



TECHNICAL STANDARD L1.

MEASURING AIR PERMEABILITY OF BUILDING ENVELOPES (DWELLINGS)

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The Air Tightness Testing & Measurement Association

c/o the British Institute of Non-Destructive Testing
1 Spencer Parade
Northampton
NN1 5AA

Tel: +44 (0)1604 630124

Fax: +44 (0)1604 231489

web: www.attma.org

www.bindt.org

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Section 1 – Introduction

1.1 Basis for measurement

The requirements of ATTMA for the measurement of the air permeability of buildings are generally based on BS EN 13829:2001 - 'Thermal Performance of Buildings - Determination of air permeability of buildings - Fan pressurisation method' with enhancements recommended by ATTMA.

This document provides the technical standard to be followed for the testing of Dwellings as set out in Regulation 20B and Approved Document L1A 2010 of the Building Regulations for England and Wales, Technical Booklet Part F1 in Northern Ireland, and Section 6 of the Domestic Handbook (Scotland).

For a testing organisation to show full compliance with this standard, they should have suitable third party monitoring systems in place. This is demonstrated by either holding building air leakage testing UKAS accreditation for organisations in line with BS ISO:17025:2005 or having an active registration with the BINDT L1 testing scheme.

Guidance for test procedures for the testing of Non-Dwellings (as set out in Regulation 20B and Approved Document L2A 2010 of the Building Regulations for England and Wales, F2 in Northern Ireland, and Section 6 (Commercial) in Scotland) is provided within companion reference document ATTMA Technical Standard L2 (downloadable from www.attma.org).

1.2 Background

1.2.1 What is air leakage?

Air leakage is the uncontrolled flow of air through gaps and cracks in the fabric of a building (sometimes referred to as infiltration or draughts). This is not to be confused with ventilation, which is the controlled flow of air into and out of the building through purpose built ventilators that is required for the comfort and safety of the occupants. Too much air leakage leads to unnecessary heat loss and discomfort to the occupants from cold draughts. The increasing need for higher energy efficiency in buildings and the need in future to demonstrate compliance with more stringent Building Regulations targets means that airtightness has become a major performance issue. The aim should be to '*Build tight – ventilate right*'. Taking this approach means that buildings cannot be too airtight, however it is essential to ensure appropriate ventilation rates are achieved through purpose built ventilation openings.

1.2.2 What is the impact of air leakage?

Fabric heat losses have been driven down over many years by the various versions of the Building Regulations and there is limited return in reducing them down significantly further. The improvements made in the thermal performance of building materials have raised the importance of designing and constructing less leaky building envelopes.

Airtightness of buildings was addressed for the first time in the UK in the 2002 edition of Part L of the Building Regulations (England and Wales), and in subsequent years has also been incorporated in various degrees in to Part F (Northern Ireland), and Section 6 (Scotland). The airtightness of the UK building stock has traditionally been proven to be poor, which leads not only to unnecessary ventilation heat loss but also to widespread occupant dissatisfaction.

1.2.3 Why should we test?

Gaps and cracks in the building fabric are often difficult to detect simply by visual inspection. Air leakage paths through the building fabric can be tortuous; gaps are often obscured by internal building finishes or external cladding. The only satisfactory way to show that the building fabric is reasonably airtight is to measure the leakiness of the building fabric as a whole. Air leakage is quantified as *Air Permeability*. This is the leakage of air ($\text{m}^3.\text{h}^{-1}$) in or out of the building, per square metre of building envelope at a reference pressure difference of 50 Pascals (i.e. $\text{m}^3.\text{h}^{-1}.\text{m}^{-2}$ @ 50 Pa) between the inside and outside of the building.

1.3 Measuring air leakage

Assessment of building envelope air leakage involves establishing a pressure differential across the envelope and measuring the air flow required to achieve that differential. This is normally achieved by utilising variable flow portable fans which are temporarily installed in a doorway, or other suitable external opening.

HVAC plant is switched off and temporarily sealed prior to the test. Passive ventilation should also be temporarily sealed. All doors and windows on the exterior of the air test envelope are closed. The test fans are switched on and the flow through them increased until a building pressure of 50 – 100 Pa is achieved. The total air flow through the fan and the building pressure differential created between the inside and outside is recorded. The fan speed is then slowly adjusted to produce sequential steps of not more than 10 Pa building pressure differential, with the fan flow and pressure differential data recorded at each step.

The recorded fan flow (Q) and building pressure differential (Δp) data allow a relationship to be established. This can be defined in terms of the power law equation:

$$Q = C (\Delta p)^n \quad 1$$

Where C and n are constants that relate to the specific building under test.

The total air flow required to achieve the reference pressure differential of 50 Pa can then be calculated from the equation (see Appendix A). This airflow is then divided by the total building envelope area (A_E) to provide the leakage rate in $\text{m}^3.\text{h}^{-1}.\text{m}^{-2}$ @ 50Pa.

1.4 Fan Pressurisation Systems



Single fan in single door used for dwellings (door fans typically move $2 \text{ m}^3 \cdot \text{s}^{-1}$, which allows properties with envelope areas of up to 720 m^2 to be tested at a specification of $10 \text{ m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ @ 50 Pa).

