BS EN ISO 9972:2015

BSI Standards Publication

Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method

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National foreword

This British Standard is the UK implementation of EN ISO 9972:2015. It supersedes BS EN 13829:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/540, Energy performance of materials components and buildings.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2015

ISBN 978 0 580 74685 7

ICS 91.120.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 September 2015.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN ISO 9972

September 2015

ICS 91.120.10

Supersedes EN 13829:2000

English Version

Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:2015)

Performance thermique des bâtiments - Détermination de la perméabilité à l'air des bâtiments - Méthode de pressurisation par ventilateur (ISO 9972:2015)

Wärmetechnisches Verhalten von Gebäuden - Bestimmung der Luftdurchlässigkeit von Gebäuden - Differenzdruckverfahren (ISO 9972:2015)

This European Standard was approved by CEN on 20 June 2015.

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CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN ISO 9972:2015 E

European foreword

This document (EN ISO 9972:2015) has been prepared by Technical Committee ISO/TC 163 "Thermal performance and energy use in the built environment" in collaboration with Technical Committee CEN/TC 89 “Thermal performance of buildings and building components” the secretariat of which is held by SIS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2016, and conflicting national standards shall be withdrawn at the latest by March 2016.

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Endorsement notice

The text of ISO 9972:2015 has been approved by CEN as EN ISO 9972:2015 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 1, *Test and measurement methods*.

This third edition cancels and replaces the second edition (ISO 9972:2006), which has been technically revised.

Introduction

The fan-pressurization method is intended to characterize the air permeability of the building envelope or parts thereof. It can be used, for example,

a) to measure the air permeability of a building or part thereof for compliance with a design air-tightness specification,

b) to compare the relative air permeability of several similar buildings or parts of buildings, and

c) to determine the air-leakage reduction resulting from individual retrofit measures applied incrementally to an existing building or part of building.

The fan pressurization method does not measure the air infiltration rate of a building. The results of this method can be used to estimate the air infiltration rate and resulted heat load by means of calculation.

Other methods, like tracer gas, are applicable when it is desired to obtain a direct measurement of the air infiltration rate. A single tracer gas measurement, however, gives limited information on the performance of ventilation and infiltration of buildings.

The fan-pressurization method applies to measurements of air flow through the construction from outside to inside or vice versa. It does not apply to air flow measurements from outside through the construction and back to outside.

The proper use of this International Standard requires knowledge of the principles of air flow and pressure measurements. Ideal conditions for the test described in this International Standard are small temperature differences and low wind speeds. For tests conducted in the field, it needs to be recognized that field conditions can be less than ideal. Nevertheless, strong winds and large indoor-outdoor temperature differences are to be avoided.

Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method

1 Scope

This International Standard is intended for the measurement of the air permeability of buildings or parts of buildings in the field. It specifies the use of mechanical pressurization or depressurization of a building or part of a building. It describes the measurement of the resulting air flow rates over a range of indoor-outdoor static pressure differences.

This International Standard is intended for the measurement of the air leakage of building envelopes of single-zone buildings. For the purpose of this International Standard, many multi-zone buildings can be treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones.

International Standard does not address evaluation of air permeability of individual components.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7345, *Thermal insulation — Physical quantities and definitions*

3 Terms, definitions, and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345 and the following apply.

3.1.1
air leakage rate
air flow rate across the building envelope

Note 1 to entry: This movement includes flow through joints, cracks, and porous surfaces, or a combination thereof, induced by the air-moving equipment used in this International Standard (see Clause 4).

3.1.2
building envelope
boundary or barrier separating the inside of the building or part of the building subject to the test from the outside environment or another building or another part of the building

3.1.3
air change rate
air leakage rate per internal volume across the building envelope

3.1.4
air permeability
air leakage rate per the envelope area across the building envelope

3.1.5
specific leakage rate
<envelope> air leakage rate per the envelope area across the building envelope at the reference pressure difference

3.1.6
specific leakage rate
<floor> air leakage rate per net floor area across the building envelope at the reference pressure difference

3.1.7
effective leakage area
leakage area calculated at the test reference pressure differences across the building envelope

3.1.8
specific effective leakage area
<envelope> leakage area per the envelope area across the building envelope at the reference pressure difference

3.1.9
specific effective leakage area
<floor> leakage area per net floor area across the building envelope at the reference pressure difference

3.1.10
to close an opening
to set an opening in close position using the closing device present on the opening without additionally increasing the airtightness of the opening

Note 1 to entry: If there is no way to close the opening (i.e. without closing device), it remains open.

3.1.11
to seal an opening
to make an opening hermetic by any appropriate means (adhesive, inflatable balloon, stopper, etc.)

3.2 Symbols

Symbol	Quantity	Unit
A_E	envelope area	m^2
A_F	floor area	m^2
ELA_{pr}	effective leakage area at the reference pressure difference	m^2
ELA_{Epr}	specific effective leakage area per the building envelope area at the reference pressure difference	m^2/ m^2
ELA_{Fpr}	specific effective leakage area per the floor area at the reference pressure difference	m^2/ m^2
C_{env}	air flow coefficient	$m^3/(h·Pa^n)$
C_L	air leakage coefficient	$m^3/(h·Pa^n)$
n_{pr}	air change rate at the reference pressure difference	h^{-1}
p	pressure	Pa
p_{bar}	uncorrected barometric pressure	Pa
p_v	partial water vapour pressure of water	Pa
p_{vs}	saturation vapour pressure of water	Pa
q_{50}	air leakage rate at 50 Pa	m^3/h
q_{Epr}	specific leakage rate per the building envelope area at the reference pressure difference across the envelope	$m^3/(h·m^2)$
q_{Fpr}	specific leakage rate per the floor area at the reference pressure difference across the envelope	$m^3/(h·m^2)$
q_m	measured air flow rate	m^3/h
q_{pr}	air leakage rate at the reference pressure difference	m^3/h
q_r	readings of air flow rate	m^3/h
V	internal volume	m^3
Δp	induced pressure difference	Pa
Δp_0	zero-flow pressure difference (average)	Pa
$\Delta p_{0,1}$; $\Delta p_{0,2}$	zero-flow pressure difference before and after the test (air moving equipment closed)	Pa
Δp_{0+}; Δp_{0-}	average of the positive and negative values of zero-flow pressure difference (+ and – mean positive pressure and negative pressure across the envelope respectively)	Pa
Δp_m	measured pressure difference	Pa
Δp_r	reference pressure difference	Pa
φ	relative humidity	—
T_0	absolute temperature at standard conditions	K
T_e	external air absolute temperature	K
T_{int}	internal air absolute temperature	K
θ	Celsius temperature	°C
ρ	air density	kg/m^3
ρ_0	air density at standard conditions	kg/m^3
ρ_e	external air density	kg/m^3
ρ_{int}	internal air density	kg/m^3

4 Apparatus

4.1 General

The following description of apparatus is general in nature. Any arrangement of equipment using the same principles and capable of performing the test procedure within the allowable tolerances is permitted. Examples of equipment configurations commonly used are indicated in Annex A.

