Testing buildings for air leakage
CIBSE TM23:2019 (consultation draft)

Foreword

CIBSE TM23 was first published in 2000. At that time it was proposed that air-tightness testing be introduced into the building regulations in England and Wales (Wales at that time not having its own regulations). There was then an International Standard for the test method, but it dated from 1976.

The 2002 revisions to Part L introduced air tightness testing into the Approved Documents as a way of establishing the performance of buildings. That guidance referred to CIBSE TM23 as a source of the test method. However, it was not until 2006 that Regulation 43 of the Building Regulations was introduced to require air tightness testing. Regulation 43 also recognised a competent persons' scheme for air tightness testing. By this time a British and European Standard had been adopted.

Today, airtightness is usually tested by the blower door method at a pressure differential of 50Pa, generally by a competent person belonging to one of two approved schemes. They follow the methodology which evolved from TM23 and is now published by one of the schemes, although there is now a British, European and International Standard for airtightness testing, BS EN ISO 9972-2015.

In recent years an additional test method to supplement the blower door test has been developed and evaluated for field use. The low pressure pulse test applies a pressure pulse to the building envelope and measures the pressure response in the building volume following the release of the pressure pulse. It dynamically measures building air leakage directly at a lower pressure differential of 4Pa, which is more representative of conditions that properties are likely to experience.

As part of the package of proposals presented with the Government consultation *The Future Homes Standard: changes to Part L and Part F of the Building Regulations for new dwellings* it is proposed that the test methodology should be published independently of the approved schemes, and that the low pressure pulse method should also be included in the test method publication and recognised by government.

The MHCLG consultation is seeking views on introducing the Pulse test as an approved method of airtightness testing for new dwellings with a designed airtightness of between 1.5 $m^3/m^2/h$ and the maximum allowable airtightness value.

To ensure that the approved methodology for airtightness testing is independent of all organisations with an associated competent person scheme, Government proposes approving as the airtightness testing methodology a revised edition of CIBSE TM23.

This revised draft of TM23 has been produced in response to this. As well as containing details of the fan pressurisation test method and references to the BS EN ISO standard for such tests, it also contains a section on the low pressure pulse methodology. If the Pulse method is accepted as an approved method, then the relevant section of TM23 will be referenced in the Building Regulations and associated guidance.

CIBSE is therefore consulting on the proposed revisions to TM23. We are inviting comment on the draft and welcome constructive suggestions that seek to improve the draft. The revised draft has been thoroughly updated in-line with established industry practices.

The scope of this revised guidance is to:

- Provide an introduction to the importance of the relationship between building energy efficiency, air tightness and ventilation
- Describe the Government approved test method(s) and test procedure(s)
- Provide additional guidance on building airtightness.

CIBSE welcomes comment on the this updated version of TM23.

A template is available for submitting comments on the draft.

The draft is open for comment until 10th January 2020, which is the closing date for the consultation on Part L, Part F and the proposed Future Homes Standard.

NOTE: A full table of contents will be added prior to publication, and the TM will be indexed.

1 Introduction

Ventilation of buildings is a subject of increasing interest because of its impact on effective building performance, occupant health and comfort and the increasing focus on energy consumption and carbon emissions from buildings. One particular reason is the increasing attention to ventilation in Building Regulations and Standards, driven by the twin concerns of occupant wellbeing and energy efficiency. There is also a growing awareness of the connection between ventilation and the building envelope.

Ventilation provides fresh air for occupants, dilutes pollutants, and exhausts heat gains. In leaky buildings much of the required ventilation is provided by fortuitous air leakage, usually referred to as air infiltration. In the design and construction of modern buildings the aim is to provide an airtight envelope and to introduce ventilation in a deliberate and controlled way, either naturally or by mechanical means or by a combination of both.

Failure to balance air infiltration and controlled ventilation in a building can lead to:

- a significant increase in energy use
- inability of the heating system to meet comfort levels
- cold draughts
- failure of the designed ventilation system, whether it be natural or mechanical
- polluted air entering the building
- reduced thermal performance of the construction.

For these reasons and others, the requirement to measure the air leakage of new domestic and non-domestic buildings was introduced into building regulations and standards in recent years. This has led to wide spread improvements throughout the industry with designers, specifiers, consultants, product manufacturers, site teams and testers all increasingly able to construct and indeed retrofit buildings to ever better levels of airtightness.

However, when increasing the airtightness of the building envelope, designers and specifiers must ensure that adequate ventilation is provided The requirements for non-domestic buildings and dwellings differ from dwellings due to their patterns of occupation and use. Adequate means of ventilation for combustion appliances and for the removal of moisture from dwellings should always be considered.

2 Aim

This guidance addresses air leakage testing of both non-domestic buildings and dwellings. It describes two currently available test methods, the fan pressurisation method which has been used for over twenty years, and the low pressure pulse method, which has been developed more recently.

The guidance describes the analysis required to determine the air permeability and air change rate of a building at a given internal to external reference pressure. This includes a description of these two parameters and how they are used to show compliance with regulations and for air infiltration modelling. There is also guidance on how to interpret the test results to determine an accepted measure of air leakage.

Guidance is given on how to design to minimise air leakage in both domestic and non-domestic buildings.

Consultation note: The original edition of TM23 provided benchmark figures for air leakage indices and air permeability values for comparison across a range of common building types. Given the extensive industry experience with air tightness testing there is much greater knowledge and understanding of the subject and of typical air tightness performance of buildings. CIBSE would welcome feedback on what level of guidance on design for airtightness and leakage diagnostics would be useful within this TM..

3 Current Standards

When the first edition of this guidance was published, there was one recognised test method, and the international standard dated from 1976. It had not been adopted in the UK.

There is now one internationally adopted standard for air tightness testing using fan pressurisation of a building which is BS EN ISO 9972:2015 (1), Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method.

This is the latest edition of the standard, first published in 1976, and also supersedes BS EN 13829, which had the same title. As a European Standard it is automatically adopted as a British Standard, and the 2015 revision brought the content of the European and International test methods into alignment.

