted for the difference between inside and outside conditions to give the airflow through the building envelope; and
- the envelope airflow has to be adjusted for the difference between outside conditions and reference conditions to give the reference air flow.

The following symbols will be used:

- C is a flow coefficient;
- h is the elevation in units of m;
- μ is the dynamic viscosity of air in units of kg/m·s;
- Q is the airflow in units of m^3/s;
- P is the air pressure in units of Pa;
- ρ is the air density in units of kg/m^3; and
- T is the air temperature in units of ºC.

The following subscripts will be used:

- a – is the actual air flow through the flow measuring device, adjusted for the calibration density;
- bd – stands for blower door;
- c – is for the calibration conditions;
- e – is for the building envelope;
- i – is for the inside conditions;
- m – is for measured (measured air flow, Q_m, is also called the indicated flow);
- o – is for the outside conditions;
- r – is for the standard reference conditions.

The initial equations shown below are for a depressurization test and are followed by the equation for a pressurization test denoted as [for pressurization].

In certain fluid flow measuring devices (orifice plates, nozzles, venturis, pitot tubes, etc.) and the blower doors assumed in this standard, flow, pressure difference and density are related according to:

Equation 11

$$Q \propto \sqrt{\frac{\Delta P}{\rho}}$$

Therefore, the indicated flow from the measuring device output may be estimated using the following equation:

Equation 12

$$Q_m = C_{bd} \times \sqrt{\frac{\Delta P}{\rho_c}}$$

However, the true airflow rate through the measuring device is calculated based on the actual inside air density ρ_i using the following equation[10]:

Equation 13

$$Q_a = C_{bd} \times \sqrt{\frac{\Delta P}{\rho_i}}$$ [for pressurization $Q_a = C_{bd} \times \sqrt{\frac{\Delta P}{\rho_o}}$]

By rearranging Equation 12 for C_{bd}[11] and substituting into Equation 13 the actual flow of air going through the fan can be estimated using the following equation:

Equation 14

$$Q_a = Q_m \times \sqrt{\frac{\rho_c}{\rho_i}}$$ [for pressurization $Q_a = Q_m \times \sqrt{\frac{\rho_c}{\rho_o}}$]

Furthermore, continuity of mass is shown through the following equation:

Equation 15

$$\rho_i \times Q_a = \rho_o \times Q_e$$ [for pressurization $\rho_i \times Q_e = \rho_o \times Q_a$]

Rearranging Equation 15, the envelope airflow rate can be written as:

Equation 16

$$Q_e = Q_a \times \frac{\rho_i}{\rho_o}$$ [for pressurization $Q_e = Q_a \times \frac{\rho_o}{\rho_i}$]

Substituting Equation 14 into Equation 16 gives:

[10] It is possible that some test fan manufacturers have a different approach for the indicated flow. Follow the manufacturer's instructions to determine the volumetric flow through the test fan if it differs from the formulas above.

[11] C_{bd} is actually dependent on the Reynolds number, but for the range of flows used in this test, it is assumed constant.

Equation 17

$$Q_e = Q_m \times \sqrt{\frac{\rho_c}{\rho_i}} \times \frac{\rho_i}{\rho_o} \qquad \text{[for pressurization } Q_e = Q_m \times \sqrt{\frac{\rho_c}{\rho_o}} \times \frac{\rho_o}{\rho_i}\text{]}$$

The final step is to adjust the flow for standard reference conditions. The air leakage characteristics of the building, specifically the pressure exponent n, must be determined first so the regression required in Annex B has to be done and then this correction is applied to the flow coefficient C rather than the individual flows[12]. This adjustment allows for both the difference in density between the test and reference conditions, as well as the difference in viscosity.

Equation 18

$$C_r = C_e \times \left(\frac{\rho_o}{\rho_r}\right)^{(1-n)} \left(\frac{\mu_o}{\mu_r}\right)^{(2n-1)} \qquad \text{[for pressurization } C_r = C_e \times \left(\frac{\rho_i}{\rho_r}\right)^{(1-n)} \left(\frac{\mu_i}{\mu_r}\right)^{(2n-1)}\text{]}$$

Density can be determined as using:

Equation 19

$$\rho = 1.2041\left(1 - \frac{0.0065 \times h}{293}\right)^{5.2553} \left(\frac{293}{T + 273}\right)$$

Viscosity can be determined using:

Equation 20

$$\mu = \frac{1.458 \times 10^{-6}(T + 273)^{0.5}}{1 + \frac{110.4}{T + 273}}$$

If the user is willing to accept a loss in precision it is possible to make some simplifications. These will reduce the density adjustments to a fairly simple temperature ratio.

Equation 18 can be rewritten in terms of flow rather than the flow coefficient.

Equation 21

$$Q_r = Q_e \times \left(\frac{\rho_o}{\rho_r}\right)^{(1-n)} \left(\frac{\mu_o}{\mu_r}\right)^{(2n-1)}$$

[the formula for pressurization will be presented at the end of the development]

Substituting Equation 17 into Equation 21:

Equation 22

$$Q_r = Q_m \times \sqrt{\frac{\rho_c}{\rho_i}} \times \frac{\rho_i}{\rho_o} \times \left(\frac{\rho_o}{\rho_r}\right)^{(1-n)} \left(\frac{\mu_o}{\mu_r}\right)^{(2n-1)}$$

[12] The adjustment for the reference conditions was, in the previous version of CAN/CGSB-149.10, applied to the flows using an n of 0.5 which eliminates viscosity from the adjustment and simplifies the density portion of the equation. This introduces a small error depending on the actual value of n. See Equation 28 for a simplified adjustment based on this assumption.

From the ideal gas law, Equation 23 can be substituted into Equation 22 for each set of density ratios:

Equation 23

$$\rho \propto \frac{P}{T + 273.15}$$

Equation 24

$$Q_r = Q_m \times \sqrt{\frac{P_c}{P_i} \cdot \frac{(T_i + 273)}{(T_c + 273)}} \times \frac{P_i}{P_o} \cdot \frac{(T_o + 273)}{(T_i + 273)} \times \left(\frac{P_o}{P_r} \cdot \frac{(T_r + 273)}{(T_o + 273)}\right)^{(1-n)} \left(\frac{\mu_o}{\mu_r}\right)^{(2n-1)}$$

By substituting the following assumptions:

- standard temperature of T_r = 20 ºC;
- standard pressure of P_r = 101.325 kPa;
- assuming that the indoor and outdoor pressures are approximately equal, such that P_i = P_o;
- assume n = 0.5 (as was done in the previous version of CAN/CGSB-149.10).

This equation can be reduced to:

Equation 25

$$Q_r \approx Q_m \times \sqrt{\frac{P_c}{P_i} \cdot \frac{(T_i + 273)}{(T_c + 273)}} \times \frac{P_i}{P_o} \cdot \frac{(T_o + 273)}{(T_i + 273)} \times \sqrt{\frac{P_o}{101.325} \cdot \frac{(20 + 273)}{(T_o + 273)}} \left(\frac{\mu_o}{\mu_r}\right)^{0}$$

Further reducing:

Equation 26

$$Q_r \approx Q_m \times \sqrt{\frac{(T_o + 273)}{(T_i + 273)} \cdot \frac{P_c}{101.325} \cdot \frac{(20 + 273)}{(T_c + 273)}}$$

Since the temperature and pressure for calibration is fixed for a given blower door, it can be further reduced to:

Equation 27

$$Q_r = Q_m \times \sqrt{\frac{(T_o + 273)}{(T_i + 273)}} \times a\ constant$$

Furthermore, if the blower door is calibrated at or close to the reference conditions, or if the values from the blower door are already adjusted for the calibration pressure, the constant reduces to 1 and Q_r can be written as:

Equation 28

$$Q_r = Q_m \times \sqrt{\frac{(T_o + 273)}{(T_i + 273)}}$$ [for pressurization $Q_r = Q_m \times \sqrt{\frac{(T_i + 273)}{(T_o + 273)}}$]

Annex B
(normative)

Determination of the fit of multi-point test data

B.1 Multi-point test data procedure

If data has been collected at N corrected pressure differentials, ΔP_1, ΔP_2, …, ΔP_N giving corrected airflow rates Q_{r1}, Q_{r2}, …, Q_{rN}, respectively, the following procedure shall be used to fit an equation of the following type to the data:

Equation 29

$$Q = C \times \Delta P^n$$

Equation 29 is linearized by taking the natural log:

Equation 30

$$lnQ = lnC + n \times ln\Delta P$$

A weighted linear regression analysis to determine C and n can now be performed.