Periodic calibration of the measurement system, used in this test method, according to manufacturer specifications or to standardized quality insurance systems is required.

4.2 Equipment

4.2.1 Air-moving equipment

Device that is capable of inducing a specific range of positive and negative pressure differences across the building envelope or part thereof. The system shall provide a constant air flow at each pressure difference for the period required to obtain readings of air flow rate.

4.2.2 Pressure-measuring device

Instrument capable of measuring pressure differences with an accuracy of ±1 Pa in the range of 0 Pa to 100 Pa.

4.2.3 Air flow rate measuring system

Device capable of measuring air flow rate within ±7 % of the reading.

Care shall be taken if the principle underlying the measurement of volumetric flow rate is an orifice. The reading of the air flow rate shall be corrected according to air density [see Formula (2)].

4.2.4 Temperature-measuring device

Instrument capable of measuring temperature to an accuracy of ±0,5 K.

5 Measurement procedure

5.1 Measurement conditions

5.1.1 General

There are two modes for this measurement procedure: depressurization or pressurization of a building or part of a building. Regardless of which mode is used, the air leakage of building envelope can be measured. The accuracy of this measurement procedure is largely dependent on the instrumentation and apparatus used and on the ambient conditions under which the data are taken.

NOTE 1 Pressurization means that the pressure inside the building is higher than outside. Depressurization means that the pressure inside the building is lower than outside.

NOTE 2 If the product of the indoor/outdoor air temperature difference, expressed in Kelvin, multiplied by the height, expressed in metres, of the building or measured part of the building gives a result greater than 250 mK, it is unlikely that a satisfactory zero-flow pressure difference can be obtained (see 5.3.3).

NOTE 3 If the wind speed near the ground exceeds 3 m/s or the meteorological wind speed exceeds 6 m/s or reaches 3 on the Beaufort scale, it is unlikely that a satisfactory zero-flow pressure difference can be obtained (see 5.3.3).

5.1.2 Measured extent

The extent of the building or part of the building measured depends on the purpose of the test and is defined as follows.

a) Normally, the part of the building measured includes all deliberately conditioned rooms (i.e. rooms that are intended to be directly or indirectly heated, cooled, and/or ventilated as a whole).

b) If the aim of the measurement is compliance with the air-tightness specification of a building code or standard and the measured extent is defined in this code or standard, the measured extent is defined as in this code or standard.

c) If the aim of the measurement is compliance with the air-tightness specification of a building code or standard and the measured extent is not defined in this code or standard, the measured extent is defined as in a).

d) In special cases, the measured extent can be defined in agreement with the client.

Individual parts of a building can be measured separately, e.g. in apartment buildings, each apartment can be measured individually. However, interpretation of results shall consider that air leakage measured in this way can include flow through leaks to adjacent parts of the building.

NOTE 1 It is possible that an apartment building meets air-tightness requirements, but that one or more individual apartments do not.

NOTE 2 Good practice requires measuring pressures induced in adjoining spaces, such as the attic and basement or adjacent apartments, since air flow into or out of these spaces can be induced by the test method.

5.1.3 Time of measurement

The measurement can take place only after the completion of the envelope of the building or part of the building to be tested.

NOTE A preliminary air permeability measurement of the air barrier of the building under construction can allow leakages to be repaired more easily than after the building has been completed.

5.2 Preparation

5.2.1 Building preparation methods

This International Standard describes several types of test methods depending on the purpose. The preparation of the building depends on the test method selected.

a) Method 1 is the test of the building in use where the natural ventilation opening being closed and the whole building mechanical ventilation or air conditioning opening being sealed.

b) Method 2 is the test of the building envelope where all the intentional openings being sealed, the doors, windows, and trapdoors being closed.

c) Method 3 is the test of the building for a specific purpose, the treatment of the intentional openings being adapted to this purpose according to the standard or policy in each country.

NOTE The choice of the method depends on the purpose of the test. For example, the method 1 could be used in the context of clean rooms, method 2 to compare different construction techniques, and method 3, for compliance with the air-tightness specification of a building code or standard, in the context of calculation of energy performance of buildings.

5.2.2 Heating, ventilation and air conditioning systems and other building equipment

All devices taking air from or rejecting air to outside, which are not used for the intentional (de-) pressurization according to 5.2.5, shall be turned off, e.g. heating systems with indoor air intake, mechanical ventilation and air conditioning systems, kitchen hoods, tumble-dryers, etc. Water traps in plumbing systems shall be filled with water or sealed.

Open fireplaces shall be cleared of ashes.

Take measures to avoid exhaust hazards from heating systems. Take into account heating sources in adjacent apartments.

5.2.3 Intentional openings in the envelope

For the purpose of method 1:

Close all windows, doors and trapdoors in the envelope.

Ventilation openings in the envelope for natural ventilation shall be closed.

Openings for whole building mechanical ventilation or air conditioning shall be sealed, i.e. to seal

a) either the main ducts, between the fan and the building envelope,

b) either all the individual air terminal devices, or

c) the openings to the outside (intakes and exhaust).

Other intentional openings in the envelope including intermittent use mechanical ventilation or air conditioning shall be closed.

Fire-guards and smoke-guards shall be in their normal position of use, e.g. fire-guards and smoke-guards that are usually closed and that open automatically in case of fire remain closed; fire-guards and smoke-guards that are normally open and that close automatically in case of fire remain open.

Openings not intended for ventilation in the envelope, for example, postbox installed at external door or wall, combustion appliance and so on, shall be closed. The cracks in the envelope are excluded.