BS EN ISO 9972:2015 is intended for the measurement of the air permeability of buildings or parts of buildings in the field. It specifies the use of mechanical pressurisation or depressurisation 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. More specific details of the limits of its applicability are set out in the Introduction to the Standard.

BS EN ISO 9972:2015 is intended for the measurement of the air leakage of building envelopes of single-zone buildings. For the purpose of the 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.

For low pressure testing a new method of test, the low pressure pulse method, has been developed as detailed in this guidance and as part of the package of proposals presented with the Government consultation *The Future Homes Standard: changes to Part L and Part F of the Building Regulations for new dwellings*. It is proposed that the test methodology should be published independently of the approved schemes, and that the low pressure pulse method[1] should also be included in the test method guidance and be recognised by government. In addition, a proposal for a new formal standard for the low pressure pulse method is also currently being considered for development by BSI.

The low pressure pulse method is included in this guidance to provide an alternative method where appropriate, as discussed below.

4 Definitions

For the purposes of this document, the following terms and definitions apply:

- **Airtightness** is the term used to describe the tendency of a building to admit air or allow it to escape in an uncontrolled manner. The smaller the **air leakage** for a given pressure difference across a building, the tighter the **building envelope**.
- **Air Leakage** – the amount of air going into or out of a building when subject to a pressure differential, which may be expressed as the air leakage rate.
- **Building Envelope** – the boundary or barrier which separates the **internal volume** (or building volume) subject to the test from the outside environment or another part of the building not under test.
- **Specific leakage rate** – the **air leakage** measured at a specific pressure differential across the **building envelope**.
- **Air Change rate**, Nx - the air leakage rate per unit of time, usually one hour (m^3h^{-1}), of air from a space per cubic metre (m^3) of **internal volume**, for a specified internal to external pressure difference.
  NOTE: air change rate of 10 h^{-1} at 50 Pa or 2 h^{-1}at 4Pa.
- **Air Permeability**, APx – the air leakage rate per unit of time, usually one hour (m^3h^{-1}) of air from a space per square metre (m^2) of **building envelope** area (including the solid floor), for a specified internal to external pressure difference. For example, AP50 = 10$m^3h^{-1}m^{-2}$ at 50 Pa or AP4 = 2$m^3h^{-1}m^{-2}$ at 4Pa.
- **Internal Volume**, V – the total volume within the conditioned space of a building, enclosed by the building envelope, given in m^3.
  NOTE 1: this includes the heated, cooled or mechanically ventilated spaces within a building or part of a building being tested, and excludes lofts, attics, basements and attached structures which are not conditioned.
  NOTE 2: may be referred to as Building Volume
- **Envelope Area**, - the area of the **building envelope**.

1 https://buildtestsolutions.com/technologies/pulse-air-permeability-measurement-system/

NOTE: this may include the area of a solid floor or basement walls, as specified in the detailed test method.

- **Specific effective leakage area –** the leakage area (m^2) across the **building envelope** or the net floor area at the test reference pressure differences.
  NOTE: the area to be used is specified as part of the test procedure.

Consultation note: suggestions are invited for additional terms that need to be defined, along with draft definitions.

5 Air leakage and air-tightness

5.1 What is air leakage?

Air leakage is the fortuitous infiltration and exfiltration of air through a building envelope or component due to the porosity of building fabric materials, interfaces between materials and components and imperfections in the construction of the building. It takes place, for example, through the following:

- porous constructions such as bricks, blocks, mortar joints
- cracks around and interfaces between doors, windows, walls, panels, and cladding details
- interfaces between the structure and the construction envelope
- service entries such as pipes, ducts, flues, ventilators and cables
- joist connections within intermediate floors
- inadequate, poorly installed or damaged primary air barriers or vapour control membranes

Air leakage reduces the thermal performance of a building by providing a ventilation path within the construction for heat loss, therefore ‘short-circuiting’ the thermal insulation, and reducing the overall thermal performance. Air leakage can account for as much as half of the overall heat loss from a building, and with the increases thermal performance of building fabric in the past two decades is the dominant component in controlling heat loss. Measured air leakage is also an important indicator of build quality, with low leakage generally indicating a better build with a complete, continuous and uninterrupted air barrier.

Air leakage under natural conditions is typically referred to as infiltration and is caused by pressure difference effects driven by temperature difference, wind and/or stack effect. Wherever infiltration occurs, there is a corresponding exfiltration somewhere else in the building. During the summer, infiltration can bring humid, outdoor air into buildings. In winter, exfiltration can result in moist indoor air moving into cold wall cavities and can result in condensation and ultimately mould or rot. This can have significant health effects and cause structural defects to develop.

Given the variability of temperature, wind, buoyancy and stack effects as well as the bearing that local sheltering effects can have on these factors, direct measurement of air infiltration as a single point in time measurement often provides limited information. For this reason, air leakage is a more general term used to describe uncontrolled flow of air through gaps and cracks in the fabric of a building. Air leakage testing measures the air tightness of a building or the air leakage rate at a given induced pressure difference.

5.2 Why measure air leakage?

There are four main reasons for measuring air leakage of buildings:

- To identify ways to reduce heat loss: uncontrolled air leakage can account for up to half of the space heating or cooling load within a building and may deliver an excessive level of background ventilation for the fresh air needs of the occupants. This will be particularly prevalent during times of high wind speed or large differences between internal and external air temperature, resulting in a major increase in the heating or cooling load of the building.
- To avoid occupant discomfort and health risks: Air leakage can give rise to localised draught discomfort for people located near the area of leakage: for example, near poorly sealed windows or leaky roofs. This in turn may trigger increased heating demand, which is a problem for vulnerable occupants in buildings where fuel poverty is also likely. A very airtight inadequately ventilated building can also give rise to poor indoor air quality with stale, moisture laden polluted air unable to escape. Equally, a very leaky building can allow polluted external air to enter a building and for internal conditioned air to escape in an uncontrolled manner.
- To control ventilation: Excessive air leakage makes it difficult to control ventilation systems. Air leakage affects the performance of both natural and mechanical ventilation systems in buildings, either providing too little or too much make-up air and generally making systems become very unpredictable, inefficient and unreliable. Problems may also arise due to the location of air intakes to a building where there are local sources of pollution, where air leakage can provide an unplanned path for polluted air to enter the building.
- To size heating, ventilation and air-conditioning (HVAC) systems accurately: Uncontrolled air leakage has an impact on the sizing of HVAC systems. In some cases, air leakage from a building may be so great that the HVAC system cannot provide comfort conditions during extreme seasonal temperature or wind conditions. Systems are often 'oversized' to offset uncertainties over air leakage. This is inefficient and may make compliance with energy efficiency requirements of building codes hard to achieve.