B.1.1 Regression analysis

Calculate the following sums:

Equation 31

$$\sum_{i=1}^{N} {Q_i}^2 ln\,\Delta\,P_i = {Q_1}^2\,ln\,\Delta\,P_1 + {Q_2}^2 ln\,\Delta\,P_2 + \dots + {Q_N}^2 ln\,\Delta\,P_N$$

Equation 32

$$\sum_{i=1}^{N} {Q_i}^2 (ln\,\Delta\,P_i)^2 = {Q_1}^2\,(ln\,\Delta\,P_1)^2 + {Q_2}^2 (ln\,\Delta\,P_2)^2 + \dots + {Q_N}^2 (ln\,\Delta\,P_N)^2$$

Equation 33

$$\sum_{i=1}^{N} {Q_i}^2 ln\,Q_i = {Q_1}^2\,ln\,Q_1 + {Q_2}^2 ln\;\;Q_2 + \dots + {Q_N}^2 ln\,Q_N$$

Equation 34

$$\sum_{i=1}^{N} {Q_i}^2 (ln\,Q_i)^2 = {Q_1}^2\,(ln\,Q_1)^2 + {Q_2}^2 (ln\;\;Q_2)^2 + \dots + {Q_N}^2 (ln\,Q_N)^2$$

Equation 35

$$\sum_{i=1}^{N} {Q_i}^2 (ln\,\Delta\,P_i)\,(ln\,Q_i) = {Q_1}^2\,(ln\,\Delta\,P_1)(ln\,Q_1) + {Q_2}^2 (ln\,\Delta\,P_2)(ln\,Q_2) + \dots + {Q_N}^2 (ln\,\Delta\,P_N)(ln\,Q_N)$$

Equation 36

$$\sum_{i=1}^{N} {Q_i}^2 = {Q_1}^2 + {Q_2}^2 + \ldots + {Q_N}^2$$

Using Equation 31 to Equation 36, calculate the following quantities:

Equation 37

$$S_{XX} = \left(\sum_{i=1}^{N} {Q_i}^2\right)\left(\sum_{i=1}^{N} {Q_i}^2 \,(ln\, \Delta\, P_i)^2\right) - \left(\sum_{i=1}^{N} {Q_i}^2 \,ln\, \Delta\, P_i\right)^2$$

Equation 38

$$S_{YY} = \left(\sum_{i=1}^{N} {Q_i}^2\right)\left(\sum_{i=1}^{N} {Q_i}^2 \,(ln\, Q_i)^2\right) - \left(\sum_{i=1}^{N} {Q_i}^2 \,ln\, Q_i\right)^2$$

Equation 39

$$S_{XY} = \left(\sum_{i=1}^{N} {Q_i}^2\right)\left(\sum_{i=1}^{N} {Q_i}^2 \,(ln\, \Delta\, P_i)(ln\, Q_i)\right) - \left(\sum_{i=1}^{N} {Q_i}^2 ln\, \Delta\, P_i\right)\left(\sum_{i=1}^{N} {Q_i}^2 ln\, Q_i\right)$$

Equation 40

$$S_{Y/X} = \sqrt{\frac{S_{YY} - n\, S_{XY}}{\left(\sum_{i=1}^{N} {Q_i}^2\right)(N-2)}}$$

Using equations 31, 32, 36, 37, and 38, calculate the best-fit estimates of the regression coefficients, n and C:

Equation 41

$$n = \frac{S_{XY}}{S_{XX}}$$

Equation 42

$$C = exp\left(\frac{\sum_{i=1}^{N} {Q_i}^2 ln\, Q_i}{\sum_{i=1}^{N} {Q_i}^2} - n\frac{\sum_{i=1}^{N} {Q_i}^2 ln\, \Delta\, P_i}{\sum_{i=1}^{N} {Q_i}^2}\right)$$

B.1.2 Assessment of the fit

The following statistical analysis can be used to assess the quality of the fit. Recommendations of acceptable values for the fit criteria can be found in section 7.5.2.1.

Using Equation 37, Equation 38 and Equation 39, calculate the correlation coefficient r:

Equation 43

$$r = \sqrt{\frac{{S_{XY}}^2}{S_{XX}\, S_{YY}}}$$

Calculate the relative error, εQ_i of the estimated flow at each measured ΔP_i (optional):

Equation 44

$$\varepsilon_{Q_i} = \left| \frac{\hat{Q}_i - Q_i}{Q_i} \right|$$

Where $\hat{Q}_i$ can be calculated from the regression line for all measured ΔP_i using Equation 45 while Q_i is the measured flow:

Equation 45

$$\hat{Q}_i = C \times \Delta P_i{}^n$$

B.1.3 Error limits

Using Equation 31, Equation 36, Equation 37, and Equation 40 calculate the relative standard error of the estimate of Q for a given pressure difference ΔP, ε_P can be determined as follows:

Equation 46

$$\varepsilon_P = \frac{S_{Y/X}}{\sqrt{\sum_{i=1}^{N} Q_i{}^2}} \sqrt{1 + \frac{\left[\left(\sum_{i=1}^{N} Q_i{}^2\right) \cdot ln\Delta P - \sum_{i=1}^{N} Q_i{}^2 ln\,\Delta\,P_i\right]^2}{S_{XX}}}$$

Calculate the relative standard error of $\hat{Q}$ at 10 Pa, which is also the relative standard error for the $ELA10$, using $ln\Delta P$ = $ln10$ in Equation 46:

Equation 47

$$\varepsilon_{10} = \frac{S_{Y/X}}{\sqrt{\sum_{i=1}^{N} Q_i{}^2}} \sqrt{1 + \frac{\left[\sum_{i=1}^{N} Q_i{}^2 \cdot ln10 - \sum_{i=1}^{N} Q_i{}^2 ln\,\Delta\,P_i\right]^2}{S_{XX}}}$$

For further independent use of the regression coefficients, calculate the standard errors using Equation 32, Equation 36, Equation 37 and Equation 40 (optional):

For C:

Equation 48

$$S_C = S_{Y/X} \sqrt{\frac{\sum_{i=1}^{N} Q_i{}^2 (ln\,\Delta\,P_i)^2}{S_{XX}}}$$

Therefore, the standard error range for C is $exp\,(ln\,C \pm S_c)$.

For n:

Equation 49

$$S_n = \frac{S_{Y/X}}{\sqrt{\frac{S_{xx}}{\sum_{i=1}^{N} {Q_i}^2}}}$$

Therefore, the standard error range for n is $n \pm S_n$.

Annex C
(normative)

Multi-zone airtightness test

This Annex describes the methodology to perform a multi-zone test. If section 6.2 determines that a multi-zone test is required, then Annex C shall be used. The procedures described in this standard have to be modified when there is more than one zone within the total building envelope area being tested.

C.1 Multiple fans

The first option is to use multiple fans to depressurize each zone simultaneously. Before performing the calculations, specifically the pressure difference and flow correction in 7.3 and 7.4, the pressure differences for each zone are averaged and the airflow for each zone are summed as described in 6.2.2.1.

In theory this can be done for as many zones as the user has test fans, but there is both a practical limit based on equipment and manpower as well as cumulative error as multiple readings are added together. Practice suggests that 4 zones is a reasonable limit.