Section 2 -Air Leakage Standards

2.1 Good and Best Practice Standards

Recommended airtightness standards for a variety of different building types have been established over many years. The airtightness of buildings, as defined in the Approved Documents L1A and L2A, is based on air permeability where the envelope area is defined as the surface area of boundary walls, roof and floor. For improved energy efficiency and much better control of the indoor environment, better airtightness standards are required than the relatively relaxed worst acceptable limit set by the Building Regulations. When calculating the dwelling's carbon dioxide emission rate (DER) it may be necessary to set much higher standards for airtightness to ensure the proposed dwelling is within the target emission rate (TER) required to demonstrate compliance with Building Regulations Part L (England and Wales), Part F1 (Northern Ireland), or Section 6 of the Domestic Handbook (Scotland). The following table provides current normal and best practice airtightness criteria for different dwelling types:

Type	Air permeability $m^3.h^{-1}.m^{-2}$ @ 50 Pascals		Air Change Rate h^{-1} @ 50 Pascals
	Best practice	Normal	
Dwellings			
<i>naturally ventilated</i>	5.0	7.0	-
<i>mechanically ventilated</i>	1.0	5.0	-
<i>PassivHaus Standard</i>	-	<1.0	0.6

2.2 Building Regulation Requirements Part L 2010 (England and Wales), Part F1 (Northern Ireland), or Section 6 of the Domestic Handbook (Scotland).

Regulation 20B of the Building Regulations 2010 (England and Wales) requires that pressure testing is carried out on new buildings, in order to be satisfied that provision has been made to limit heat gains and losses through the building fabric. This includes heat transfer by air leakage.

For new dwellings, as defined in Building Regulations Approved Document L1A 2010 (England and Wales), Technical Booklet Part F1 (Northern Ireland), and Section 6 of the Domestic Handbook (Scotland) advises that pressure tests should be carried out on a representative sample of dwellings.

The general requirement is for the dwellings to be tested to comply with a maximum air permeability of $10 m^3.h^{-1}.m^{-2}$ at a reference pressure differential of 50 Pascals. However, in order to comply with the carbon emission target, lower air permeability may be required by the Building Regulations and dwellings tested for compliance accordingly.

Section 3 - Specific Test and Building Preparation Procedure

3.1 Pre Test Requirements

Liaison should be made with the client over the date and time of the test procedure. The client should be made fully aware of the nature of the test and the degree of disruption that it may cause to construction works and/or operation of the dwelling.

The test procedure can be significantly affected by extremes of weather (wind speed, internal/external temperatures). Weather forecasts should be checked prior to the proposed test date and if inclement weather is predicted, re-scheduling may be necessary.

There may be occasions when the dwelling needs to be tested in conditions that are less than ideal and under these circumstances this must be stressed in the test report. However, if tests need to be carried out during periods of 'fresh' (≥ 6 m/s) wind speeds, the zero flow pressures are likely to exceed 5 Pascals making the test result invalid.

3.2 Building Envelope Calculations

An accurate evaluation of the dwelling or test area envelope (A_E) must be made prior to the test being undertaken. The necessary fan flow required to undertake the test should be calculated from this figure.

The dwelling envelope will normally be calculated from accurate dimensioned drawings. It must be confirmed that the drawings used for the measurement are current and reflect dimensions of the completed dwelling.

The extent of the dwelling to be tested must be confirmed. This will reflect the extent of the 'conditioned space' within the dwelling, i.e. spaces that are heated or cooled.

The area of the dwelling envelope should be measured along the line of the component to be relied upon for air sealing. This will generally be the inner surface of the wall or roof assembly.

Areas are measured as flat, i.e. no allowance is made for undulating profiles such as profiled cladding or textures to wall components. Similarly the surfaces within window and external door reveals are excluded.

The calculated envelope area will be referred to in subsequent data analysis and test reports. This calculation should normally be undertaken by the testing organisation. The output from the calculation should be recorded and retained by the testing organisation, along with relevant drawings for future reference.

3.2.1 Air Permeability Envelope Area (m^2)

For an Air Permeability Envelope Area (A_E), all walls (including basement walls, if the basement is subject to test), roof and the floor are considered as part of the building envelope.

This is the method of envelope measurement referred to in the Building Regulations.