Do not take any further measures to improve the air-tightness of the building envelope.

For the purpose of method 2:

Close all windows, doors, and trapdoors in the envelope.

Ventilation openings for natural ventilation shall be sealed. Openings for mechanical ventilation or air conditioning shall be sealed as specified for method 1.

All remaining intentional openings in the envelope shall be sealed, except the windows, doors, and trapdoors which remain closed.

For the purpose of method 3:

The intentional openings in the envelope shall be closed, sealed, or open according to the specific purpose of the test (for example, for compliance with the air-tightness specification of a building code or standard).

Openings not intended for ventilation in the envelope shall be closed, sealed, or open according to the specific purpose of the test.

For the purpose of all methods

Make general observations of the condition of the building. Take notes on the windows, doors, opaque walls, roof and floor, position of adjustable openings and any sealing applied to intentional openings.

Table 1 — Conditions of openings in the measurement

	Method 1	Method 2	Method 3
Classification of openings of buildings	**Building in use**	**Building envelope**	**Specific purpose**
Ventilation openings for natural ventilation	closed	sealed	Closed, sealed, or open as specified
Openings for whole building mechanical ventilation or air conditioning	sealed	sealed	Closed, sealed, or open as specified
Openings for mechanical ventilation or air conditioning (only intermittent use)	closed	sealed	Closed, sealed, or open as specified
windows, doors, and trapdoors in envelope	closed	closed	Closed, sealed, or open as specified
openings not intended for ventilation	closed	sealed	Closed, sealed, or open as specified

5.2.4 Openings inside the measured extent

The entire building or part of the building to be tested shall be configured to respond to pressurization as a single zone.

All interconnecting openings (door, trapdoor, etc.) in the part of the building to be tested shall be opened.

For practical and safety reasons, it is allowed to keep some doors closed, for example, the access doors to elevators or to high-voltage cabins.

5.2.5 Air-moving equipment

Connect the air-moving equipment to the building envelope using a window, door, or vent opening. Ensure that the joints between the equipment and the building are sealed to eliminate any leakage.

If the building heating, ventilation and air conditioning system is used as the air-moving equipment, arrange the fans and dampers to allow the system to pressurize or to depressurize the building in a manner such that the total inward or outward air flow rate can be measured (see A.4).

NOTE Proceed carefully when selecting the position of the air-moving equipment. It is possible that the selected door, window, or vent is a major air leak of the building and is excluded from the measurement due to the presence of the air-moving equipment.

5.2.6 Pressure measuring devices

The indoor/outdoor pressure difference is usually measured at the lowest floor level of the building envelope under consideration.

NOTE In tall buildings, it is good practice to measure the pressure difference at the top floor level of the building envelope under consideration as well.

Ensure that interior and exterior pressure taps are not influenced by the air moving equipment. The exterior pressure tap should be protected from the effects of dynamic pressure, e.g. by fitting a T-pipe or connecting it to a perforated box. Especially in windy conditions, it is good practice to place the exterior pressure tap some distance away from the building, but not close to other obstacles.

For measuring the pressure, the tubing shall not be exposed to large temperature differences (e.g. due to the sun).

5.3 Steps of the procedure

5.3.1 Preliminary check

Always check the complete building envelope at approximately the highest pressure difference used in the test for large leaks and failings of temporarily sealed openings. If such leaks are detected, take detailed notes.

Any temporary sealing found missing or deficient, e.g. of heating, ventilation and air conditioning components, shall be fixed at this time.

5.3.2 Temperature and wind conditions

To correct the air flow rate measurement for air density, read the temperature inside and outside the building before, during or after the test.

Record the wind speed or force. Determining wind force by visual assessment of trees, water, etc., in terms of the Beaufort scale (see Table D.1) is sufficient.

5.3.3 Zero-flow pressure difference

Short-circuit the pressure-measuring device and check or adjust the zero reading at the starting of the testing.

Temporarily cover the opening of the air moving equipment and connect the pressure measuring device to measure inside-outside pressure difference. Record the values of the zero-flow pressure difference over a period of at least 30 s (minimum 10 values) and calculate

— the average of the positive values of zero-flow pressure difference, Δp_{01+},

— the average of the negative values of zero-flow pressure difference, Δp_{01-}, and

— the average of all values of zero-flow pressure difference, Δp_{01}.

Repeat this process at the end of the test (to obtain Δp_{02+}, Δp_{02-}, and Δp_{02}).

If the absolute value of Δp_{01+}, Δp_{01-}, Δp_{02+}, or Δp_{02-} is higher than 5 Pa, the test shall be declared not valid. If a test report is produced for such a test, this failure to meet required test conditions shall be stated in the test report.

NOTE The reference pressure value (zero) is outside.

5.3.4 Pressure difference sequence

Uncover and turn on the air-moving equipment.

The test is carried out by taking measurements of air flow rate and indoor-outdoor pressure difference over a range of applied pressure differences in increments of no more than approximately 10 Pa. For each test, at least five approximately equally spaced data points between the lowest and the highest pressure differences shall be defined.

The lowest pressure difference shall be approximately (i.e. with an allowance of ±3 Pa) 10 Pa or five times the value of the zero-flow pressure difference (Δp_{01}), whichever is the greater.

The highest pressure difference shall be at least 50 Pa, but it is recommended that readings are taken at pressure differences up to 100 Pa for best accuracy of calculated results.

However, because of the large size of many non-domestic buildings and practical limitations on the capacity of portable air-moving equipment used to test them, it can be found that a pressure difference of 50 Pa is not achievable. In these cases, either additional air-moving equipment or air-moving equipment with higher capacity should be employed (to increase total capacity) and/or the test may be carried out up to the highest pressure difference that can be achieved with the available air-moving equipment. In such cases, the test shall not be valid unless a pressure difference of 25 Pa can be achieved. Where the highest pressure difference is between 25 Pa and 50 Pa, this shall be clearly recorded in the test report with a statement that the requirements of this International Standard have not been fully met and an account of the reasons why. An alternative solution is to measure large buildings by dividing into some small parts.

It is recommended that two sets of measurements be made: for pressurization and depressurization. However, it is permitted to make only one set of measurements for either pressurization or depressurization and still comply with the requirements of this International Standard.

NOTE 1 It is more precise to take data at higher pressure differences than at lower differences. Therefore, it is important to exercise special care when measurements are taken at low pressure differences.