C.2 Multiple tests

The second option is to test the zones individually while monitoring the pressure difference between the adjacent zones and outside, and mathematically combining the results. The following procedures and formulas have been derived for the following combinations of test fans and zones:

- two tests using one test fan with two zones;
- three tests using one test fan with three zones;
- two tests using two test fans with three zones.

The equations are based on the work done by DePani as reported in "*A Study on Single Blower Door Methods for Multifamily Building in Montreal*". His work was further developed on behalf of NRCan for inclusion in the HOT2000 energy simulation software. The "one test fan with two zone" combination will be used to illustrate the methods in detail and develop the equations. The final equations for the other tests methods will be presented at the end of the Annex C.

DePani premised his work on a single-point test. However, the two-point or multi-point tests in this standard can also be used, in which case an estimate for the flow at a reference pressure difference appropriate for the desired results (typically at $\Delta\hat{P}$ = 50 Pa) can be determined using the derived flow coefficient and pressure exponent Equation 2 from 7.5 or 7.6. So for the purposes of this section, $\hat{Q}$ will be used to describe the flow at the desired test pressure. $\Delta\hat{P}$ will be used to describe the desired pressure difference (e.g. 50 Pa) or, in the case of the adjacent zones, $\Delta\hat{P}$ will be the average adjacent zone pressure difference prorated by the ratio of the average tested zone pressure difference divided by the desired pressure difference.

C.3 One test fan with two zones

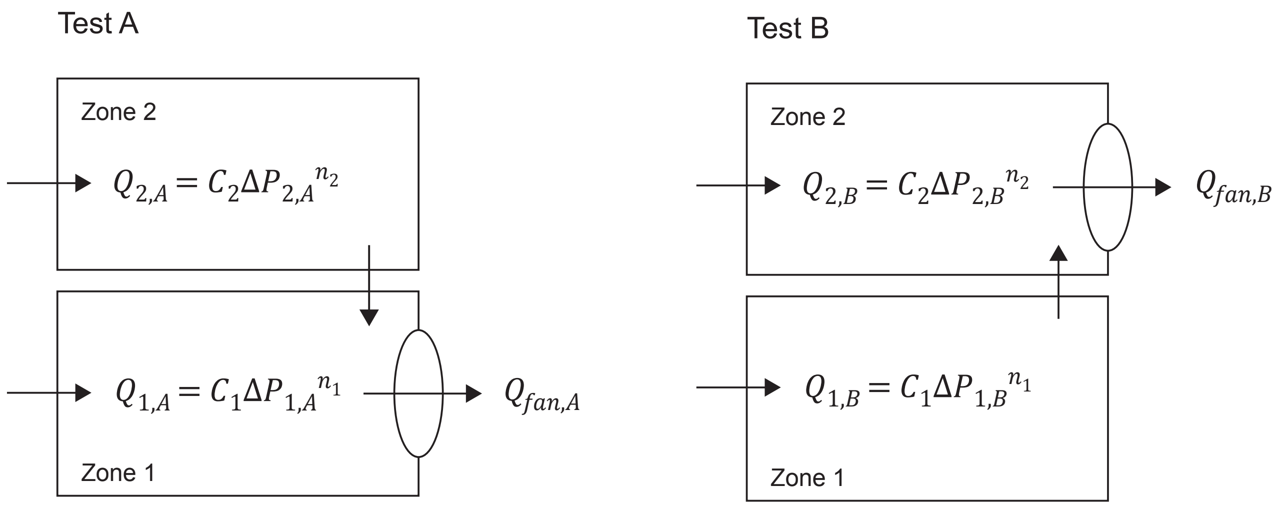
Two tests are done, one after the other, with the test fan in one zone for the first test and the second zone for the second test.

C.3.1 Set up

Both zones are set up according to the procedures in section 6.1.

The two different test setups are shown in Figure 3.

Figure 3 – One test fan, two zone test setups



C.3.2 Test procedure

Each test is completed according to the procedures in 6.2. For test A, the test fan is set up in zone 1 and $\Delta P_{2,A}$ is recorded in addition to $Q_{fan,A}$ and $\Delta P_{1,A}$ in accordance with the procedures in section 6.

For test B, the test fan is moved to zone 2 and $\Delta P_{1,B}$ is recorded in addition to $Q_{fan,B}$ and $\Delta P_{2,B}$.

C.3.3 Completion of the test

Both zones are returned to the pretest condition in accordance with 6.3.

C.4 Calculations

Pressure differences and airflows are corrected according to 7.3 and 7.4.

C.4.1 Multi-point or two-point test

If a multi-point or two-point test was done, determine the flow coefficients C_A and C_B and pressure exponents n_A and n_B for test A and B according to 7.5 or 7.6. Note that these values do not represent the leakage characteristics of the building or either of the zones since some comes to the fan through multiple flow paths. They are used only to determine a fan flow at a given pressure difference in order to complete the calculations below. They are not to be confused with the C and n values shown in Figure 3, or in the formulas below.

Then use Equation 45 to determine:

$\hat{Q}_{fan,A} = C_A \times \Delta\hat{P}^{n_A}$ and

$\hat{Q}_{fan,B} = C_B \times \Delta\hat{P}^{n_B}$

where $\Delta\hat{P}$ is a suitable pressure difference for the desired results (e.g. 50 Pa if ACH50 is the desired result).

Results for $\hat{Q}_{fan,A}$, $\Delta\hat{P}_{1,A}$, $\Delta\hat{P}_{2,A}$, and $\hat{Q}_{fan,B}$, $\Delta\hat{P}_{1,B}$, $\Delta\hat{P}_{2,B}$ from a single-point test can be used directly in the following equations. Ideally, $\Delta\hat{P}_{1,A}$ and $\Delta\hat{P}_{2,B}$ are the same or close, and are as close to the desired pressure difference as possible.

C.5 Formulas for one test fan with two zones

For test A a mass balance requires that:

Equation 50

$$\hat{Q}_{fan,A} = C_1 \Delta\hat{P}_{1,A}{}^{n_1} + C_2 \Delta\hat{P}_{2,A}{}^{n_2}$$

Equation 51

$$\hat{Q}_{fan,B} = C_1 \Delta\hat{P}_{1,B}{}^{n_1} + C_2 \Delta\hat{P}_{2,B}{}^{n_2}$$

The following are known:

- $\hat{Q}_{fan,A}, \Delta\hat{P}_{1,A}, \Delta\hat{P}_{2,A}$
- $\hat{Q}_{fan,B}, \Delta\hat{P}_{1,B}, \Delta\hat{P}_{2,B}$

The following are unknown:

- $C_1, n_1, C_2, n_2,$

There are 4 unknowns and only 2 equations. By assuming that all pressure exponents are 0.65, a reasonable estimate based on several studies of attached houses, there are only 2 unknowns, so there are sufficient equations to solve for the flow coefficients. For the balance of the Annex all exponents will be written without a subscript and are assumed to be n = 0.65.

Solve Equation 50 for C_1 and Equation 51 for C_2.

Equation 52

$$C_1 = \frac{\hat{Q}_{fan,A} - C_2 \Delta\hat{P}_{2,A}{}^{n}}{\Delta\hat{P}_{1,A}{}^{n}}$$

Equation 53

$$C_1 = \frac{\hat{Q}_{fan,B} - C_1 \Delta\hat{P}_{1,B}{}^{n}}{\Delta\hat{P}_{1,B}{}^{n}}$$

Insert Equation 53 into Equation 50 and solve for C_1 and insert Equation 52 into Equation 51 and solve for C_2.