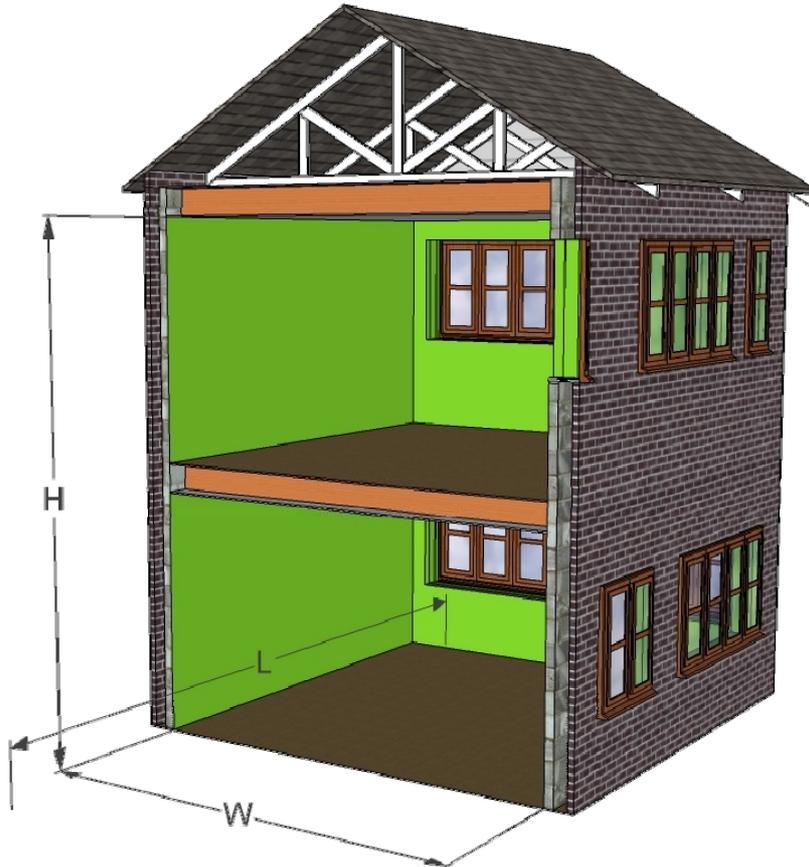
The envelope area of the dwelling will need to be calculated. A dwelling envelope area calculation example can be seen in the Sections 3.2.3 & 3.2.4.

3.2.2 Air Change Rate Volume (m^3)

The Air Change Rate Volume (V) is the volume of air inside the dwelling under test, for all the zones incorporated within the test zone, with no deductions for furniture. This is not a requirement to show compliance with the Approved Document, but may be produced for information only.

3.2.3 Cold Roof Construction Envelope Area Calculation

A cold roof has the insulation at the horizontal ceiling level and usually a large void or space between the insulation and the pitched roof rafters.



Where: $L = 7.40 \text{ m}$ $W = 4.40 \text{ m}$ $H = 5.30 \text{ m}$

Cold roof construction - air barrier at first floor ceiling		
Area	Calculation (m)	Result (m ²)
Floor area	$L \times W$ (7.40x 4.40)	32.56
Roof area	$L \times W$ (7.40 x 4.40)	32.56
Wall area	$2 \times H \times (L + W)$ $2 \times 5.30 \times (7.40 + 4.40)$	125.08
<i>Total</i>		190.20m²

3.2.4 Warm Roof Construction Envelope Area Calculation

A warm roof has the insulation running along the pitched roof rafters with an air barrier *normally* running parallel along the inside face of the insulation.



Where:

L1 = 7.40 m	W1 = 4.40 m	H1 = 5.10 m	R1 = 1.50 m
L2 = 3.98 m	W2 = 0.85 m	H2 = 1.44 m	R2 = 0.93 m
L3 = 0.40 m	W3 = 2.70 m	H3 = 1.06 m	R3 = 0.57 m
L4 = 0.40 m	W4 = W2	H4 = 2.10 m	
L5 = 1.30 m	W5 = 0.58 m		
	W6 = 1.91 m		
	W7 = 1.51 m		

Warm roof construction - air barrier along line of rafters, and first floor ceiling		
Area	Calculation (m)	Result (m ²)
Floor area	$L \times W1$ (7.40 x 4.40)	32.56
Roof area	$((2 \times L1) - L5) \times W2 + (L1 \times W5) + (L4 \times W6) + (L1 \times R1) + ((L1 - L5) \times R1) + ((R1 - R2) \times L3) + ((W6 + W7) \times R3)$ $((2 \times 7.40) - 1.30) \times 0.85 + (7.40 \times 0.58) + (0.50 \times 1.91) + (7.40 \times 1.50) + ((7.40 - 1.30) \times 1.50) + ((1.50 - 0.93) \times 0.40) + ((1.91 + 1.51) \times 0.57)$	39.15
Wall area	$(2 \times (W1 + L1) \times H1) + (((2 \times L1) - L5) \times H2) + (2 \times W3 \times H2) + (W5 \times H3) + (W3 \times H3) + (L5 \times H4) + (((L4 + L5)/2) \times (H2 + H3 - H4)) + (2 \times W4 \times H4) + ((W7 - W4) \times (H4 - H2))$ $(2 \times (4.40 + 7.40) \times 5.10) + (((2 \times 7.40) - 1.30) \times 1.44) + (2 \times 2.70 \times 1.44) + (0.58 \times 1.06) + (2.70 \times 1.06) + (1.30 \times 2.10) + (((0.50 + 1.30)/2) \times (1.44 + 1.06 - 2.10)) + (2 \times 0.85 \times 2.10) + ((1.51m - 0.85) \times (2.10 - 1.44))$	158.15
	Total	229.86m²

3.3 Fan System Selection

The fan system will almost always consist of one unit located within an external opening to the dwelling envelope, or area under test. Adequate fan capacity must be available to undertake the test. This will be established from the target specification, and the envelope area calculation. The fan flow rate must be no less than 100% of the required flow rate at 50 Pa to achieve the worst acceptable dwelling specification.