NOTE 2 It is advisable to check that the condition of the building envelope have not changed during each test, for example, that sealed openings have not become unsealed or that doors, windows, or dampers have not have been forced open by the induced pressure.

6 Expression of results

6.1 Reference values

Depending on the purpose of the test, possibly for compliance to a building code or standard, additional reference values could be used, such as, for example, the wall and roof envelope area, or the envelope area through which heat losses are considered in the calculation of the energy performance of buildings. If such values are used, they shall be defined in the report.

6.1.1 Internal volume

The internal volume, V, is the volume inside the building or measured part of the building.

Overall internal dimensions shall be used to calculate this volume (see Figure 1). No subtraction shall be made for the volume of internal walls or floors. No subtraction shall be made for the volume of the cavities inside the building envelope.

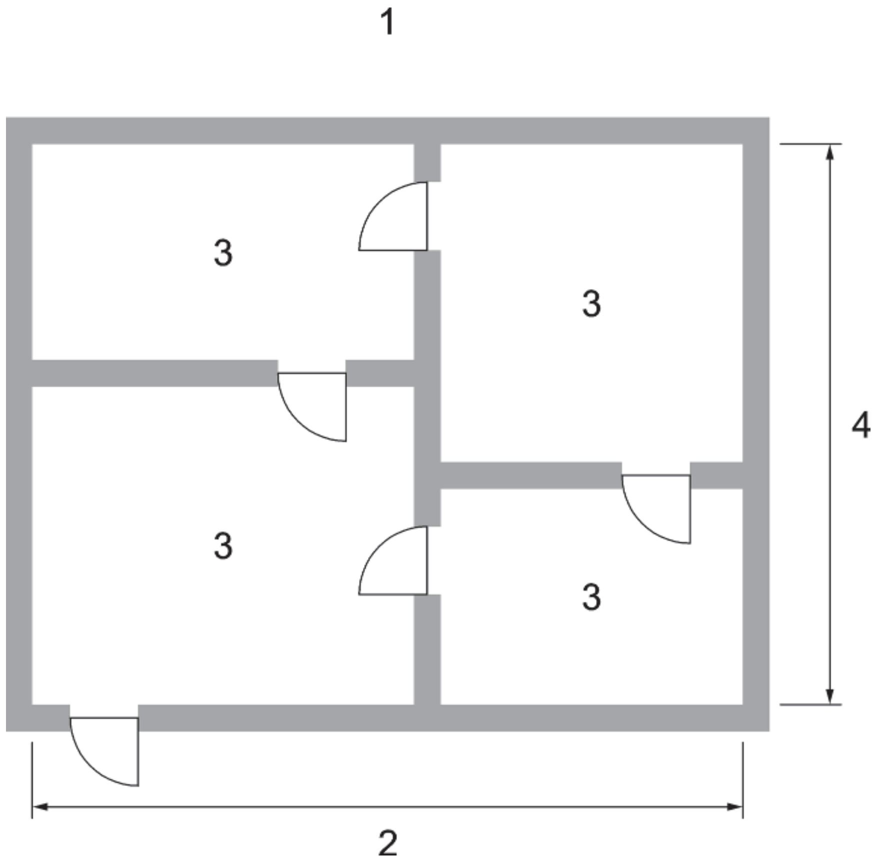
The volume of the furniture is not subtracted.

6.1.2 Envelope area

The envelope area, A_E, of the building or measured part of the building is the total area of all floors, walls, and ceilings, bordering the internal volume. This includes walls and floors below external ground level.

Overall internal dimensions shall be used to calculate this area, e.g. the floor area may be calculated as multiplied the length 2 by the length 4. No subtractions shall be made for the area at junction of internal walls, floors, and ceilings with exterior walls, floors and ceilings (see Figure 1).

NOTE In the context of this International Standard, the envelope area of a row house includes the division wall(s). The envelope area of an apartment in a multiple story building includes the floors, walls and ceilings to adjacent apartments.



Key

1 outside

2 overall internal width

3 inside

4 overall internal depth

Figure 1 — Overall internal dimension of the plan

6.1.3 Net floor area

The net floor area, A_F, is the total area of all floors belonging to the building or measured part of the building. It is calculated according to national regulations.

6.2 Calculation of the air leakage rate

Subtract the average zero-flow pressure difference (offset) from each of the measured pressure differences, Δp_m, to obtain the induced pressure differences, Δp, using Formula (1).

Attention shall be drawn to plus or minus signs.

$$\Delta p = \Delta p_{\mathrm{m}} - \frac{\Delta p_{0,1} + \Delta p_{0,2}}{2} \tag{1}$$

First, convert the readings, q_{r}, of the air flow rate measuring system into measured air flow rates, q_{m}, at the temperature and pressure at the flow measuring device in accordance with manufacturer's specifications:

$$q_{\mathrm{m}} = f\left(q_{\mathrm{r}}\right) \tag{2}$$

Then, convert the air flow rates, q_{m}, to air flow rates, q_{env}, through the building envelope for depressurization using Formula (3).

$$q_{\mathrm{env}} = q_{\mathrm{m}}\left(\frac{\rho_{\mathrm{int}}}{\rho_{\mathrm{e}}}\right) \approx q_{\mathrm{m}}\left(\frac{T_{\mathrm{e}}}{T_{\mathrm{int}}}\right) \tag{3}$$

where

ρ_{int}	is the internal air density, in kg per cubic meters;
ρ_{e}	is the external air density, in kg per cubic meters;
T_{int}	is the internal air absolute temperature, in K;
T_{e}	is the external air absolute temperature, in K.

Convert the measured air flow rate, q_{m}, to air flow rate through the building envelope, q_{env}, for pressurization using Formula (4).

$$q_{\mathrm{env}} = q_{\mathrm{m}}\left(\frac{\rho_{\mathrm{e}}}{\rho_{\mathrm{int}}}\right) \approx q_{\mathrm{m}}\left(\frac{T_{\mathrm{int}}}{T_{\mathrm{e}}}\right) \tag{4}$$

Plot the air flow rate through the building envelope against the corresponding pressure differences on a log-log plot to complete the air leakage graph for both pressurization and depressurization (see Figure 2).