Equation 54

$$C_1 = \frac{\hat{Q}_{fan,A} - \hat{Q}_{fan,B}\left(\frac{\Delta\hat{P}_{2,A}}{\Delta\hat{P}_{2,B}}\right)^n}{\Delta\hat{P}_{1,A}{}^n - \Delta\hat{P}_{2,A}{}^n\left(\frac{\Delta\hat{P}_{1,B}}{\Delta\hat{P}_{2,B}}\right)^n}$$

Equation 55

$$C_2 = \frac{\hat{Q}_{fan,B} - \hat{Q}_{fan,A}\left(\frac{\Delta\hat{P}_{1,B}}{\Delta\hat{P}_{1,A}}\right)^n}{\Delta\hat{P}_{2,B}{}^n - \Delta\hat{P}_{1,B}{}^n\left(\frac{\Delta\hat{P}_{2,A}}{\Delta\hat{P}_{1,A}}\right)^n}$$

The flow coefficient for the two zones combined is:

Equation 56

$$C_{total} = C_1 + C_2$$

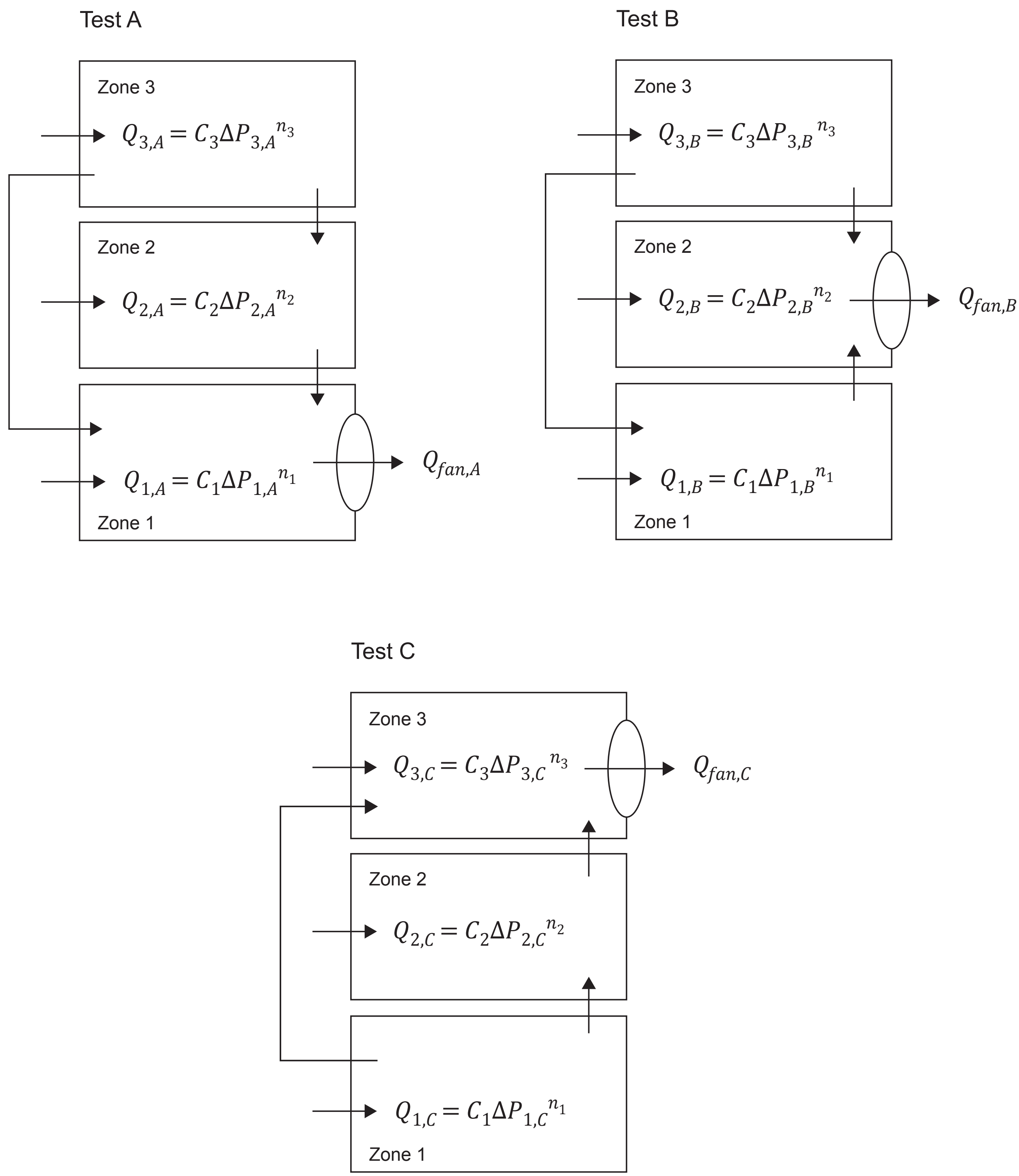
C.6 Formulas for one test fan with three zones

The formulas for the three zone tests, while more complicated, can be developed in a similar fashion. The final results are shown here.

C.6.1 Set up

The zones are set up according to the procedures in 6.1. The three different test setups are shown in Figure 4.

Figure 4 – Three zone one fan test set up



C.6.2 Formulas

Equation 57

$$C_1 = \frac{\left(\hat{Q}_{fan,B} - \hat{Q}_{fan,A}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}\right) - \frac{\left(\hat{Q}_{fan,B} - \hat{Q}_{fan,C}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,C}{}^{n}}\right)\times\left(\Delta\hat{P}_{2,B}{}^{n} - \Delta\hat{P}_{2,A}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}\right)}{\Delta\hat{P}_{2,B}{}^{n} - \Delta\hat{P}_{2,C}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,C}{}^{n}}}}{\left(\Delta\hat{P}_{1,B}{}^{n} - \Delta\hat{P}_{1,A}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}\right) - \frac{\left(\Delta\hat{P}_{1,B}{}^{n} - \Delta\hat{P}_{1,C}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,C}{}^{n}}\right)\times\left(\Delta\hat{P}_{2,B}{}^{n} - \Delta\hat{P}_{2,A}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}\right)}{\Delta\hat{P}_{2,B}{}^{n} - \Delta\hat{P}_{2,C}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,C}{}^{n}}}}$$

Equation 58

$$C_2 = \frac{\left(\hat{Q}_{fan,B} - \hat{Q}_{fan,A}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}\right) - C_1\times\left(\Delta\hat{P}_{1,B}{}^{n} - \Delta\hat{P}_{1,A}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}\right)}{\left(\Delta\hat{P}_{2,B}{}^{n} - \Delta\hat{P}_{2A}{}^{n}\frac{\Delta\hat{P}_{3,B}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}\right)}$$

Equation 59

$$C_3 = \frac{\hat{Q}_{fan,A} - C_2\Delta\hat{P}_{2,A}{}^{n} - C_1\Delta\hat{P}_{1,A}{}^{n}}{\Delta\hat{P}_{3,A}{}^{n}}$$