From information available, and through liaison with the client, the location for the installation of the fan equipment should be established prior to the test date. A number of issues must be considered:

1. Access for fan equipment to be delivered and installed.
2. Air flow restrictions in front and around fans. A clear door opening is preferred.
3. Any electrical power supplies which may be necessary.
4. Local restrictions, e.g. noise, working hours etc.
5. Acceptable route for the air to flow from the fans to equalise pressure throughout the test enclosure.

The test can be undertaken either through pressurisation or depressurisation of the building envelope. This may be dictated by the specification, proposed test equipment, or by the practicalities of site conditions. Whichever method(s) are necessary the nature of the test pressurisation should be confirmed prior to the test date. This may affect temporary sealing methods and locations.

The fan system and associated equipment utilised must be calibrated in accordance with traceable standards, and must be within accepted calibration periods (see Appendix B).

3.4 Building Preparation

Prior to the test being undertaken, the dwelling must be prepared to allow effective (de)pressurisation and representative results to be obtained. The method of preparation referred to in this document is generally compliant with BS EN 13829:2001 Method B – Test of the Building Envelope.

To allow pressure to equalise fully around the test enclosure, all internal doors should be fully opened and restrained. All areas of the dwelling to be tested should be connected by openings no smaller than a single leaf doorway (say 800mm x 2000mm). Any areas of the building where this is not achievable must be recorded and noted within the test report.

Further guidelines for preparation include:

- All drainage traps should be filled with water.
- All incoming service penetrations (e.g. power, telecoms) should be permanently sealed.
- All external doors and windows should be closed (but not additionally sealed). This includes door thresholds. The exception to this will be apertures to which test equipment is connected.

- Background trickle ventilators, passive ventilation systems and permanently open uncontrolled natural ventilation openings should be temporarily sealed.
- Mechanical ventilation and air conditioning systems should be turned off. These systems should be temporarily sealed to prevent air leakage through the systems during the test.

For the result of the test to be representative, the external envelope should be in its final completed state. However it may be necessary to erect some temporary seals/screens to allow the test to be undertaken, (for example if a door or window has been broken, or is missing). Any such temporary seals must be robust enough to withstand the maximum test pressure (100 Pa).

Temporary seals employed during the test (including the method of closure of mechanical ventilation systems) must be spot checked and recorded for inclusion in the test report. The application and recording of these seals for the testing of dwellings is the responsibility of the tester. It should be noted that temporary sealing to large and complex systems should not be under-estimated. Careful co-ordination and planning will be required to ensure all systems are adequately sealed. The testing organisation should undertake a reasonable assessment of the building envelope, both prior to and after the test being undertaken.

Any elements at variance with these guide notes should be highlighted within the final report such that the client/building inspector may assess whether the result obtained is adequately representative of how the building would perform in its final completed condition. As temporary seals to unfinished works may, in practice, be more airtight than the envelope element that they replace, results obtained with such temporary seals should be qualified accordingly by the testing organisation.

3.5 Further Test Equipment

In addition to the fan (de)pressurisation system, other pieces of equipment must be utilised during the test.

The internal/external pressure difference is normally measured at approximately the geometric centre of the dwelling or enclosure being tested. Measurements are normally obtained through small bore tubing (no greater than 6mm internal diameter). The internal reference tube must be located away from corridors or doorways where air movement (dynamic pressure) is likely to affect the readings obtained. Separate measurements should be taken on the highest and ground floor levels of the dwelling tested in cases where there is concern over pressure equalisation as in 3.4 paragraph 2. This shall be used to ascertain that uniform building pressure is achieved within a range of less than 10% between the ground and top floor, and should be recorded at the highest flow rate achieved, the test is invalid outside this range and should be repeated after sufficient opening have been found to ensure uniform pressure.

Pressure tubes should be kept away from locations where they may be trapped, or may become heated or cooled excessively. The external reference tube should preferably be located away from the building envelope. This must terminate out of the air flows induced by the fan pressurisation system, and sheltered from any wind.

Where this is not possible i.e. a top / intermediate floor apartment, the adjacent floor, the reference tube should be taken to an adjacent apartment or floor, and all the doors and windows opened to ensure a free air supply is provided.

Suitably calibrated differential pressure measuring devices shall be employed to measure the indoor/outdoor pressure difference.

Suitably calibrated thermometers must be used internally and externally to the dwelling, to allow temperatures to be recorded before and after the test procedure. Where a variation in the internal or external air temperature is recorded during the test, an average shall be calculated.

The location of all measurement devices/terminations must be recorded on site test data sheets.

Measurement of barometric pressure is also necessary before and after the test.

3.6 Site Test Procedure

When the dwelling has been suitably prepared, the test can commence. The client should be advised and asked to ensure that all external doors and windows remain closed for the duration. When testing flats, terraced houses, or any dwellings that are directly adjacent to other properties, doors and/or windows should be opened in all adjacent properties (e.g. above, below and on either side) and in the access corridor. This is to ensure that pressure equalises between the adjacent properties and outside the building. Where it is not possible to access any of these properties, for example if they are occupied, this should be noted in the test report.

Whilst it is safe for the test to be undertaken with people remaining inside the dwelling, it is often easier for the site operatives/staff to evacuate the dwelling for the period of the test.

External and internal temperatures should be recorded (T_{e1} , T_{i1}), where necessary an average reading may be taken, e.g. in multi storey residences.