The converted data shall be used to determine the air flow coefficient, C_{env}, and air flow exponent, n, in accordance with Formula (5) using a least squares technique:

$$q_{\mathrm{env}} = C_{\mathrm{env}}\left(\Delta p\right)^{n} \tag{5}$$

where

n	is the air flow exponent;
Δp	is the induced pressure difference, in Pa;
q_{env}	is the air flow rate through the building envelope, in cubic meters per hour.

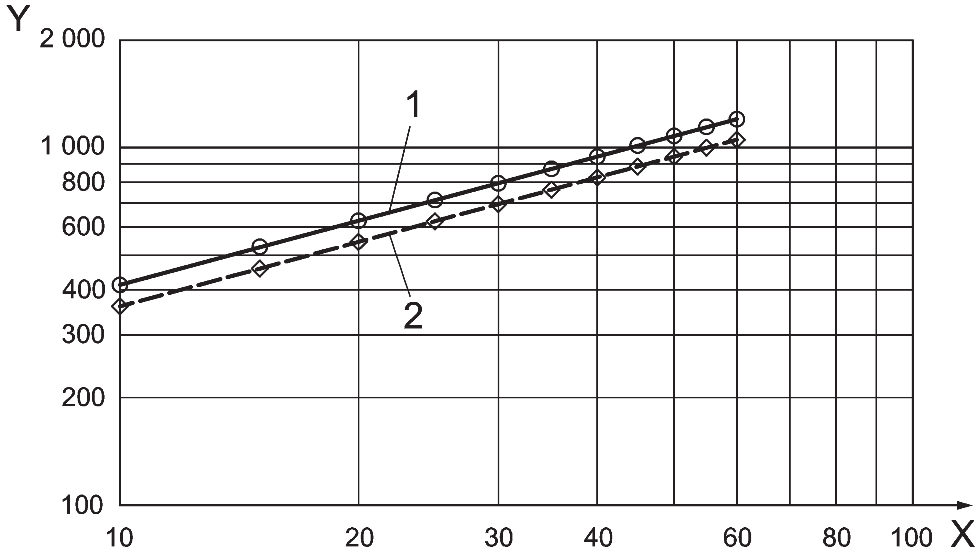
In determining the fit of Formula (5), the confidence intervals of the derived air flow coefficient, C_{env}, and air flow exponent, n, should be calculated.

NOTE C_{env} and n can be calculated using the procedure of Annex C.

Also, the coefficient of determination (of the log-log plot) r^2 shall be calculated.

C_{env}, n, and r^2 shall be calculated separately for pressurization and depressurization.

For test results to be valid in terms of this International Standard, n shall be in the range 0,5 to 1 and r^2 shall be not less than 0,98.



Key

X pressure difference, expressed in Pascal

Y air flow rate, expressed in cubic meters per hour

1 pressurization

2 depressurisation

Figure 2 — Example of an air leakage graph

The air leakage coefficient, C_L, is obtained by correcting to the air flow coefficient, C_{env}, to standard conditions [20 °C and 1,013 × 10^5 Pa], using Formula (6) for depressurization and Formula (7) for pressurization:

$$C_L = C_{env}\left(\frac{\rho_e}{\rho_0}\right)^{1-n} \approx C_{env}\left(\frac{T_0}{T_e}\right)^{1-n} \tag{6}$$

where

ρ_0 is the air density at standard conditions, in kg/cubic meters;

T_0 is the air absolute temperature at standard conditions, in K.

$$C_L = C_{env}\left(\frac{\rho_{int}}{\rho_0}\right)^{1-n} \approx C_{env}\left(\frac{T_0}{T_{int}}\right)^{1-n} \tag{7}$$

Annex B contains the appropriate tables and formulae for the temperature, barometric pressure, and relative humidity dependence of ρ. In general, the effect of barometric pressure is negligible. If it is to be considered, use the uncorrected barometric pressure measured on site or the barometric pressure according to height above sea level. Relative humidity can be set to 0 % (dry air).

The air leakage rate, q_{pr}, at the reference pressure difference, Δp_r, expressed in m^3/h, is determined using Formula (8):

$$q_{pr} = C_L \left(\Delta p_r \right)^n \tag{8}$$

The pressure reference for the air leakage rate is usually equal to 50 Pa.

e.g. $q_{50} = C_L \left(50Pa \right)^n$

6.3 Derived quantities

6.3.1 General

Derived quantities are calculated for the mean air leakage rate at the reference pressure for the pressurization and the depressurization test. However, in case the test has been done for one mode only, use the air leakage rate available.

6.3.2 Air change rate at reference pressure difference

The air change rate, n_{pr}, at the reference pressure difference is calculated by dividing the air leakage rate at the same reference pressure difference by the internal volume according to 6.1.1 using Formula (9):

$$n_{pr} = \frac{q_{pr}}{V} \tag{9}$$

The pressure reference for this derived quantity is usually equal to 50 Pa.

EXAMPLE

$$n_{50} = \frac{q_{50}}{V}$$

6.3.3 Specific leakage rate (envelope)

The specific leakage rate (envelope), q_{Epr}, at the reference pressure difference, is calculated by dividing the air leakage rate at the same reference pressure difference by the envelope area according to 6.1.2 using Formula (10):

$$q_{Epr} = \frac{q_{pr}}{A_E} \tag{10}$$

The pressure reference for this derived quantity is usually equal to 50 Pa.

EXAMPLE

$$q_{E50} = \frac{q_{50}}{A_E}$$

6.3.4 Specific leakage rate (floor)

The specific leakage rate (floor), q_{Fpr}, at the reference pressure difference, is calculated by dividing the air leakage rate at the reference pressure difference by the floor area according to 6.1.3 using Formula (11):

$$q_{Fpr} = \frac{q_{pr}}{A_F} \tag{11}$$

The pressure reference for this derived quantity is usually equal to 50 Pa.

EXAMPLE

$$q_{F50} = \frac{q_{50}}{A_F}$$

6.3.5 Effective leakage area

The effective leakage area, ELA_{pr}, at the reference pressure difference, Δp_r, is calculated using Formula (12):

$$ELA_{pr} = \frac{1}{3\,600} C_L \left(\frac{\rho_0}{2} \right)^{0,5} \left(\Delta p_r \right)^{n-0,5} \tag{12}$$

The pressure reference for this derived quantity is usually equal to 10 Pa.