Equation 60

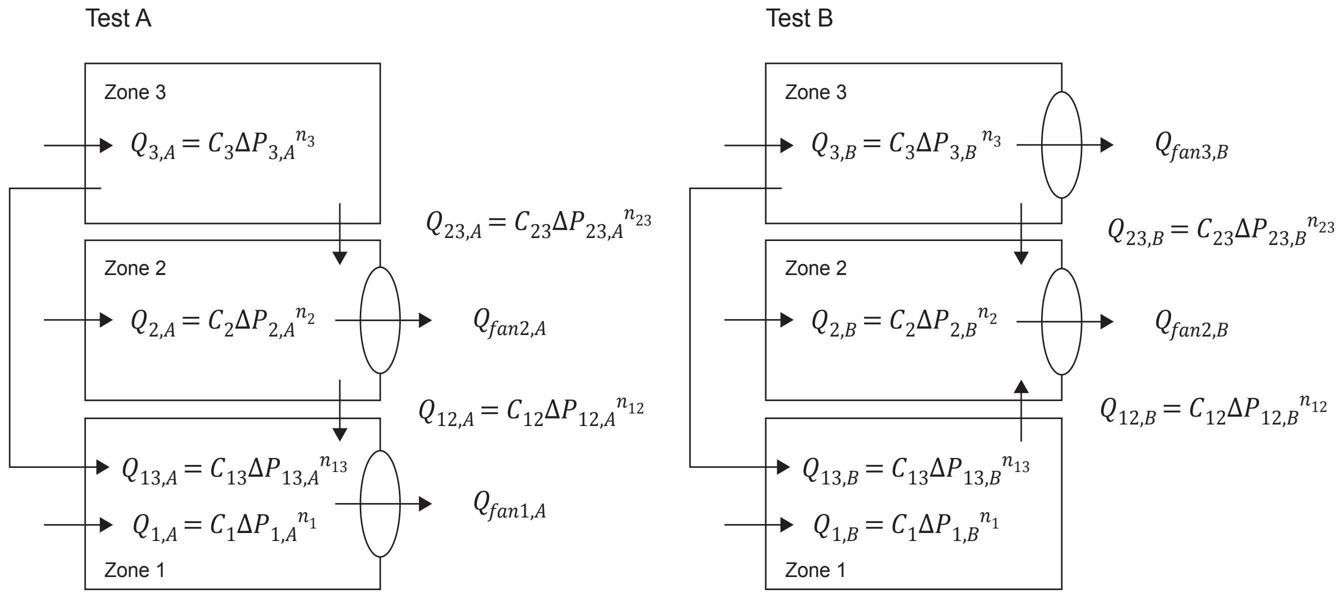
$$C_{total} = C_1 + C_2 + C_3$$

C.7 Formulas for two test fans with three zones

C.7.1 Set up

The zones are set up according to the procedures in 6.1. The two different test setups are shown in Figure 5. Note that the fan that remains in the same zone for both tests, labeled Fan 2, should ideally be in the zone with the highest leakage or in the zone with the most partition area adjoining the other zones.

Figure 5 – Three zone two fan test set up



C.7.2 Formulas

Equation 61

$$C_1 = \frac{\hat{Q}_{fan2,A} + \hat{Q}_{fan1,A}\{1 + F_{13}[F_3 - F_2]\} - \hat{Q}_{fan2,B}F_2 - \hat{Q}_{fan3,B}F_3}{\Delta\hat{P}_{1,A}^n\{1 + F_{13}[F_3 - F_2]\} - \Delta\hat{P}_{1,B}^n F_2}$$

Equation 62

$$C_2 = \frac{\hat{Q}_{fan2,B} + \hat{Q}_{fan1,A}F_{13} - C_1\left[\Delta\hat{P}_{1,B}^n + \Delta\hat{P}_{1,A}^n F_{13}\right]}{\Delta\hat{P}_{2,B}^n}$$

Equation 63

$$C_3 = \frac{\hat{Q}_{fan3,B} - \hat{Q}_{fan1,A}F_{13} + C_1\Delta\hat{P}_{1,A}^n F_{13}}{\Delta\hat{P}_{3,B}^n}$$

Where:

Equation 64

$$F_{13} = \left(\frac{\Delta\hat{P}_{13,B}}{\Delta\hat{P}_{13,A}}\right)^n$$

Equation 65

$$F_2 = \left(\frac{\Delta\hat{P}_{2,A}}{\Delta\hat{P}_{2,B}}\right)^n$$

Equation 66

$$F_3 = \left(\frac{\Delta\hat{P}_{3,A}}{\Delta\hat{P}_{3,B}}\right)^n$$

Annex D
(informative)

Specimen of a test report

GENERAL INFORMATION			
Name of company			
Address of company			
Name of tester			
Address of building			
Date of test (YYYY-MM-DD)		Date of report (YYYY-MM-DD)	
Test fan system manufacturer and model			
Calibration date			

WEATHER DATA	
Outdoor temperature (ºC)	
Wind conditions	
Elevation (m)	

TEST INFORMATION			
Test fan installation location			
Test option	☐ Multi-point	☐ Two-point	☐ Single-point
Type of assessment	☐ As-operated	☐ Closed-up	
Pressure boundary set-up	☐ Unguarded	☐ Guarded (for attached buildings)	
Test execution	☐ Automated	☐ Manual	
Deviation from method			

ENVELOPE	
Building envelope	
Area (m^2) (specify A_t or A_e for attached buildings)	
Interior volume (m^3)	
Other	

MEASURED DATA						
Initial pressure difference $\Delta P_{m,i}$ (Pa)						
Final pressure difference $\Delta P_{m,f}$ (Pa)						
Q_m (L/s) (number of values depends on test type)						
ΔP (Pa) (number of values depends on test type)						
Initial indoor temperature (ºC)						

CORRECTED DATA						
ΔP(Pa)						
Q_r (L/s)						

CALCULATED DATA	
C_r (L/($s{\cdot}Pa^n$))	
n	
r	
Corrected flow at 50 Pa, Q_r50 (L/s)	
Standard error for Q_r50	
ELA (cm²)	
Standard error for $ELA10$	
$ACH50$	
$NLA10$ (cm²/m²)	
$NLR50$ (L/s·m²)	

PLOT OF MEASURED DATA

Figure 6 – Linear plot of data

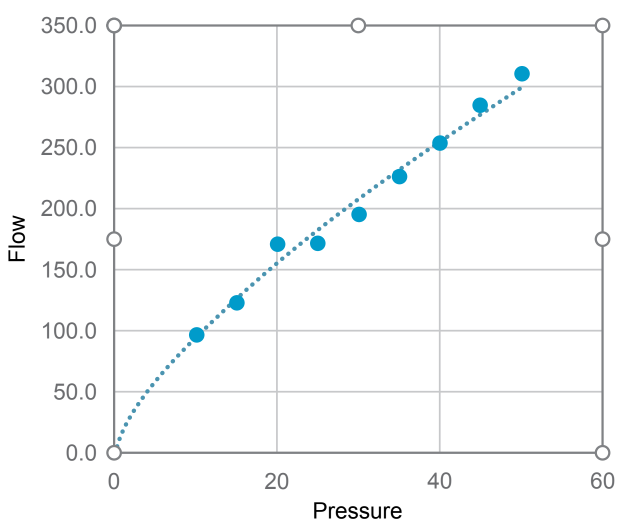
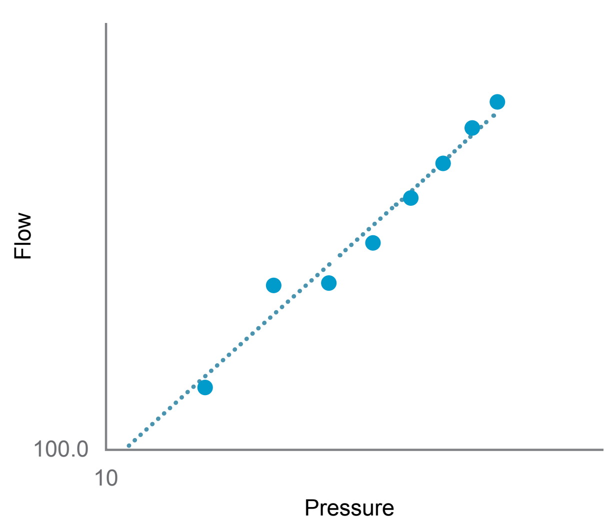


Figure 7 – Logarithmic plot of data



Annex E
(informative)

Practical guide to minimizing errors in test results

E.1 Introduction

This Annex is intended to assist users of CAN/CGCB-149.10 in taking appropriate steps to minimize errors and improve the overall accuracy and repeatability of airtightness test results.

E.1.1 For a more rigorous analysis of uncertainty and error estimation techniques for airtightness tests, the reader is referred to the referenced literature in Bibliography.

E.1.2 Perform both pressurization and depressurization tests and average the results.

E.2 Defining sources of uncertainty and errors in ELA estimates

E.2.1 The likelihood of error is directly related to the level of uncertainty for all the variables that may influence test results.

E.2.2 For simplicity in this Annex, the level of uncertainty associated with key variables will be referred to in terms of the potential error. For example, if a gauge has an uncertainty of ±10%, then this is referred to as a potential error of 10%.