All pressure measuring and flow measurement devices should be zeroed as necessary at this stage.

With the opening(s) of the air moving equipment temporarily covered, the pressure measuring devices should be connected to the internal/external reference pressure tubes. The following zero flow pressure difference readings shall be recorded:

$\Delta P_{0,1+}$	<i>The average of positive values recorded over a minimum of 30 seconds</i>
$\Delta P_{0,1-}$	<i>The average of negative values recorded over a minimum of 30 seconds</i>
$\Delta P_{0,1}$	<i>The average of all values recorded over a minimum of 30 seconds</i>

If any of $\Delta P_{0,1+}$, $\Delta P_{0,1-}$, $\Delta P_{0,1}$ are found to be in excess of ± 5 Pa, conditions are not suitable to undertake a valid test, and the client should be advised.

Wind speed and temperature may be the cause of excessive static pressures, and waiting until the environmental conditions change may reduce the figure to an acceptable level. It should also be confirmed that mechanical ventilation systems are suitably isolated so as not to cause this effect.

Once acceptable zero flow pressure difference readings have been taken, covers from the air moving equipment should be removed. Air pressurisation equipment can then be turned on to pressurise or depressurise the dwelling/enclosure.

The test is carried out by taking a series of measurements of air flow rates and corresponding indoor/outdoor pressure difference over a range of fan flows.

Due to the instability of induced pressures at lower levels, the minimum measured and corrected pressure difference must be the greater of 10 Pa, or five times the zero flow pressure difference measured prior to the test (the greater of $\Delta P_{0,1+}$, $\Delta P_{0,1-}$).

The highest pressure difference (corrected) must be greater than 50 Pa. If less than 50 is achieved, the test is not valid and this must be recorded within the final test report along with the reason why. Readings taken at low pressures will be more adversely affected by environmental conditions and any conclusions drawn from such a report should be treated with caution.

The test can be undertaken with the dwelling envelope either positively or negatively pressurised, and results obtained in either situation are valid. Alternatively both positive and negative tests may be carried out, and an average of the results calculated.

It is recommended that pressurisation systems are switched on in a controlled manner. Great care must be taken to ensure that the dwelling does not become over pressurised (>100 Pa) as this may present a risk to internal finishes and the fabric of the dwelling.

Measurements must be taken at a minimum of 5 pressures between the maximum and minimum induced pressures, i.e. a minimum of 7 points, with intervals between pressures being no greater than 10 Pa. It is recommended that wherever possible 8 to 10 pressure differences are recorded. It is normally beneficial to take readings over a broad range of building pressures (a minimum of 25 Pa range).

Adequate time must be allowed for induced pressures to stabilise throughout the dwelling envelope.

Once steady pressure (Δp) and flow (Q) readings are obtained, these shall be recorded. Where multiple fans are utilised, it must be ensured that flow measurement readings are taken for each fan.

When a full set of data has been recorded, the pressurisation system should be switched off and the fan opening re-covered. The following should then be recorded:

$\Delta P_{0,2+}$ *The average of positive values recorded over a minimum of 30 seconds*

- $\Delta P_{0,2-}$ *The average of negative values recorded over a minimum of 30 seconds*
- $\Delta P_{0,2}$ *The average of all values recorded over a minimum of 30 seconds*

If any of $\Delta P_{0,2+}$, $\Delta P_{0,2-}$, $\Delta P_{0,2}$ is found to be in excess of ± 5 Pa, the conditions have not been suitable to undertake a valid test, and the client should be advised.

Should any test have been undertaken with zero flow pressure difference (either before or after the test) in excess of ± 5 Pa, then any result obtained must be qualified accordingly. Whilst the test undertaken may provide an approximate result, this should not be used to prove compliance with any specification.

External and internal temperatures should be recorded (T_{e2} , T_{i2}). Where necessary an average reading may be taken.

Following the test it should be confirmed that the dwelling conditions have remained stable during the test, and that temporary seals and external doors/windows/vents have remained closed.

3.7 Test Results

The recorded test data must be analysed and corrected in accordance with the standard equations contained within Appendix A.

For the purpose of this standard the final air permeability test result is expressed as a rate of leakage per hour per square metre of dwelling envelope at a reference pressure differential of 50 Pa ($\text{m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ @ 50 Pa). This is calculated by dividing the total calculated leakage flow rate (Q_{50}) by the envelope area (A_E).

When figures for an indicative air change rate are required (e.g. for Passivhaus compliance purposes), this can be expressed as a proportion of a complete volume change to occur every hour at a pressure differential of 50 Pa (h^{-1} @ 50 Pa). This is calculated by dividing the total calculated leakage flow rate (Q_{50}) by the volume (V) of the area subject to test.