6.3.6 Specific effective leakage area (envelope)

The specific leakage area, ELA_{Epr}, is calculated with dividing the leakage area at the reference pressure difference by the envelope area according to 6.1.2 using Formula (13):

$$ELA_{Epr} = \frac{ELA_{pr}}{A_E} \tag{13}$$

The pressure reference for this derived quantity is usually equal to 10 Pa.

EXAMPLE

$$ELA_{E10} = \frac{ELA_{10}}{A_E}$$

6.3.7 Specific effective leakage area (floor)

The specific leakage area, ELA_{Fpr}, is calculated with dividing the leakage area at the reference pressure difference by the floor area according to 6.1.3 using Formula (14):

$$ELA_{Fpr} = \frac{ELA_{pr}}{A_F} \tag{14}$$

The pressure reference for this derived quantity is usually equal to 10 Pa.

EXAMPLE

$$ELA_{F10} = \frac{ELA_{10}}{A_F}$$

7 Test report

The report shall contain at least the following information:

a) all details necessary to identify the object tested: postal address (including apartment number if any) and estimated date of construction of the building;

b) a reference to this International Standard, i.e. ISO 9972, and any deviation from it;

c) method of test (1, 2, or 3) and mode of test (pressurization, depressurization, or both);

d) test object:

   1) description of which parts of the building were subject to the test;

   2) internal volume of space subject to the test;

   3) documentation of calculations, such that the stated results can be verified;

   4) the status of all openings on the building envelope, closed, sealed, open, etc.;

   5) detailed description (including means) of temporarily sealed openings, if any;

   6) the position of the sealing of the mechanical ventilation, if any;

   7) the type of heating, ventilating and air conditioning system;

e) apparatus and procedure, i.e. equipment and technique employed;

f) test data:

   1) zero-flow pressure differences $\Delta p_{0,1+}$, $\Delta p_{0,1-}$, $\Delta p_{0,2+}$, $\Delta p_{0,2-}$, $\Delta p_{0,1}$, and $\Delta p_{0,2}$ for pressurization and depressurization test;

   2) inside and outside temperatures;

   3) wind speed, barometric pressure, if it is part of the calculation;

   4) table of induced pressure differences and corresponding air flow rates;

   5) air leakage graph, see Figure 2, for example;

   6) the air flow coefficient, C_{env}, the air flow exponent, n, and the air leakage coefficient, C_L, for both pressurization and depressurization tests;

   7) any derived quantity and corresponding reference value according to national regulation.

g) date of test.

8 Uncertainty

8.1 General

The overall uncertainty of a pressurization test depends on many factors. For any derived quantity, an estimate of the confidence interval should be included in the data analysis.

NOTE Annex C describes a simplified procedure for estimating the uncertainty of the derived quantities of C and n. This uncertainty is not the uncertainty of the measurement.

8.2 Reference value

The accuracy of reference values can be estimated using error propagation calculation.

NOTE Typically, the uncertainty is between 3 % and 10 %.

8.3 Overall uncertainty

The overall uncertainty in the derived quantities described in 6.3.1 to 6.3.7 of a pressurization test made in accordance with this International Standard can be estimated using error propagation calculation. This calculation should include uncertainties of all quantities used for the final result.

NOTE In calm conditions, the overall uncertainty is lower than 10 % in most cases. In windy conditions, the overall uncertainty can reach ±20 %.

Annex A
(informative)

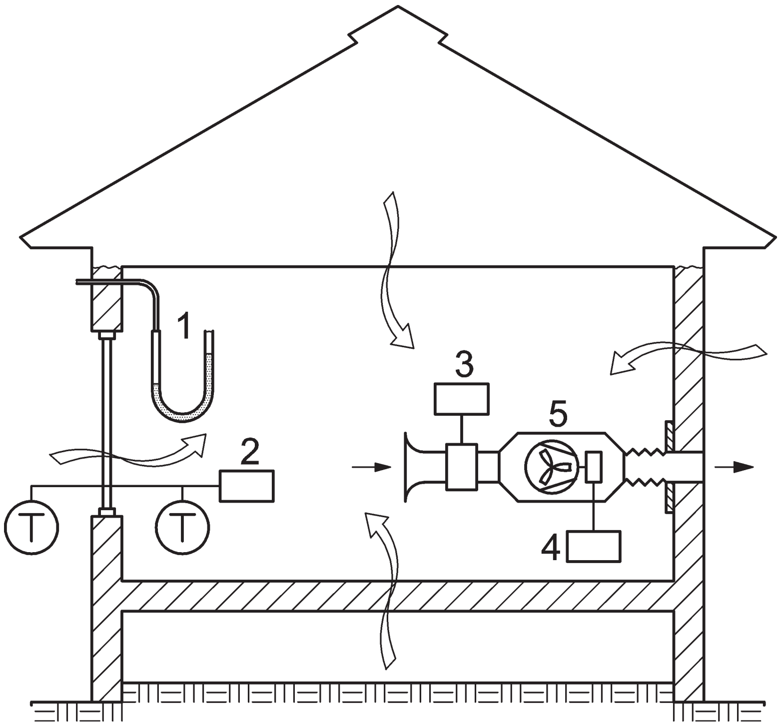
Description of equipment used to pressurize buildings

A.1 General

There are several ways to create a negative or positive pressure in the building envelope. The most common are described in A.2 to A.4.

A.2 Fan and duct system

An assembly, including a fan, a duct and an airflow meter, is connected to the building (see Figure A.1). The size of the air duct and the capacity of the fan are matched so that the linear flow velocity within the air duct falls within the range of measurement of the air flow meter.



Key

1 pressure-measuring device

2 temperature-measuring device

3 airflow measuring system

4 fan control

5 fan

Figure A.1 — Schematic layout of equipment for whole building test

A.3 Blower door

A blower door assembly is a device used for performing envelope permeability measurements. The assembly includes a door or window mount for a fan or blower that is adjustable to fit common door or window openings. The fan or blower should possess a variable speed motor to accommodate the range of required air flow rates.

A.4 Building heating or ventilation and air conditioning system fans

To determine the air permeability of large buildings, it can be possible to use the fan for building ventilation system for pressurization and depressurization of the building. An initial site inspection is advisable to establish the number of main supply (or exhaust) fans, likely air flow performance, the possibility of operating the fans with either 100 % outside air or 100 % exhaust air, and the available means of controlling the supply (or exhaust) air flow rates (e.g. adjusting damper openings or adjusting fan speeds). The duct system can also be examined and suitable locations for air flow rate measurements selected.