E.2.3 The first step in improving the accuracy of test results is to understand the different sources of potential errors and their interaction with each other. Without such an understanding, it is impossible for users to judge the relative benefit of any efforts to improve accuracy, and thus use their time efficiently.

E.2.4 Every airtightness test has three general variables, which represent fundamental sources of error:

a) Error of the measuring instrument (E_i), e.g. a pressure gauge which is not properly calibrated and gives erroneous readings.

b) Error of the measuring method (E_m), e.g. some leaks may open up in size as pressure increases, in other words the characteristic being measured is influenced by the test procedure.

c) Error of the operator (E_o), e.g. an operator marks the wrong pressure difference after reading the gauge, or forgets to close all the windows in the building before a test. Some practitioners argue this should not be included as a source of error since errors of accuracy are difficult to bound. It is included here for explanatory purposes and to maintain consistency with analysis completed by others. See section 3.

E.2.5 The total potential error, E_{total}, for any particular test may be approximated by adding the maximum error estimated for each of these three sources. However, the errors do not combine through simple addition. Instead, they combine “in quadrature” as shown in the equation below, where the errors are relative, not absolute:

Equation 67

$$E_{total} = \sqrt{{E_i}^2 + {E_m}^2 + {E_o}^2}$$

E.2.6 The effect of adding the three sources of error in quadrature is usually to reduce the total error relative to what would occur through simple addition. For example, if the estimated maximum error due to the measuring instruments, the method and the operator are each 10%, the overall potential error will be about 17%, rather than the 30% that would result from simple addition. The total error is reduced to 17% because statistically, it is unlikely that all three sources will produce their worst errors, in the same direction, in the same test.

E.2.7 Adding errors in quadrature does not have the same kind of effect if one of the sources of error is much greater than the others. For example, if the instrument error is 10%, and the method and operator errors are each 3%, the net error becomes 11%, or almost the same as simple addition.

E.2.8 The key lesson to take from these examples is that in order to reduce effectively the overall potential for errors in the test results, it is necessary to first reduce any exceptionally large sources of errors, and thereafter to reduce all three potential sources of errors concurrently.

E.2.9 Consider, for example, two strategies for reducing errors in a test where the existing potential for errors is 10% for each source:

a) Ignore the method and operating errors, and buy an expensive piece of test equipment that reduces the instrument error to only 1%, or

b) Spend time and money to reduce each source of error to about 5%.

E.2.9.1 The first strategy provides an overall potential error of 14%. The second strategy is much better, reducing the potential error to just 9%.

E.2.10 The level of error for airtightness test results is difficult to estimate without knowing the level of uncertainty for all the variables — something that is often difficult to determine. Some general rules of thumb may be helpful. For example, instrument error is usually fixed, assuming the instruments are properly maintained and calibrated. The key is usually to take extra steps to ensure that operator and method error are not a lot larger than the equipment error.

E.3 Strategies for improving accuracy

E.3.1 General

This section provides a number of general strategies for reducing errors of an airtightness test. This is not an exhaustive list of options. Emphasis has been given to the most common problems reported by field practitioners, and to practical methods for avoiding these problems.

It is important to understand the purpose of the test. If it is to meet a specified leakage criterion at a fixed pressure difference (typically $ACH50$) then a single point test with reasonable time averaging may suffice. Conversely if the test results are to be used in ventilation or energy calculations then the envelope air leakage at lower pressures needs to be known. There is a tradeoff between precision at higher test pressures and accuracy in determining the envelope leakage closer to normal operating conditions (that requires an assumption of pressure exponent for single-point testing). Detailed studies [(Walker *et al.* (2013)] have shown that up to about 6 m/s of windspeed, multi-point testing is more accurate than single point testing.

E.3.2 Strategy 1: Take more readings

E.3.2.1 The use of multiple measurements is a simple way to reduce measurement, method and operator uncertainty in the test, since the error of an average is inversely proportional to the square root of the number of readings making up the average; see bibliography. For instance, this implies that four readings are twice as precise as one reading.

E.3.2.2 Multiple measurements may imply repeating the whole test or taking each reading several times and calculating an average.

E.3.2.3 The time averaging functionality available in most digital manometers is effectively the same as taking multiple readings and averaging them.

E.3.3 Strategy 2: Multi-point testing options

E.3.3.1 The choice of test option (two-point or multi-point) may be used to reduce test uncertainty.

E.3.3.2 The choice between the two-point and multi-point test is less clear. Surprisingly, the two-point test is theoretically more accurate than a multi-point test, as long as the two points are accurate. However, the multi-point test is thought to produce more informative results because it allows for an analysis of relative standard error and a correlation coefficient. Statistical analysis and observations of the input data can be used to highlight problems such as instrumentation failures or changes in the building set-up, and thus the test tends to be more rigorous.

E.3.4 Strategy 3: Reduce the error of the measuring instrument

E.3.4.1 Digital gauge accuracy of ±1% is more than sufficient for the purpose of this standard given that the error from operators and method is likely to be at least as great, even under ideal conditions.

To minimize error of the measuring device, all equipment needs to be calibrated at appropriate intervals using recommended procedures.

A simple and quick method for checking calibration is to connect two manometers together. Since the pressure measuring devices commonly available for airtightness testing have two channels, this can be as simple as connecting a hose between the two channels. If the two channels differ by more than 2% a more thorough verification or full calibration may be required.

E.3.4.2 It is essential to maintain a calibration record for each measuring gauge or element to ensure that the instrument history can be tracked and understood. Good practice requires periodic use of the System Calibration Check (Annex G), performing the manufacturer recommended checks, and calibration of the measuring system.

E.3.5 Strategy 4: Reduce the error of the measuring method inside

E.3.5.1 Avoid non-standard conditions

One of the most noticeable errors in pressure readings is the fluctuation of the measurement caused by gusting wind, especially the readings of indoor-outdoor pressure difference in the 15 to 30 Pa range. Even a steady wind that does not cause fluctuations can be a source of error, since the result is a pressure gradient over the surface of the building envelope. Another source of error is the pressure difference between inside and outside due to the stack effect. The obvious solution to avoiding such errors is to test at times when wind is calm and temperature differences between inside and outside are moderate. However it is not always possible to choose ideal conditions, and decisions must be made about whether the potential error from non-standard wind and temperature is acceptable or not. Ideal test conditions are a wind speed of 0 to 2 m/s and a temperature difference between inside and outside of 15 ºC or less. Errors due to a steady wind or stack effect are largely eliminated by subtracting off the offset pressure.

E.3.5.2 Temperature impact of extended test duration

Extended test durations can change the temperature of the building, especially when doing pressurization tests, such that the temperature used for air density corrections may be incorrect. This can be mitigated by:

- keeping the test time as short as possible (generally speaking under 10 minutes will be adequate for most outside temperatures);

- averaging the before and after temperatures;
- correcting each airflow based on density corrections using a temperature collected at each reading.

E.3.6 Strategy 5: Reduce the error of the operator

E.3.6.1 Use checklists and standard sequences

A common source of error in conducting the tests before and after sealing work is that the building is not set up in the same way during the two tests. This results in a serious limitation on the reproducibility of the test. Checklists and test reports are one of the best means of reducing this type of operator error. They also help to ensure correct sequencing, completeness of procedures and a return to original configuration after a test has been completed.

E.3.6.1.1 Checklists are especially useful for:

a) equipment set-up;

b) building set-up; and

c) test procedure steps.

E.3.6.1.2 Standardized reports should include information on:

a) measurement procedure;

b) anomalies in the set-up; and

c) test conditions.

E.3.6.1.3 Table 3 and Table 4 provide sample checklists for building set-up and equipment set-up that may be adopted to fit the particular needs of a user. Annex D provides a sample measurement procedure report.

E.3.6.2 Take special care in set-up for airtight buildings

In an exceptionally airtight building, it is possible for the greatest leakage to occur in the door or window used for the set-up of the test fan system. In such cases, care must be taken when fitting equipment. A check for leakage around the panels and test fan is recommended. Therefore the degree of effort taken to seal the test fan assembly can introduce a noticeable variation in the test results.