Section 4 - Test Report

The report shall contain at least the following information:

- a) All details necessary to identify the dwelling tested; purpose of test (method A or B) as per BS EN 13829:2001; post address and estimated date of construction of the dwelling.
- b) A reference to this standard and any deviation from it.
- c) Test object:
 - description of which parts of the dwelling were subject to the test;
 - envelope area;
 - documentation of test calculations so that the stated results can be verified;
 - the general status of openings on the dwelling envelope, latched, sealed, open, etc.;
 - detailed description of temporarily sealed openings, if any;
 - the type of heating, ventilating and air conditioning system.
- d) Apparatus and procedure:
 - equipment and technique employed;
 - serial number for each calibrated item of equipment used;
 - date of calibration expiry for each calibrated item of equipment used.
- e) Test data:
 - 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 pressurisation and depressurisation test;
 - internal and external temperatures before and after the test;
 - barometric pressure before and after the test;
 - differential pressure on ground and top floor at highest flow rate achieved (if required);
 - table of induced pressure differences and corresponding air flow rates;
 - air leakage graph, with value of correlation coefficient r^2 ;
 - the air flow coefficient C_{env} , the air flow exponent, n , and the air leakage coefficient C_L , for both pressurisation and depressurisation tests determined by the method indicated;
 - Air permeability result.
- f) Date and time of test.
- g) Name and address of organisation/individual carrying out the test and details of the credentials permitting them to do so (UKAS Accreditation or BINDT L1 Registration number).

Appendices

Appendix A - Equations and Corrections

A.1.0 Equations

A.1.1 Corrections for zero flow pressure differences

Zero flow pressure difference corrections should be applied to the observed dwelling differential pressures for wind and stack effects. Subtract the average zero-flow pressure difference from each of the measured pressure differences, Δp_m , to obtain the induced pressure differences, Δp_{env} , using equation 2:

$$\Delta p_{env} = \Delta p_m - \frac{\Delta p_{0,1} + \Delta p_{0,2}}{2} \quad 2$$

where $\Delta p_{0,1}$ is the average of all zero flow pressure differences at the start of the test and $\Delta p_{0,2}$ is the average of all zero flow pressure differences at the end of the test.

A.1.2 Calculation of air density

The air density, ρ , in $\text{kg}\cdot\text{m}^{-3}$, at a temperature, θ , in $^{\circ}\text{C}$ and at the absolute pressure, p_{bar} , in Pa, can be obtained by equation 3. This may be calculated as an average of temperature and absolute pressure readings taken immediately before, during and immediately after the test.

$$\rho = \frac{p_{bar} - 0.37802 \cdot p_v}{287.055 \times (\theta + 273.15)} \quad 3$$

Where: $p_v = \varphi \times e^{\left\{ 59.484085 - \left(\frac{6790.4985}{\theta + 273.15} \right) - 5.02802 \cdot [\ln(\theta + 273.15)] \right\}}$

and, φ can be taken as 0.5 (i.e. 50% relative humidity)

A.1.3 Correction for actual and observed airflow through the measuring device

The actual flow rate Q_m through the fan is a function of the measured values at the last fan calibration and measured values during the air test.

$$Q_m = Q_c \frac{\rho_c}{\rho_m} \quad 4$$

Where Q_m is the actual volumetric flow rate through the fan during the test, Q_c is the airflow rate from the last calibration of the fan, ρ_m is the density of air passing through the fan during the test ($\text{kg}\cdot\text{m}^{-3}$) and ρ_c is the air density recorded during fan calibration.

A.1.4 Correction for internal/external air density differences

A correction is required for the internal/external density differences between air passing through the airflow measuring device and air passing through the dwelling envelope. The correction to be applied depends on whether the building is being pressurised or depressurised.

A.1.4.1 Corrections to airflow rate for **pressurisation** tests:

Convert the measured airflow rate, Q_m , to airflow through the dwelling envelope, $Q_{env(out)}$, for pressurisation using equation 5:

$$Q_{env(out)} = Q_m \frac{\rho_e}{\rho_i} \quad 5$$

where $Q_{env(out)}$ is the actual air flow volume out through the envelope, ρ_e is the mean external air density (kg.m^{-3}) and ρ_i is the mean internal air density (kg.m^{-3}).

A.1.4.2 Corrections to airflow rate for **depressurisation** tests:

Convert the measured airflow rate, Q_m , to airflow through the dwelling envelope, $Q_{env(in)}$, for depressurisation using equation 6:

$$Q_{env(in)} = Q_m \frac{\rho_i}{\rho_e} \quad 6$$

where $Q_{env(in)}$ is the actual air flow volume in through the envelope, ρ_e is the mean external air density (kg.m^{-3}) and ρ_i is the mean internal air density (kg.m^{-3}).

A.1.5 Determination of constants C and n using a least squares technique

The results from a steady state building test will give a dataset comprising of dwelling differential pressures (Δp_{env}) and corresponding fan flow rates (Q_m), and follow the relationship stated in equation. There are a number of curve fitting approximations available to produce a best-fit line between these points. The most straightforward of these is the least squares approximation. Equation 1 is rearranged by taking the logarithm of each side to form an equation for a straight line:

$$y = mx + b$$

where $y = \ln(Q_m)$
and $x = \ln(\Delta p_{env})$

The points recorded are fitted through the points $(x_1, y_1), \dots, (x_i, y_i)$ so that the sum of the squares of the distances of those points from the straight line is minimum. The airflow rates and corresponding pressure differences are plotted on a log-log graph for pressurisation and depressurisation as required.