Since it is often difficult to satisfy accepted criteria for air flow rate measurements in ducts in an actual heating, ventilation and air conditioning system, the air flow rate, $q_{\text{env,s}}$, can be determined by using a constant injection of tracer gas into the air stream entering the building. The air flow rate, $q_{\text{env,s}}$, expressed in m^3/s (see Figure A.1), is determined using Formula (A.1).

$$q_{\text{env,s}} = \frac{q}{w_{\text{B}}} \tag{A.1}$$

where

q is the tracer gas injection rate, in m^3/s;

w_{B} is the tracer gas concentration, in m^3/m^3.

Particular care is required where dampers and/or fan speeds are normally controlled automatically (e.g. by a building energy management system) to ensure that they can be operated independently as required for the test. Some heating, ventilation and air conditioning system interior grilles or openings might also have to be sealed in order to perform the test.

Annex B
(informative)

Dependence of air density on temperature, dew point,and barometric pressure

The air density, ρ, expressed in kilograms per cubic metre, at a temperature, θ, expressed in degrees Celsius, barometric pressure, p_{bar}, expressed in Pascal, and the relative humidity, φ, expressed in percent, can be obtained by Formula (B.1):

$$\rho = \frac{p_{bar} - 0,37802\, p_v}{287,055\left(\theta + 273,15\right)} \quad \text{(B.1)}$$

where

p_v is the partial water vapour pressure in air calculated using Formula (B.2).

$$p_V = \varphi\, p_{VS} \quad \text{(B.2)}$$

where

p_{vs} is the saturation water vapour pressure in air at a temperature, θ, obtained using Formula (B.3).

$$p_{vs} = \exp\left[59,484\,085 - \frac{6\,790,4\,985}{\theta + 273,15} - 5,028\,02\,\text{In}\left(\theta + 273,15\right)\right] \quad \text{(B.3)}$$

For instrument capable of measuring relative humidity, the required accuracy will be ±5 %; relative humidity value is measured at the outside for pressurizing test, and at the inside for depressurizing test.

Annex C
(informative)

Recommended procedure for estimating uncertaintyin derived quantities

This International Standard contains several derived quantities which are often used to summarize the air permeability of the building or part of the building tested. The following method is recommended: all derived quantities depend on the estimation of the air leakage coefficient, C, and air flow exponent, n, of Formula (5) to Formula (7). Make a logarithm transformation of the variables q and Δp for each reading to determine C and n.

$$x_i = \ln(\Delta p_i)$$

$$y_i = \ln\left(q_i\right) \quad \text{for } i = 1 \ldots N$$

where N is the total number of test readings. Formula (5) then transforms to Formula (C.1).

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

Compute the following quantities:

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

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

$$s_x^2 = \frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2 \tag{C.4}$$

$$s_y^2 = \frac{1}{N-1}\sum_{i=1}^{N}\left(y_i - \bar{y}\right)^2 \tag{C.5}$$

$$s_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right) \tag{C.6}$$

Then, the best estimate of n, $\ln(C)$ and C are given by Formula (C.7) to Formula (C.9):

$$n = \frac{s_{xy}}{s_x^2} \tag{C.7}$$

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

$$C = \exp^{\left(\bar{y} - n\bar{x}\right)} \tag{C.9}$$

An estimate of the confidence intervals of C and n can be determined as follows.

The standard deviation of n is given by Formula (C.10):

$$s_n = \frac{1}{s_x}\left(\frac{s_y^2 - n s_{xy}}{N-2}\right)^{\frac{1}{2}} \tag{C.10}$$

The estimate of the standard deviation of ln(C) is given by Formula (C.11):

$$s_{\text{In}(C)} = s_n \left(\frac{\sum_{i=1}^{N} x_i^2}{N}\right)^{\frac{1}{2}} \tag{C.11}$$

If $T(P, N)$ is the confidence limit of the two-sided student's t distribution for a probability P on N events, then half the length of the confidence intervals at that probability for ln(C) and n is given by Formula (C.12) and Formula (C.13), respectively:

$$I_{\text{In}(C)} = s_{\text{In}(C)} T(P, N-2) \tag{C.12}$$

$$I_n = s_n T(P, N-2) \tag{C.13}$$

The values of the two-sided confidence limits $T(P, N)$ for a student's t distribution are given in Table C.1.

This means that with a probability, P, the air flow exponent, n, lies in the confidence interval ($n - I_n$, $n + I_n$) and the air leakage coefficient, C, lies in the confidence interval given by Formula (C.14):

$$\left\{C \exp\left[-I_{\text{In}(C)}\right], C \exp\left[I_{\text{In}(C)}\right]\right\} \tag{C.14}$$

The estimate of the standard deviation around the regression line [Formula (C.1)] at the value x is given by Formula (C.15):

$$s_y(x) = s_n \left\{\frac{N-1}{N} s_x^2 + \left(x - \overline{x}\right)^2\right\}^{\frac{1}{2}} \tag{C.15}$$

Half of the length of the confidence interval in the estimate of y using Formula (C.1) at any x is given by Formula (C.16):

$$I_y(x) = s_y(x) T(P, N-2) = I_y(\text{In}\,\Delta p) \tag{C.16}$$

Therefore, the air flow rate, q, predicted by Formula (5) at any pressure difference, Δp, with a probability, P, lies in the confidence interval given by Formula (C.17):

$$\left\{q\exp\left[-I_{\text{y}}\,\text{In}(\Delta p)\right], q\exp\left[I_{\text{y}}\,\text{In}(\Delta p)\right]\right\} \tag{C.17}$$