E.3.6.3 Adapt equipment to prevent mistakes when connecting tubes

This may imply the use of labels or different sizes of connectors, or the covering of exterior tube ends with protection (e.g. foam covers) to prevent moisture and dirt from blocking the tubes.

E.3.6.4 Develop a quality assurance program

This may entail occasional repeat checks by another group or at least another operator with preferably other equipment. Alternately, perform tests on the same building, where there are no changes to building envelope integrity.

Table 4 – Example of equipment set-up checklist

Step	Task Description
1	Use same opening when retesting a building.
2	Locate outside tube where it will be least subject to the wind and other influences.
3	Install test fan equipment and ensure a tight seal.
4	Connect tubing through envelope opening to building pressure gauge.
5	Connect tube from test fan to flow pressure gauge.
6	Perform building set-up as per 6.1.
7	Conduct test as per 6.2 of this standard, using data collection forms as per Annex D.

Annex F
(informative)

Options for wind-pressure dampening

F.1 Theory

Wind will cause pressures on the surfaces of the building as well as noticeable pressure fluctuations due to changing wind conditions. These fluctuations will increase the relative standard error of the test results.

Stack effect caused by the difference between indoor and outdoor temperatures will create an offset pressure. In extreme cases this can be 3 Pa per storey of building height. Density differences between the air leaving through the test fan and entering through leakage are corrected for in the airflow corrections covered in Annex E.

Subtraction of the offset pressure will largely correct stagnation pressure from a steady wind and from stack effect. Under gusty conditions, pressure fluctuations make accurate gauge readings difficult to obtain. A wind-averaging and dampening system, as described below, shall be provided to make reading of pressure easier and more reliable.

F.2 System options

F.2.1 Electronic time averaging

Ten second time averaging is the specified minimum in 6.2.1. On windy days the test can be done with longer time averaging until the requirements of 7.5.2.1 are met. The necessary time averaging can be predicted by using the steps below in order to avoid repeating the test unnecessarily. Alternatively, the test can be run again and the data points combined with the initial test, effectively doubling the number of points taken, until the requirements of 7.5.2.1 are met.

To predict the appropriate time averaging period perform the following steps:

- With the test fan covered, take sufficient samples to obtain ten 10 second baseline pressure readings.
- Determine the largest variation from the average (i.e. the larger of; average minus the largest reading and average minus the smallest reading).
- If the largest variation is ≤ 1 Pa the default 10 second time averaging is sufficient.
- For 1< variation ≤ 2 use 20 second time averaging.
- For a variation >2 use 30 second time averaging.

Using this method provides a very accurate baseline and a high confidence that, in most cases, the test results will be reliable. However, note that there is still a possibility that the test may not be valid and will have to be redone.

F.2.2 Other methods

Other physical systems or methods can help if the equipment has limited choice for time averaging or if the conditions are particularly difficult:

- Place the outdoor tube on the leeward (i.e. downwind) side of the building at the intersection of the ground and the wall[13].
- Use a longer outdoor tube (don't exceed 30 m).
- Insert a capillary tube in the outdoor tube (a capillary tube of 0.5 mm inside diameter and 75 mm length is adequate for most system set-ups).
- Use a static tip on the outdoor tube.
- Place the end of the tube in a sheet (e.g. a drop cloth).
- A combination of the above.

Care must be taken in the setup to avoid negative impacts due to leaks and temperature influence for anything that adds length or joints to the tubing

F.2.3 Wind fluctuations and unintended pressure offsets

The following can increase fluctuations due to wind or cause unintended pressure offsets and should be avoided:

- placing the outdoor tube in a container or cavity, including a bucket of water, which can actually amplify pressure fluctuations,
- leaving the tube exposed to the sun which can create an offset pressure from the buoyancy and thermal expansion of the heated air in the tube, as well as transient pressures if the sun is blocked or wind blowing on the tube causes its temperature to change,
- a kinked or pinched tube.

[13] This may appear to be counterintuitive since stagnation pressures are increased closer to the building. However, field experience suggests that the fluctuations are minimized at this location.

Annex G
(informative)

System calibration check

G.1 Introduction

G.1.1 Calibration

The system calibration check is a field procedure that is intended to verify that the airtightness-testing equipment and operator are capable of accurately measuring an equivalent leakage area. System calibration checks shall be executed by persons who are thoroughly familiar with this standard, and with the equipment manufacturer's operating instructions.

G.1.2 Manufacturer alternative

This Annex describes one method for conducting a system calibration check. An acceptable alternative is to use procedures and equipment provided for this purpose by a manufacturer of airtightness testing equipment. When a manufacturer provides a procedure, the levels of accuracy and the reporting requirements should be at least as stringent as described in this Annex.

G.2 Basic principle

G.2.1 Test fan system

A test fan system is set up and used to measure the ELA of a tight room or building. A hole of known size is then opened up between the room or building and the outside and the test fan system is used again to measure the ELA. The new ELA should equal the sum of the first ELA measurement and the known hole size. The known hole size is then changed, and the test repeated. If the change in ELA is measured accurately in both cases there is a reasonable confidence that the test fan system is performing as intended.

Note: Although this method may seem crude, it has proven remarkably accurate in field tests. The entire procedure can be completed in a period as short as a half-hour. It provides a convenient means of testing the ability of the operator and the accuracy of the entire measurement system, including the gauges, tubing connections, flow elements, and computer calculations.

G.3 Limitations

G.3.1 Calibration

This procedure is not intended to be used to re-calibrate test fan systems. For details on equipment calibration, see 5.5 of this standard. The results of a system calibration check do not necessarily determine the accuracy of the test fan system. Consider the following possibilities:

- If the system calibration check results are found to be accurate, either everything is okay or two or more errors are present, but they compensated for each other during the test.
- If the system calibration check results are found to be inaccurate, then the equipment may be malfunctioning (e.g. due to blocked tubing, software bug, damaged flow element), the operator has made an error in operating the equipment or in following the system calibration check procedures; or both of the above[14].

[14] Wind or stack effect can affect accuracy of this method. A jet of air coming in through an orifice and impinging on the entrance to the blower door fan can cause large errors. The exhaust from a blower door impinging on the added hole can also cause large errors. If the added hole is too small, the % error can be very large.

G.4 Equipment

G.4.1 Equipment list

The following equipment is required:

- test fan system; and
- holes of known size.

G.4.2 Holes of known size

The following should be noted on construction of holes of known size:

a) The holes of known size should be circular or rectangular holes cut out of rigid material. If rectangular holes are used, the aspect ratio of the hole (ratio of width to height) should be less than five.

b) The edges should be cut at 90º to the surface of the rigid material, and kept as sharp as possible.

c) The centre of the hole should be at least 1.5 times the diameter of the hole (or length for rectangular holes) from the edge of walls, ceilings, window and door casings, and other protrusions that could disturb the airflow.

d) The thickness of the material should be less than 0.02 × the hole diameter. For example, a hole of 25 cm in diameter would be cut from materials that are 0.5 cm or thinner.

e) The material should be shaped and constructed in a manner that allows it to be tightly fitted into the envelope of the space to be tested. For example, a sheet of rigid plastic with a circular hole can be mounted above the fan depressurization equipment, and taped to the doorway. Alternatively, a sheet of plastic or cardboard could be placed over a window opening and taped to the window trim.

f) It is preferable to have several holes, so the total hole size can be easily varied to create a range of ELAs. A sheet with a smaller hole can be mounted over top of the sheet with the larger hole. Alternatively, several holes of similar size can be cut in different locations on the same sheet, and then plugged or left open as appropriate. If several holes are cut in a single sheet, the minimum distance between the centres of any two holes in simultaneous use should be 3 times the diameter or length of the larger hole.

g) Finally, to adjust hole size it is possible to tape a piece of cardboard over part of a hole to make it smaller.