With ready access to and increased regulatory requirements for air tightness testing, best practice is for buildings to be designed for low levels of air leakage and tested to demonstrate that those levels have been achieved.

5.3 Principles of air leakage test measurement

There are currently two methods of testing air leakage of buildings, the fan pressurisation test and the low pressure pulse test. Each offers particular benefits and drawbacks, and selection of the preferred method should be based on the intended application in any specific case.

Air leakage testing of buildings was first widely reported in the US (2) and then introduced into the UK in the late 1980s and 1990s (3-9). This was originally based upon the mounting of a fan (or fans) in a suitable aperture within the building envelope which were used to pressurise the building from the outside. The pressure applied to achieve a constant pressure difference between the inside and outside of the building, usually 50 Pa, is measured. The fan speed is increased in increments up to the maximum and then decreased in steps from the maximum. At each fan speed the air volume flow rate through the fan (equal to the air leakage through the building envelope) and the pressure difference across the building envelope is recorded. This method is intended to characterise the air permeability of the building envelope.

The fan pressurisation test can be used to measure the air permeability of a building (or part of it) for compliance with a design airtightness requirement. It can be used to compare the relative air permeability of several similar buildings or parts of buildings. It can also be used to determine the air-leakage reduction resulting from individual retrofit measures applied incrementally to an existing building or part of a building.

The fan technique provides a reliable high pressure stress test of the building envelope and is very effective in diagnosing air leakage paths. However, it does not measure the air infiltration rate of a building and it does not provide reliable measurements at low pressure. The results of this method are typically used to estimate the level of air leakage at ambient pressure levels and resultant space heating and ventilation implications by means of calculation. This is explained further in section 7.

The low-pressure pulse (LPP) method is a compressed air based dynamic technique used to measure air permeability directly at an internal/external pressure difference of 4 Pa. The test system releases a measured amount of air from a portable compressed air receiver into a building, generating a flow rate through the gaps and cracks in the building envelope.

The change of internal pressure in the building due to this flow is seen as a pulse and its representation is characteristic of the building's air leakage in the 1–10 Pa range. In contrast to the fan pressurisation method, this technique provides a reliable direct measurement of the ambient air leakage rate of a building allowing for reliable assessment of as-inhabited conditions, background ventilation rates and space heating requirements. However, as an instantaneous dynamic test the LPP method cannot provide a means of sustained pressurisation for leakage path diagnostic purposes.

Other methods, like tracer gas methods, are applicable when a direct measurement of the air infiltration rate is required. A single tracer gas measurement, however, gives limited information on the performance of ventilation and infiltration of buildings. These methods are typically used in a vacant property where a concentration of inert gas is released into a building or part of it whilst a series of sensors are used to measure the natural rate of concentration decay. This rate of decay is fundamentally determined by the level of air tightness of the building envelope, but is also heavily affected by point in time local factors such as the specific internal/external temperature difference, site wind conditions, building shielding factor and terrain condition.

In selecting the most appropriate measurement method, key considerations might include:

- The purpose of the measurement, for example whether it is for determining compliance with a specific design air permeability specification at a given reference pressure, or

- Whether the measurement is intended to understand the as-inhabited air infiltration rate, ventilation needs and resultant heating loads and occupant comfort, or
- As a means to assess construction build quality and/or to determine the air-leakage reduction resulting from retrofit measures application to an existing building or part of a building.
- If the tester or client is looking to compare the relative air permeability of several similar buildings or parts of buildings and therefore looking to be consistent with the measurement method applied.
- The weather conditions, exposure and occupancy situation of the given test building.

This guidance provides further detail concerning both the fan-pressurisation method and low-pressure pulse method.

5.4 Preparing a building for testing

Regardless of test equipment used, the following building measurement and preparation and test condition limitations should be observed for an air leakage measurement to be valid.

5.4.1 Building measurement and preparation

Where measurements of area or volume are required, then the tester should take reasonable steps to confirm that any measurements supplied by the client are accurate. This should always include some measurement on site at the time of test to confirm the accuracy of the values provided.

The results of the test rely on accurate measurement, and where the tester has concerns about the accuracy of measurements provided they have a responsibility to seek accurate data. If they are unable to do so, they should record their concerns on the test report. 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.

5.4.1.1 Internal volume

The internal volume, V, is defined above and also in BS EN ISO 9972:2015. It is the total internal volume of the conditioned space that is being tested. It is important to note that internal dimensions are to be used and no subtraction is to be made for the volume of internal walls, floors, furniture, voids or cavities inside the conditioned building envelope.

Consultation note: comment is invited on whether it would be helpful to add a worked example and visual illustration.

5.4.1.2 Envelope area

The building envelope area is defined above and also in BS EN ISO 9972:2015. It is the boundary or barrier separating the interior volume of the building from the outside environment. It is defined as the internal surface area of the external facade and is calculated from the dimensions bordering the internal volume of the building under test.

This area is given by the total of the walls, top floor ceiling (or underside of roof) depending on where the air barrier is, walls and floors below external ground level and includes the area of the lowest floor, with no deductions made for the junction of internal walls, floors, and ceilings with exterior walls, floors and ceilings.

Furthermore, the envelope area includes the division wall(s) between terrace, end terrace and semi-detached properties. The envelope area of an apartment in a multiple story building includes the floors, walls and ceilings to adjacent apartments.