Table C.1 — Two-sided confidence limits $T(P, N)$ for a student's t distribution

N	***P***					
	0,8	**0,9**	**0,95**	**0,99**	**0,995**	**0,999**
1	3,0780	6,3138	12,7060	63,6570	127,3200	636,6190
2	1,8860	2,9200	4,3027	9,9248	14,0890	31,5980
3	1,6380	2,3534	3,1825	5,8409	7,4533	12,9240
4	1,5330	2,1318	2,7764	4,6041	5,5976	8,6100
5	1,4760	2,0150	2,5706	4,0321	4,7733	6,8690
6	1,4400	1,9430	2,4469	3,7074	4,3170	5,9590
7	1,4150	1,8946	2,3646	3,4995	4,0293	5,4080
8	1,3970	1,8595	2,3060	3,3554	3,8325	5,0410
9	1,3830	1,8331	2,2622	3,2498	3,6897	4,7810
10	1,3720	1,8125	2,2281	3,1693	3,5814	4,5787
∞	—	1,6450	1,9600	2,5760	2,8070	3,2910

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

Annex D
(informative)

Beautofort scale of wind (extract)

Table D.1 — Beaufort scale for wind force indication

Beaufort number	Descriptive term	Velocity equivalent at a standard height of 10 m above open flat ground				Specifications			Probable wave height[a]	Probable wave height[a]
		Mean velocity in knots	m s^{-1}	km h^{-1}	m.p.h.	Land	Sea	Coast	m	feet
0	Calm	<1	0 to 0,2	<1	<1	Calm; smoke rises vertically	Sea like a mirror	Calm	—	—
1	Light air	1 to 3	0,3 to 1,5	1 to 5	1 to 3	Direction of wind shown by smoke drift but not by wind vanes	Ripples with the appearance of scales are formed, butwithout foam crest	Fishing smack just has steerage way	0,1 (0,1)	1/4 (1/4)
2	Light breeze	4 to 6	1,6 to 3,3	6 to 11	4 to 7	Wind felt on face; leaves rustle; ordinary vanes moved by wind	Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break	Wind fills the sails of smacks which then travel at about 1 knots to 2 knots	0,2 (0,3)	1/2 (1)
3	Gentle breeze	7 to 10	3,4 to 5,4	12 to 19	8 to 12	Leaves and small twigs in constant motion; wind extends light flag	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses	Smacks begin to careen and travel about 3 knots to 4 knots	0,6 (1)	2 (3)
4	Moderate breeze	11 to 16	5,5 to 7,9	20 to 28	13 to 18	Raises dust and loose paper; small branches are moved	Small waves, becoming longer; fairly frequent white horses	Good working breeze, smacks carry all canvas with good list	1 (1,5)	3 1/2 (5)
5	Fresh breeze	17 to 21	8,0 to 10,7	29 to 38	19 to 24	Small trees in leaf begin to sway; crested wavelets form on inland waters	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray)	Smacks shorten sail	2 (2,5)	6 (8 1/2)

[a] This table is only intended as a guide to show roughly what can be expected in the open sea, remote from land. It should never be used in the reverse way; i.e. for logging or reporting the state of the sea. In enclosed waters, or when near land, with an offshore wind, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves.

Table D.1 *(continued)*

Beaufort number	Descriptive term	Velocity equivalent at a standard height of 10 m above open flat ground				Specifications			Probable wave height[a]	Probable wave height[a]
		Mean velocity in knots	m s^{-1}	km h^{-1}	m.p.h.	Land	Sea	Coast	m	feet
6	Strong breeze	22 to 27	10,8 to 13,8	39 to 49	25 to 31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray)	Smacks have double reef in mainsail; care required when fishing	3 (4)	9$^1/2$ (13)
7	Near gale	28 to 33	13,9 to 17,1	50 to 61	32 to 38	Whole trees in motion; inconvenience felt when walking against wind	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	Smacks remain in harbour and those at sea lie to	4 (5,5)	13$^1/2$ (19)
8	Gale	34 to 40	17,2 to 20,7	62 to 74	39 to 46	Breaks twigs off trees; generally impedes progress	Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind	All smacks make for harbour, if near	5,5 (7,5)	18 (25)
9	Strong gale	41 to 47	20,8 to 24,4	75 to 88	47 to 54	Slight structural damage occurs (chimney pots and slates removed)	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble and roll over; spray may affect visibility	—	7 (10)	23 (32)
10	Storm	48 to 55	24,5 to 28,4	89 to 102	55 to 63	Seldom experienced inland; trees uprooted; considerable structural damage occurs	Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the surface of the sea takes on a white appearance; the tumbling of the sea becomes heavy and shock-like; visibility affected	—	9 (12,5)	29 (41)

[a] This table is only intended as a guide to show roughly what can be expected in the open sea, remote from land. It should never be used in the reverse way; i.e. for logging or reporting the state of the sea. In enclosed waters, or when near land, with an offshore wind, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves.

Table D.1 *(continued)*

Beaufort number	Descriptive term	Velocity equivalent at a standard height of 10 m above open flat ground				Specifications			Probable wave height[a]	Probable wave height[a]
		Mean velocity in knots	m s^{-1}	km h^{-1}	m.p.h.	Land	Sea	Coast	m	feet
11	Violent storm	56 to 63	28,5 to 32,6	103 to 117	64 to 72	Very rarely experienced; accompanied by widespread damage	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected	—	11,5 (16)	37 (52)
12	Hurricane	64 and over	32,7 and over	118 and over	73 and over	—	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected	—	14 (—)	45 (—)

[a] This table is only intended as a guide to show roughly what can be expected in the open sea, remote from land. It should never be used in the reverse way; i.e. for logging or reporting the state of the sea. In enclosed waters, or when near land, with an offshore wind, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves.

Annex E
(informative)

Detection of the leakage location

Detecting the location of leakages is necessary to reduce the leakage area and to estimate the leakage distribution of buildings. The methods are as follows.

a) Subtraction method

The envelope area and/or devices to be detected are covered air barrier sheet. After measuring the leakage area with and without the air barrier sheet, the difference between the both provides the leakage area to be known.

b) Using the infrared thermo viewer

During the test (depressurization), a thermal camera can be used to localize air infiltration as long as there is a temperature difference between indoor and outdoor.

c) Using smoking

The smoke is generated to visualize the airflow through the envelope, devices, etc. and to detect the location of the leakage. This method might need the practical skill, e.g. smoke generation rate.

Also, it might be possible to feel the airflow around the devices, etc. on the envelope with fingers, but it is not consistent because of the individual variation.

d) Using an air velocity meter

During the test (pressurization or depressurization), an air velocity meter can be hold against places on the envelope area or devices where one might suspect leakages. If the instrument shows an air velocity, it is an indication of leakage.

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