The calculation of the factors m and b for a given (de)pressurisation test are as follows:-

$$d \sum XY = \sum (\ln[\Delta p_{env}] \times \ln[Q_m]) \quad 7$$

$$d \sum XX = \sum (\ln[\Delta p_{env}] \times \ln[\Delta p_{env}]) \quad 8$$

$$d \sum YY = \sum (\ln[Q_m] \times \ln[Q_m]) \quad 9$$

$$d \sum X = \sum \ln[\Delta p_{env}] \quad 10$$

$$d \sum Y = \sum \ln[Q_m] \quad 11$$

$$m = \frac{(d \sum X \times d \sum Y) - (i \times d \sum XY)}{(d \sum X \times d \sum X) - (i \times d \sum XX)} \quad 12$$

where i = number of data points

$$b = \frac{(d \sum X \times d \sum XY) - (d \sum XX \times d \sum Y)}{(d \sum X \times d \sum X) - (i \times d \sum XX)} \quad 13$$

from this the air flow coefficient, C_{env} , and air flow exponent, n , are obtained:

$$C_{env} = e^b \quad 14$$

and

$$m = n \quad 15$$

A.1.6 Correction of airflow rates through the dwelling envelope to standard temperature and pressure

The relationship is established between volumetric flow rate through the fan and the induced dwelling envelope pressure difference:

$$Q_{env} = C_{env} \times \Delta p_{env}^n \quad 16$$

where Q_{env} is the air flow rate through the dwelling envelope ($m^3 \cdot h^{-1}$) and Δp_{env} is the induced pressure difference, in Pascals.

The air leakage coefficient, C_L , is obtained by correcting the air flow coefficient, C_{env} , to standard conditions (i.e. 20 °C and 101,325 Pa).

For **pressurisation** use equation:

$$C_L = C_{env} \times \left(\frac{\rho_i}{\rho_s} \right)^{1-n} \quad 17$$

For **depressurisation** use equation:

$$C_L = C_{env} \times \left(\frac{\rho_e}{\rho_s} \right)^{1-n} \quad 18$$

where ρ_i is the indoor air density kg.m^{-3} , ρ_e is the outdoor air density kg.m^{-3} , and ρ_s is the air density at standard conditions (kg.m^{-3})

The air leakage rate, $Q_{\Delta p_{env}}$, for a given dwelling differential pressure, Δp_{env} , can be calculated using equation:

$$Q_{\Delta p_{env}} = C_L \times (\Delta p_{env})^n \quad 19$$

where C_L is the air leakage coefficient, in $\text{m}^3 \cdot \text{h}^{-1} \cdot \text{Pa}^n$, Δp_{env} is the induced pressure difference (Pa) and n is the air flow exponent.

A.1.7 Air permeability

The air permeability, AP_{50} , is the air leakage rate at a pressure difference of 50 Pa, divided by the building envelope area A_E (m^2). Units are $\text{m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$. The air permeability is calculated using equation 20:

$$AP_{50} = \frac{Q_{50}}{A_E} \quad 20$$

Where $Q_{50} = C_L \times 50^n$, from equation 19.

A.1.8 Air change rate

The air change rate, n_{50} , is the air leakage rate at a pressure difference of 50 Pa, divided by the building volume V (m^3). It defines the length of time required to completely change the volume of air within the dwelling, and has the units h^{-1} . The air change is calculated using equation 21:

$$n_{50} = \frac{Q_{50}}{V} \quad 21$$

Where $Q_{50} = C_L \times 50^n$, from equation 19.

A.1.9 Correlation coefficient (r^2)

The correlation coefficient (r^2) is a measure of the strength of association between the observed values of building differential pressure ($\Delta\rho_{env}$) and corresponding fan flow rates.

$$r = \frac{S_{xy}}{\sqrt{\sigma^2}}$$

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where

$$\sigma^2 = [(i \times d \sum XX) - (d \sum X \times d \sum X)] \times [(i \times d \sum YY) - (d \sum Y \times d \sum Y)]$$

$$S_{xy} = (i \times d \sum XY) - (d \sum X \times d \sum Y)$$

A.2.0 Essential parameters (r^2 and n)

Assessment of dwelling airtightness using a steady state technique relies on the premise that an equal pressure difference is maintained across the whole of the dwelling envelope. It is also paramount that no changes occur to the envelope, such as removal of temporary sealing or opening an external door during the test. Two parameters are used as indicators of the accuracy and validity of test results, r^2 and n .

A.2.1 Correlation coefficient (r^2)

The correlation coefficient, or r^2 , is indicative of the accuracy with which a curve fitting equation can be applied to a set of results. For a dwelling air leakage test an r^2 value of greater than 0.980 must be obtained. Test results that do not attain this minimum standard figure should be declared not valid and may be due to adverse environmental conditions or substandard test and data collection techniques.

A.2.2 Air flow exponent (n)

The fortuitous air leakage paths through a dwelling envelope under test will consist of a number of cracks and holes of varying shapes and size. The constants C and n are derived from the power law relationship. The air flow exponent, n , is used to describe the airflow regime through this orifice. Values should range between 0.5 and 1.0. If the value of n is not within these limits, then the test is not valid and should be repeated.