The extent of the building is the conditioned space i.e. the spaces directly heated or cooled. The entire air barrier around this is what is being measured as part of the compliance test.

Consultation note: comment is invited on whether it would be helpful to add a worked example and visual illustration.

5.4.3 Building preparation

Prior to an air leakage test being undertaken for compliance purposes, the building must be prepared to allow effective pressurisation and/or depressurisation in order for representative results to be obtained.

Measurement will typically take place only upon completion of the building or the part being tested. However, a preliminary air leakage measurement of the building under construction can allow leakages to be identified and addressed more easily than after the building has been completed.

Consultation note: comment is invited on whether it would be helpful to add a checklist of key points of building preparation.

For tests undertaken in England to meet the requirements of regulation 43 of the building regulations, the approved method is BS EN ISO 9972:2015 method 3. The purpose of the test is to demonstrate the intrinsic airtightness of the constructed building fabric.

External doors, windows and other purpose-made openings in the building envelope, including letterboxes, should be closed. Ventilation openings and louvres intended for natural or intermittent ventilation shall be closed or temporarily sealed where no such operable closing mechanism exists.

Where appropriate, combustion appliances must be switched off and any open flues and air supply openings temporarily sealed (flues from room-sealed appliances do not need to be sealed: e.g. balanced flue boilers in dwellings). Any other devices actively extracting or supplying air shall also be switched off e.g. mechanical ventilation, kitchen hoods, tumble dryers, etc. Fire and smoke dampers should remain in their default position for the test.

Openings for whole building mechanical ventilation or air conditioning shall be sealed:

- Either the main ducts, between the fan unit and the building envelope
- Either all the individual terminal devices
- Or at the openings to the outside (intakes and exhaust)

Open fire places shall be cleared of ashes and chimney flues should be sealed with an expandable balloon. Internal cupboards may be closed. Drainage traps must contain water.

Temporary measures to further improve the air-tightness of the building envelope for the duration of the test, such as sealing of sockets, downlights, bath panels and shower trays, loft hatches, access panels and doors is not permitted. Where defects in the fabric are found, then it should be noted that the use of short-lived materials to effect a repair may not be compliant with Regulation 7 of the Building Regulations.

The tester shall always record all temporary sealing and declare, with photos, as part of the test report.

5.5 Test conditions
The proper use of any air leakage measurement technique requires knowledge of the principles of air flow and pressure measurements as well as the external factors that can affect measurement results. Ideal conditions for the testing described within BS EN ISO 9972:2015 are small temperature differences and low wind speeds. For tests conducted in the field, it needs to be recognised that field conditions can be less than ideal. Strong winds and large indoor outdoor temperature differences should be avoided.

Typically, an air leakage test provides a measure of the air leakage at an internal to external pressure difference greater than that normally found during natural conditions of wind and temperature (stack effect). The test also relies on an assumption that the pressure difference is uniform over the entire building envelope. This imposes certain limiting conditions on the external climate parameters that prevail during an air leakage test. Ideally, the internal to external air temperature difference should be less than 10°C, and the near ground wind speed should be less than 6 $m.s^{-1}$. For conditions outside this range, the naturally imposed internal to external pressure differences are too high, and the variation of conditions (due to wind speed and stack effect) will make it difficult to obtain an accurate measurement of pressure difference or air flow rate.

High-rise buildings are generally more adversely affected than low-rise buildings. A hand-held omnidirectional anemometer can be used to measure wind speed, at a suitable location on site, which should be outside the local effects of buildings or site topography. Corrections to the measured airflow rate should be applied for internal and external temperatures (see Appendix A1), and barometric pressure (though usually negligible).

Internal and external temperature, wind speed and barometric pressure should be measured and recorded at the start of every test.

Before starting any test, check that:
- average near ground wind speed is below 6 $m.s^{-1}$
- combustion appliances are turned off and flues sealed
- all internal doors are open
- drainage traps contain water and the building fabric is complete
- all external doors, windows, ventilation openings are closed
- all mechanical ventilation systems are turned off and sealed.
- all heating and cooling systems are switched off at source.
- internal and external temperature, wind speed and barometric pressure has been recorded
- photos have been taken and notes recorded for all temporary sealing

6 Test methods

6.1 Test equipment and calibration

There is a choice of equipment available for each of the methods described in the document. For the fan pressurisation method there are examples of equipment in ISO 9972:2015. For the pulse method further details are available online[2] .

BS EN ISO 9972:2015 specifies calibration requirements. It states a requirement that periodic calibration of the measurement equipment being used for the test method should be undertaken “according to manufacturer specifications or to standardised quality assurance systems”.

Testers should use, service, maintain and calibrate this equipment in accordance with the manufacturer’s instructions. Where checks on performance are made these should be traceable to national standards.

6.2 Fan-Pressurisation Method

Fan pressurisation testing is to be carried out in accordance with BS EN ISO 9972:2015.

Fans currently used in pressure testing dwellings typically have maximum air volume flow rates (at 50 Pa) of up to about 1.0 $m^3.s^{-1}$. For domestic testing, there is usually only a single fan, (see figure xx) with airflow rate measured by means of pressure tappings or, for low flow rates, the pressure drop across a flow restrictor plate.

Consultation note: comment is invited on whether it would be helpful to add a figure here.

Fans currently used in pressure testing non-domestic buildings typically have maximum volume flow rates (at 50 Pa) of up to 30 $m^3.s^{-1}$. Some systems use multiple medium-sized fans, while others use a single large fan (see Figure xx). The airflow is usually measured by means of pressure tappings or flow grids situated in a long duct attached to the fan.

Consultation note: comment is invited on whether it would be helpful to add a figure or figures here.

Whatever fan system is used, to meet the standard requirements it should provide a constant air flow at each pressure difference for the period required to obtain readings of air flow rate. For the test to be valid the fan(s) used for pressure testing a building must be capable of achieving at least a 25 Pa pressure difference during the test. If a pressure difference of 50Pa cannot be achieved the measured results may be extrapolated to 50 Pa reference pressure difference. See section 7 for further details on calculation.