G.5 System calibration check procedure

G.5.1 Pressure measuring device verification

The pressure measuring device shall be verified by connecting it to a new or recently calibrated pressure measuring device or, for dual channel devices, by connecting the two channels together. The pressure induced simply by connecting the tubing to the device is usually enough to get a reading within the range normally used for airtightness testing. Be careful not to exceed the pressure limit of the device. The pressure readings should be within 2% of each other.

If the pressure measuring device fails this verification it will need to be properly checked or calibrated.

G.5.2 Choice of test conditions

a) Choose a time when wind conditions are dead calm.

b) Choose a tight room or building, with an ELA below the range that will normally be encountered in future field-testing work. The tighter the better — it's much easier to add holes than to try and make a space tighter.

c) Set up the room or building in a closed-up condition. Use tape to eliminate, if possible, any leakage areas that may open or change as a result of depressurization (e.g. dampers, loose windows, and doors).

d) Set up the test fan system in a doorway, according to this standard. Ensure that the area to the outdoors is completely unobstructed for at least 1 m around the test fan opening.

e) Ensure that the HVAC (heating, ventilating, and air-conditioning) systems are not operating, and that ductwork into adjoining spaces is completely sealed off.

f) Install the holes of known size and seal them temporarily.

G.5.3 Record hole size

Record all measurements and hole sizes, using a reporting form similar to that shown in G.7, where the area of the first and second holes are A_1 and A_2 respectively.

G.5.4 Starting ELA

Measure the starting ELA of the room or building, ELA_S. Use a multi-point or two point test giving preference to the method most commonly used by the equipment operator.

G.5.5 Measure with first hole

Unseal one or more holes of known size so as to increase the ELA of the room by an amount approximately equal to the difference between the ELA_S and the tightest ELA expected in field conditions. A minimum increase in ELA of 50% or 500 cm^2, whichever is greater, is recommended.

Measure the combination of the room ELA and the first set of known hole(s) and record it as ELA_1.

G.5.6 Measure with second hole

Unseal additional hole(s) of known size roughly equal to the first set of known holes. Note that this can be additional holes or a new larger hole, whichever is easiest, as long as the combined area of the holes is known.

Repeat the measurement of the ELA and record it as ELA_2.

G.5.7 Calculations

Calculate the % error for each test as follows:

Equation 68

$$\%\,error_1 = \frac{ELA_1 - ELA_s}{A_1} \times 100$$

Equation 69

$$\%\,error_2 = \frac{ELA_2 - ELA_s}{A_1 + A_2} \times 100$$

Where:

- $\%\,error_1$ is the error between the change in area of the tested ELA and first hole as a percentage;
- $\%\,error_2$ is the error between the change in area of the tested ELA and the sum of the first and second hole as a percentage;

- ELA_S is the tested starting ELA without any known holes open in units of cm^2;
- ELA_1 is the tested ELA with the first hole open in units of cm^2;
- ELA_2 is the tested ELA with the first and second holes open in units of cm^2;
- A_1 is the area of the first known hole in units of cm^2;
- A_2 is the area of the second known hole in units of cm^2.

Note 1: These procedures are written on the assumption that a second hole is added in addition to the first hole for the second test. It can also be done by changing the hole for one of a different size, in which case Equation 69 would be revised to show just the area of the second hole in the denominator.

Note 2: Although these procedures describe only two tests, additional holes can be added and additional tests performed.

G.6 Interpretation of the results

G.6.1 Results

The percentage error values recorded in this procedure are a combination of equipment error, method error, and operator error. Percentage errors greater than 12% are an indication of problems and should be investigated. The investigation should attempt to rule out the various possibilities, by trying out different operators, equipment components, hole sizes and so on until the source of the error is isolated. If the error is found to be a failure of the fan depressurization equipment, the system should be overhauled and, if necessary, the flow element should be recalibrated.

G.7 Example of a system calibration check report

Date of check (YYYY-MM-DD)	
Location of check	
Equipment make and model	
Equipment identification (e.g. serial number)	
Equipment owner	
Individual and company responsible for check	

Test option performed: ☐ Multi-point ☐ Two-point ☐ Single-point

Properties	Test of $hole_1$	Test of $hole_2$
ELA of room or building with holes sealed, ELA_S, cm^2	$ELA_S =$	
Known size of hole to be opened, cm^2	$A_1 =$	$A_1 + A_1 =$
ELA of room or building with hole open, cm^2	$ELA_1 =$	$ELA_2 =$
Percentage error from Equation 68 and Equation 69, %		

Signature of checker: ______________________________

Address: ______________________________

Email address: ______________________________

Telephone no. : ______________________________

Annex H
(informative)

Standard metadata

This information is used for e-reader accessible HTML tags.

Also see Table 2 for symbols and acronyms.

Abbreviation	Abbreviation title
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	The American Society of Mechanical Engineers
ASTM	ASTM International, formerly known as American Society for Testing and Materials
ASTM STP	Designation for ASTM International publication of ASTM STP1067
CAN/CGSB	National Standard of Canada/ Canadian General Standards Board
CGSB	Canadian General Standards Board
e.g.	exempli gratia in Latin meaning for example
GA	Georgia
ICS	International Classification of Standards
IHS	IHS Marketing, a company name
ISBN	International Standard Book Number
ISED	Innovation, Science and Economic Development Canada
MB	Manitoba
NE	North-east
NRCan	Natural Resources Canada
NS	Nova Scotia
PA	Pennsylvania
Pa	Pascal
pp	Pages
SE	South-east
SMOTs	Standards Methods of Testing
U.S.A.	United States of America

Images	Explanation
CGSB Expanded Logo	Trademark logo of green stylized letters of the Canadian General Standards Board / Office des normes générales du Canada and phrase Experience and excellence / Expérience et excellence
CGSB Logo	Trademark logo of black stylized letters of the Canadian General Standards Board
Flag of Canada	Trademark red and white flag of Canada indicating this standard is a publication of the Government of Canada
Government of Canada Logo	Trademark logo of Government of Canada with stylized black letters Canada and a small Canadian flag in red and white
NSC SCC Symbol	A trademark blue circle with a styled white “S” in the center with the words National Standard of Canada Standards Council of Canada / Conseil canadien des normes Norme nationale du Canada
SCC Logo	Trademark logo of black stylized S and the words Standard of Canada Standards Council of Canada Conseil canadien des normes
Figure 1 Clearances for test fan system	A diagram showing the required clearances in front of the intake of the test fan.
Figure 2 General arrangement of the test fan system	A diagram describing the arrangement of the test fan and the pressure measuring device.
Figure 3 Linear plot of data	A graph of sample pressure difference and flow data shown on linear axes.
Figure 4 Logarithmic plot of data	A graph showing the same data from Figure 3 on logarithmic axes.
G.3.1 Test A	A schematic for the setup for Test A for one test fan with two zones
G.3.1 Test B	A schematic for the setup for Test B for one test fan with two zones
G.6.1 Test A	A schematic for the setup for Test A for one test fan with three zones
G.6.1 Test B	A schematic for the setup for Test B for one test fan with three zones
G.6.1 Text C	A schematic for the setup for Test C for one test fan with three zones
G.7.1 Test A	A schematic for the setup for Test A for two test fans with three zones
G.7.1 Test B	A schematic for the setup for Test B for two test fans with three zones

Bibliography

ANSI/ASME. *Measurement Uncertainty – Instruments and Apparatus*, ANSI/ASME PTC 19.1-1985, American Society of Mechanical Engineers, New York, 1986.

ASTM STP 1067 (1990). *The Effects of Wind on Residential Building Leakage Measurement*s, in Sherman, M.H. Ed, *Air Change Rate and Airtightness in Buildings*, pp 132-145, Modera, M.P., Wilson, D.J.

DePani, Sebastiano (1999). *A study on single blower door methods for multifamily buildings in Montreal*. Masters thesis, Concordia University.

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

Schenck, H. *Theories of Experimental Experimentation*. McGraw-Hill, New York, pg. 33, 1961.