For information, n values which approach 0.5 will have fully developed turbulent flow through the dwelling elements and represents air flow through rather large apertures, which tend to be indicative of rather leaky structures. Values of n which approach 1.0, will indicate a more laminar like flow through the dwelling elements and generally represent very tight structures, or those with a myriad of very tiny holes.

A.3.0 Limiting factors

A.3.1 *Zero-flow pressure differences*

Temporarily sealing is applied to the fan(s) at the start and end of the test. Readings for dwelling differential pressures are recorded at zero airflow rate through the fan(s). If the average of the zero-flow pressure differences at the start or end of the test exceeds 5 Pa the influence of wind and/or stack pressures are theoretically too great for a valid set of readings to be obtained.

A.3.2 *Minimum acceptable dwelling differential pressures*

The dwelling differential pressures induced during an air test should be greater than those occurring naturally to minimise the influence of wind and stack effects. A maximum pressure of at least 50 Pa must be established across the envelope, with readings typically taken up to between 60 and 100 Pa. Higher building pressures may result in more accurate data in some instances. However, differential pressures above 100 Pa may result in the deformation of envelope components and must therefore be avoided. No readings should be recorded below 10 Pa, or five times the zero flow pressure difference, whichever is greater.

In exceptional circumstances, e.g. when a dwelling is unexpectedly leaky, it may not be possible to achieve a pressure difference of 50 Pa. In these cases, the failure to attain 50 Pa must be stated in the report, with an account of the reasons why. Readings taken at low pressures will be more adversely affected by environmental conditions and any conclusions drawn from such a report should be treated with caution.

Appendix B - Test Equipment Requirements

B.1.0 Introduction

The requirements of ATTMA for the accuracy of measurements are based primarily around the BS EN Standard 13829:2001 - 'Thermal Performance of Buildings - Determination of air permeability of buildings - Fan pressurisation method' with enhancements recommended by ATTMA.

All instrumentation, whatever the required tolerance, needs to satisfy the annual calibration requirements of UKAS. UKAS Certification is an ATTMA mandatory requirement for all members.

B.2.0 Accuracy

The following is a list of the required measurements and tolerances:

B.2.1 Pressure Differential Measurement (micromanometer)

An instrument capable of measuring pressure differentials with an accuracy of ± 2 Pa in the range of 0 to 100 Pa, with a UKAS accredited calibration.

B.2.2 Air Flow Rate Measurement

The device must have a UKAS accredited calibration and measure the air flow rate to within ± 7 % of reading. The reading of the air flow rate shall be corrected according to air density. Care should be taken when choosing a measurement system such that the system is relatively unaffected by irregular air entry conditions (wind velocities and local obstructions) and that there is stability in the measurement system. Where multiple fans and measurement systems are to be used in unison then the calibration of all individual units need to be verified and UKAS accredited.

B.2.3 Temperature Measurement devices

The accuracy of temperature measurement must have an accuracy of ± 1 °C within the range of -20 °C to + 40 °C.

B.2.4 Barometric Pressure

A barometer should have an accuracy of ± 5 mbar in the range 950 - 1050 mbar.

B.3.0 Calibration

Care will need to be taken in the choice of an air flow measurement system to avoid inaccuracies induced by wind effects on the flow measurement device. The proximity of local obstructions can cause inaccuracies but more particularly the proximity of two flow measurement devices, as can be found with two or more blower door type fans.

The flow measurement device will require to be calibrated against a recognised test procedure. Such test procedures will have to satisfy UKAS requirements and two standards are worthy of reference. The first is BS ISO 3966:2008 'Measurement of fluid flow in closed conduits. Velocity area method using Pitot static tubes' and the second is BS 848-1:2007 (BS EN ISO 5801:2008) 'Industrial fans. Performance testing using standardized airways'.

It will also be a UKAS requirement and by extension an ATTMA requirement to calculate estimates of uncertainties for not only the individual parameters but also a final uncertainty budget from the square root of the sum of the squares of the standard deviation of each source of uncertainty.

Appendix C - Equivalent Leakage Area (ELA)

It is often useful for the test engineer to translate the results of an air leakage test in to a more readily understandable form such as an equivalent leakage area, A (m^2). Area of 'holes' left in the structure can be a useful guide, but it is only an aerodynamic equivalent area based on a sharp edged orifice and should therefore be regarded as approximate.

The flow rate of air can be expressed by:

$$Q_{\Delta p_{env}} = C_d \times A \times \left(\frac{2 \times \Delta p_{env}}{\rho_s} \right)^n \quad 23$$

Where:

The discharge coefficient, C_d for a sharp edged orifice can be taken as 0.61, standard air density ρ_s is taken as 1.20 kg.m^{-3} , n can be taken as 0.5, the test pressure is 50 Pa, and Q_{50} is in $\text{m}^3.\text{s}^{-1}$, which allows equation to be simplified and rearranged to:

$$A = \frac{Q_{50}}{5.57} \quad 24$$

Most dwellings do not exhibit a flow index (n) of 0.5 because the air leakage paths can be long and convoluted, etc. and as such the above equation is only approximate.

The above should be treated with extreme caution since 'holes' in dwellings tend to look considerably larger than they actually are, since the other side of the 'hole' may have a tortuous exit route or be occluded by a hidden membrane.

The equivalent leakage area should only be used as a guide for remedial measures and not to determine the final air permeability value.