For testing large multi-storey office buildings it may be possible and more practical to use the building’s own HVAC system air supply fan(s) to pressurise the building, with the building’s exhaust fans turned off and the external exhaust grille sealed off. The building’s fans should be capable of creating a pressure difference across the building envelope of at least 60 Pa. Also, there should be a method of controlling the air volume flow rate by a fan speed controller or control dampers in series with the fan(s). For this approach, accurate

2 https://buildtestsolutions.com/technologies/pulse-air-permeability-measurement-system/

measurement of the HVAC air volume flow rate can be done either by a tracer gas dilution method or by a method based on measurement of average total pressure across the duct and static pressure.

6.2.1 Pressure measurement

The pressure difference created by the fan between the inside and outside of the building should be measured with a micromanometer having an operating range of at least 0–100 Pa and an accuracy of ±1 Pa. To measure the external pressure a small-bore tube (6 mm maximum internal diameter), terminated by a T-piece or perforated box to minimise dynamic pressure effects caused by wind, should be extended away from the building (if possible 10m). The internal pressure tube must be placed inside the building out of direct influence of the pressurisation fan.

6.2.2 Carrying out a fan-pressurisation test

If using a test fan, then an external door must be selected and the fan(s) installed, along with the airflow and pressure measuring apparatus. The air leakage of that door will not be included in the test result. In non-domestic buildings it is conventional only to pressurise the building because of the size of the fan equipment required (see Figure xx). However, equipment for testing dwellings is considerably more compact (see Figure xx), allowing both pressurisation and depressurisation tests to be carried out if required.

Consultation note: comment is invited on whether it would be helpful to add a figure or figures here.

If the building HVAC system is being used to pressurise the building, methods of speed control and accurate airflow measurement must be identified or otherwise installed. Automatic control of fan speed or dampers must be disabled during the test. The building HVAC exhaust fans need to be switched off and the exhaust grilles sealed.

Indoor and outdoor pressure tappings connected to the micromanometer are required.

6.2.3 Instrumentation

Instrumentation is required to measure:

— airflow rate through the fan
— internal to external pressure difference
— temperature inside the building (at least one sensor per floor)
— outside temperature
— wind speed
— barometric pressure.

6.2.4 Test Procedure

The test is carried out broadly as follows, observing the requirements of the standard at all times.

1. With the fan turned off and temporarily sealed off with plastic sheeting or a purpose-made cover, measure the pressure difference at zero airflow rate over a period of at least 30 seconds acquiring a minimum of 10 values
2. Uncover and start the fan, increasing the speed slowly until a pressure difference of 55 to 60 Pa is obtained. Sometimes this might not be achievable owing to either the

size or the leakiness of the building; no test value can be calculated if the maximum pressure difference obtainable is less than 25 Pa.

3. Check that no temporarily sealed openings have started to leak; reseal if necessary.
4. When the readings have stabilised, with the fan speed constant, take averaged values of pressure difference and airflow rate.
5. Reduce the fan speed and take further sets of readings over at least seven (ideally ten) approximately equally spaced values of pressure difference, with none lower than 10 Pa. Measurements shall be stable for 30 second before the reading is taken.
6. Check and rectify the failure of sealing of building openings during the test, usually indicated by anomalous data.
7. It is recommended that the test is repeated for both pressurisation and depressurisation but this is not mandatory and is at the discretion of the tester.

6.2.5 Data analysis

The data obtained from a fan pressurisation test consists of the volume flow rates for a range of internal/external pressure difference values. A plot of volume flow rate (Q) versus internal/external static pressure difference (ΔP) is then produced. The measured data points lie on a curve (see Figure xx), called the air leakage characteristic curve of the building. The relationship between the fan flow rate (and hence the air leakage of the building) and the induced internal–external pressure difference is of the form

$$Q = C\,(\Delta P)^n$$

where Q is the measured air volume flow rate ($m^3\ h^{-1}$); C, *n* are constants that relate to the specific building under test; and ΔP is the internal/external pressure difference (Pa).

C and *n*, for a specific test, are normally found by transforming the above equation using natural logarithms. This gives the expression

$$\ln(Q) = \ln(C) + n.\ln(\Delta P)$$

Note: for dwellings it is common for the pressurisation and depressurisation curves to differ by as much as 10% or more.

6.3 Low-Pressure Pulse Method (LPP)

The low pressure pulse technique applies a pressure pulse to the building envelope and measures the pressure response in the building volume. This may be done using one or several bursts of air and measuring the response. The pulse is usually achieved by the release of air from a compressed-air tank for a brief period, typically 1-2 seconds. The level of compression and thus the amount of air released is set by the test operative and will typically be in the range of 3 to 10 bar[3] from a 40 litre air receiver (120 - 400 bar / litres).

A temporary internal/external pressure difference is created across the building envelope, with a maximum difference of typically 10-15Pa, down to around 1-3Pa, depending on the

[3] Equivalent to 58 – 145 psi

size and leakage level of test building. During the brief air pulse, multiple data points are gathered at a range of building pressures, enabling a graph of Air Leakage Rate vs Building Pressure to be plotted. Leakage at low pressure, normally 4Pa, can then be quoted.

The room pressure sensing range of the LPP equipment is typically ±25 Pa. In instances where the air pulse released over-pressurises the building or enclosure being tested, the starting tank pressure should be adjusted so as to release less air and create a smaller air pulse. Where testing very small or particularly air-tight enclosures, it may also be necessary to prolong the valve open period to approximately 4 seconds in order to achieve an even lower air pulse flow rate that is more akin to the lower air leakage rate of the envelope in question.

The LPP accounts for wind and buoyancy effects by measuring background pressure before and after a Pulse test, and predicting pressure trends during the pulse period using these measured background pressures.

The LPP test occurs entirely within a building envelope and requires no penetrations to the outside or any external pressure tapings. The equipment is positioned approximately in the centre of the ground floor of the enclosure being tested in order to ensure an evenly distributed and non-turbulent air pulse release.

For testing large non-residential buildings, multiple LPP air receivers may be evenly distributed throughout the building or area under test. These are then charged and released simultaneously to create an evenly distributed air pulse across the building. A large volume of air needs to be released in order to create a detectable, reliable 4+ Pa rise in the background pressure of the building, but the measurement approach remains the same.

6.3.1 Pressure Measurement

The low pressure pulse method measures building leakage across a range of low pressures (2 – 15 Pa) in a dynamic manner. This requires a large number of data points to be logged in a relatively short time. Nevertheless, the results can be plotted and presented in the same format as the fan pressurisation method. Building geometry measurement and preparation is also the same for both methods.

The air permeability at 4 Pa as measured directly by the LPP method is widely considered the typical pressure differential across a building envelope over the course of the seasons (i.e. a representative whole year average). Since the test exerts no abnormal pressurisation or depressurisation loads on the building envelope, there is no requirement for combined pressurisation and depressurisation tests.

6.3.2 Instrumentation

Instrumentation is required to:

- Release a measured volume of air into the building or enclosure being tested
- Measure the background pressure within the building or enclosure being tested
- Measure the external wind speed
- Measure outside temperature
- Measure barometric pressure

6.3.3 Low Pressure Pulse Test Procedure

The low pressure pulse test procedure is undertaken as follows. As will be seen from the procedure, this is a highly automated test with much of the methodology contained in the programming of the control system.

1. The LPP air receiver (or devices in a large volume) is positioned in the centre of a room on the ground floor, at least 1m from objects that may obstruct air flow from the nozzle.
2. The compressor is then connected to the air receiver and switched on to charge the vessel to the required pressure level. This will be to a maximum of 10 bar.
3. The operative may then complete the equipment set-up by locating the pulse control device a distance of 3-4m away from the air receiver and using the data control cable to connect them both. This distance is to ensure that the air temperature and pressure sensors contained within the control unit are suitably distanced from the turbulent flow that will come from the air receiver nozzle.
4. The operative may then measure the internal volume of the space and the envelope area, inputting these values along with the volume of the discharge device(s) and user ID into the control module. Other relevant input or notes may also be entered.
5. At this point the user must also input the desired number of sequential air pulse steps based on the nature and purpose of the measurement being undertaken.
6. The test is initiated by the user, using the control system.
7. The control system runs the following protocol:
    a. Close the reference tank solenoid valve, thus setting and recording a starting atmospheric pressure reference, this happens around 0.5s before data recording begins to allow for the air in the reference tank to settle.
    b. Record pressure data at the rate of 50Hz, continuing for the duration of the test. This may be between 6 and 15 seconds, depending on the number of sequential pulse steps). Typically between 300 and 750 data points are recorded, including:
        i. Time of each data point, at 0.02s intervals;
        ii. Output from the building pressure transducer: The pressure difference between outlet pressure and reference tank pressure i.e. ΔP;
        iii. The pressure and air temperature in the main air receiver, this figure is used to calculate how much air has been released into the enclosure;
        iv. Room ambient temperature
    c. After 2 seconds, the main tank solenoid valve is opened, kept open for 1.5 seconds, and subsequently allowed to close.
    d. Measurement and data recording continues for 2.5 more seconds.
    e. Testing is complete and the reference tank solenoid is opened.
    f. The control module stores all data in a csv file and uses this data to calculate the results which are presented on the control module screen for the user.

6.3.4 Data Analysis

An overview of the mathematical theory behind the low-pressure pulse method is as follows:

For a given building, the air-flow through a building envelope during the quasi-steady period of an LPP test can be represented by equation:

$$q\{t\} = Q_p\{t\} - \frac{V}{\gamma p_i}\frac{dp_i}{dt}$$

where V is the building volume,
p_i is the air pressure within the building,
γ is the specific heat ratio of air = 1.4,
Q_p is the volume flow rate of compressed air released from the LPP device and
q is the volume flow rate through the envelope i.e. leakage.

Provided the air density and the rate of change of air pressure in the room are known, as well as the volume flow rate from the LPP device, the leakage may be calculated.

The system offers the option of running 1, 2 or 3 sequential pulse steps in order to allow volume flow rate to be measured across a range of different pressure levels. This provides a larger amount of data through which a power-law curve of fit may be drawn, improving the ability to extrapolate results. A maximum of 3 sequential steps is set as this will typically fully drain the air receiver being used for the test.

The calculations carried out in the LPP test process require three (or four if two tanks are used) data streams, measured at 50Hz for the 6-15 seconds (depending on number of sequential pulse steps) of the test. These data streams are:

- Pressure in the LPP equipment’s air tanks – used to calculate Qp,
- Pressure differential between reference tank and room – used to calculate the pressure changes in the room during the measurement.
- Time, used to synchronise results and calculate rates of change.
- The processing of the data streams can be summarised as follows:
    - Wind correction
    - Analysis of airflow responsible for building pressure change
    - Analysis of airflow from tank(s)
    - Analysis of leakage airflow
    - Combination of leakage airflow data from each step
    - Fitting curve to data
    - Quotation of leakage at 4Pa

6.3.4.1 Error analysis

Data from each step in the LPP test is combined to give leakage vs pressure readings over a range of induced pressures. The data may then be fitted to a power-law curve. The equation of this line can be used to quote figures for leakage at any pressure within the range of pressure tested, in the case of the LPP, 4Pa leakage is quoted. For figures outside of the range of induced pressures measured, extrapolation errors will be incurred and so should be avoided wherever possible.

7 Test results and reporting

The recorded test data must be analysed and corrected in accordance with section 6 of BS EN ISO 9972:2015.

7.1 Air leakage parameters: air change rate and air permeability

Two parameters are most commonly used to quantify the air leakage rate through the building envelope. These are referred to as air change rate and air permeability. These are defined as 'derived quantities' within BS EN ISO 9972:2015 and allow the measured air leakage rate to be normalised for a given building volume or envelope surface area. Both the test methods described in this document provide the outputs to present these derived quantities in the same way.

7.1.1. Air permeability

Air permeability is the air leakage parameter adopted for building regulations compliance purposes in the UK in all four administrations. It is expressed as the volume flow per hour (m^3h^{-1}) of air supplied to the space by the air-moving equipment, per square metre (m^2) of building envelope area for a specified internal to external pressure difference: for example, 5 $m^3h^{-1}.m^{-2}$ at 50 Pa or 0.9 m^3h^{-1} m^{-2} at 4 Pa. This is calculated by dividing the total calculated leakage flow rate (Q) by the envelope area (A_E).

The building envelope area is the area of the boundary or barrier separating the interior volume of the building from the outside environment. It is defined as the internal surface area of the external facade and is calculated from the internal dimensions bordering the internal volume of the building under test.

This area is given by the total of the walls, top floor ceiling (or underside of roof) depending on where the air barrier is and includes the area of the lowest floor, with no deductions for partitions or division walls with adjacent buildings or attached garages.

The extent of the building volume is as defined in section 3, and is the conditioned space i.e. the spaces directly heated, cooled or mechanically ventilated. The permeability of the entire air barrier around the building volume is measured as part of the compliance test.

7.1.2. Air change rate

The air change rate is calculated by dividing the air leakage flow rate (Q) at a given reference pressure difference by the internal volume. It is expressed as the total number of times the entire volume of air in a building changes per hour (ACH) at a specified internal to external pressure difference: for example, 5 ACH at 50 Pa or 0.9 ACH at 4 Pa.

BS EN ISO 9972:2015 defines the total internal volume of the conditioned space that is being tested. Internal dimensions are used and no subtraction made for the volume of internal walls, floors, furniture, voids or cavities inside the conditioned building envelope.

This reporting approach is also adopted by 'Passivhaus' and is also particularly useful in considering ventilation strategy implications.

7.1.3 Reference pressure

For building regulations and standards compliance purposes in the UK, the standard reference pressure difference at which air permeability or air change rate is stated is 50 Pa.

For the Low Pressure Pulse (LPP) technique that measures in the low pressure range, the performance of a building at 4Pa does not correlate directly with its performance at 50 Pa, therefore conversion is required based on the building type and nature of air leakage.

Based on testing across a large sample of residential buildings, a conversion factor of 5.3 may be applied to a 4 Pa result in order to convert it to 50 Pa for the purposes of regulatory reporting. That is, a 50Pa AP_{50}/ACH_{50} can be converted to a 4Pa AP_4/ACH_4 by a simple *division by 5.3*.

For example, an ACH_{50} of $5hr^{-1}$ is equal to an ACH_4 of $0.9hr^{-1}$.

Alternatively, results at 50 Pa must be calculated by extrapolation using the flow equation

$$Q = C(\Delta P)^n$$

the values of C and *n* are derived from a power law least squares curve fit of the flow and pressure measurements obtained in the range up to the maximum pressure difference recorded during the test.

For large and 'leaky' buildings it may also not be possible to achieve a 50 Pa pressure difference with the fan technique. In such situations, tests may be carried out up to the maximum attainable pressure difference, which should be greater than 25 Pa for a valid test result to be reported. The air volume flow rate for a pressure difference of 50 Pa is then derived in the same way as for the LPP method above.

7.1.4 Effective leakage area (ELA)

It is sometimes useful to express the total leakage of a building as an equivalent or effective area of a single opening having the same airflow leakage.

The effective leakage area, ELA (m^2), is calculated from

$$\text{ELA} = Q\ (p/2\Delta P)^{0.5}$$

where Q is airflow rate (m^3s^{-1}),
p is the density of air ($kg\ m^{-3}$),
P is the pressure difference across the opening (Pa), and
0.5 is the exponent for larger openings.

Since ELA varies with P, it is necessary to specify a reference pressure. The pressure differences of 25–60 Pa which are used for the fan pressurisation test are, for valid practical reasons, much larger than occur naturally. For this reason it is customary to quote ELA at a reference pressure between 4 Pa and 10 Pa as this is more representative of normal weather-induced conditions. This makes the low pressure pulse technique particularly well suited for such measurements, with the need for any extrapolation avoided.

The value of Q m^3s^{-1} at pressure differences lower than the measured range is obtained by extrapolation of the flow equation above.

7.1.5 Air leakage tests and infiltration rate

The two main air leakage test methods described in this guidance do not provide a direct measure of the air infiltration rate in a building, and therefore cannot be used to estimate directly the infiltration heat loss. The typical reference test pressure of 50 Pa for the fan pressurisation method is much higher than the pressure differences induced by weather conditions that drive normal air infiltration. A calculation can be carried out to relate the air leakage at 50 Pa, say, to the air infiltration rate, but this will require some knowledge of the location and nature of the air leakage paths. Direct measurement of air infiltration has traditionally required the use of tracer gases.

The low pressure pulse technique offers a practical alternative, measuring air leakage directly at 4 Pa. Whilst this is not explicitly considered the level at which infiltration occurs, it is a measurement that can be considered far more representative of day to day conditions and is why 4 Pa is the reference pressure cited in US, Swiss and French building codes. Any downward extrapolation from this pressure level is much less susceptible to errors.

For the fan pressurisation test, analysis of a large number of measurements carried out on dwellings (and usually therefore of similar volumes) has found that the air infiltration rate in air changes per hour (ACH) is approximately 1/20 of the 50 Pa air change rate (expressed as air changes per hour). The air change rate is defined as Q50/V, where Q50 is the leakage airflow rate at 50 Pa, and V is the internal volume surrounded by the building envelope. This is however only a basic approximation and can vary considerably depending on building size, form and construction as well as local climate and shielding factors.

For extrapolation of fan pressure tests in non-domestic buildings, measurements of air leakage and air infiltration have been carried out by the BRE in the same office buildings (including some combination of measurement and predictions), where it was found that the relationship given for dwellings can be modified for larger non-domestic buildings by the surface-to-volume ratio to give a relationship in the form

$$I = \frac{1}{20}\,\frac{S}{V}\,\frac{Q_{50}}{S}$$

where I is the infiltration rate in air changes per hour (h^{-1}),
S is the surface area of the walls and roof (m^2), and
V is the volume (m^3).

This can usually be simplified to

$$I = \frac{1}{60}\,\frac{Q_{50}}{S}$$

The above relationship relates to average standards of construction and average weather conditions. For typical office buildings, an air leakage index of 10 $m^3 h^{-l} m^2$ at 50 Pa implies an average air infiltration rate of about 0.2 ACH for average wind speeds.

7.2 Test Report

BS EN ISO9772:2015 requires that a test report for an air leakage test contain at least the following information:

a) All details necessary to identify the building tested: postal address and estimated date of construction of the building
b) Date and time of the test
c) A reference to standards followed and any deviations from them
d) Test building details:
   i) Description of the extent of the building subject to the test;
   ii) Internal volume of the space subject to the test;
   iii) Documentation of calculations, such that the results can be verified
   iv) The status of all openings on the building envelope, closed, sealed, open, etc;
   v) Detailed description (including means) of temporarily sealed openings, including photos
   vi) The position of the sealing of the mechanical ventilation, if any;
   vii) The type of heating, ventilation and air conditioning system;
e) Apparatus and procedure, i.e. equipment and technique employed
f) Mode of test (pressure and/or depressure)
g) Test data:
   i) Zero-flow pressure differences for pressurisation and depressure;
   ii) Internal and external air temperature;
   iii) Wind speed and barometric pressure;
   iv) Table of induced pressure difference and corresponding air flow rates;
   v) Air leakage graph
   vi) The aire flow coefficient, the air flow exponent and the air leakage coefficient for both pressurisation and depressurisation tests conducted
   vii) Any derived quantity and reference values used

8 Best practice examples and air leakage diagnostics

Consultation note: this is a proposed new section combining previously well received elements of TM23 and other references to other guidance. The following material is proposed and those responding to the consultation are asked to comment on its usefulness now and may wish to identify other examples of material that might be included.

8.1 Recommended air leakage standards

Table 1 of TM23 2000 included recommended air leakage indices and air permeabilities for some buildings types. These values were selected on the basis that they can be achieved by reasonable design and construction. They included good practice and best practice values. Much more is known about air tightness testing now, and NHBC Foundation has produced guidance. *Consultation note: it is not clear whether the table is needed in this revised edition – should table 1 be updated and retained?*

8.2 Location of air leakage

Both the fan pressurisation and low pressure pulse tests are useful in quantifying the air leakage in a building. However, neither directly identify the location of the air leakage and their use in practice is limited to providing an overall measure of air leakage as a quality assessment indicator. One benefit of the fan pressurisation method however is that it may be combined with visualization methods to locate the air leakage paths in the building envelope.

8.2.1 Smoke visualisation

If the building is depressurised (i.e. the fan extracts air from the building), smoke pencils or puffers can be used to locate air leakage paths. This is carried out on the inside of the building envelope, as the air barrier is usually located on the internal side of the construction: therefore any leakage detected can be more easily related to its source and be readily attended to. Figure xx shows the use of a smoke puffer.
Suitable figure to be inserted.

For buildings that are pressurised, smoke pencils or smoke generators can be used. When using smoke generators the exhaust of the smoke to the outside needs to be observed. The disadvantages of this method are that the whole building must be filled with smoke, and that the location of smoke exhaust on the outside may not locate the precise location of the leakage source, which is usually associated with an internal detail.

8.3 Thermography

A thermography survey using an infra-red camera can be used to locate air leakage paths, by identifying the local heating or cooling of the fabric around the leakage area.

All objects emit heat energy (that is, infra-red radiation), the amount being related to the surface temperature of the object in question. 'Thermography' is the term used to describe the process of making this heat energy visible and capable of interpretation. An infra-red camera can be used to scan the surfaces of a building and produce a 'live' heat energy picture that can be viewed on a screen. If there is air leakage into a building, it can produce a locally cooled area on the internal surface that can be detected by the camera. If there is air leakage to the outside, this can produce a locally heated area that can be similarly detected. If viewed from the outside the air leakage appears as a relatively warm area (Figure xx). If viewed from the inside the air leakage appears as a relatively cool area (Figure xx). *Figures to be added subject to comments.*

Natural wind speed and buoyancy forces can be sufficient to cause air leakage to take place such that it can be detected using thermographic equipment. It is usual in a thermographic survey to establish an air temperature difference of about 10°C between inside and outside.

In some cases it may be beneficial to perform a thermography survey in combination with a fan pressurisation or depressurisation test in order to identify air leakage paths. In such cases the pressurisation test will quantify the air leakage, and the thermographic survey may locate the leakage areas (as shown in Figure xx and xx). This application has the benefit of covering a large area quickly, and it can also give an assessment of high-level areas without resorting to access platforms etc. *Figures to be added subject to comments*

8.4 Component air leakage

The contribution to air leakage and ventilation due to components (windows, doors, vents, etc.) and elements (walls, details, etc.) of a building can be assessed either by reductive sealing or by individual component testing.

8.4.1 Reductive sealing

The air leakage rate of a whole building, or a self-contained space within a building, can be measured by either the fan pressurisation or low pressure pulse technique. The component or element of interest can then be sealed, and the measurement repeated. The reduction in air leakage can then be estimated from the difference between the 'before' and 'after' sealing measurements. Sealing can be carried out temporarily by covering and sealing the area of interest with solid partitions or plastic sheeting (Figure xx and xx). Alternatively, the method may be used to test the effectiveness of a particular permanent sealing measure before and after installation.

8.4.2 Component testing

The air leakage associated with an element or component can be tested directly by pressurisation. The component can be isolated by containing the area of interest within a temporary sealed compartment. The compartment can then be pressurised and the leakage due to the area of interest can be estimated. This method has the advantage that a smaller fan or LPP unit can be used than would be required to test by reductive sealing.

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