THE AIR TIGHTNESS TESTING AND MEASUREMENT ASSOCIATION

TECHNICAL STANDARD 1.

MEASURING AIR PERMEABILITY OF BUILDING ENVELOPES

MEASURING AIR PERMEABILITY OF BUILDING ENVELOPES

Content **Page**

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 Standard 13829:2001 - ‘Thermal Performance of Buildings - Determination of air permeability of buildings - Fan pressurisation method’ with enhancements recommended by ATTMA.

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. Airtightness of buildings was addressed for the first time in the 2002 edition of Part L of the Building Regulations. Although air pressure testing was encouraged, it was required only for buildings greater then 1,000 m^2. The airtightness of the UK building stock has been proven to be poor, which leads to unnecessary ventilation heat loss but also to widespread occupant dissatisfaction.

Just to take one example from research, a comparison was made between two notionally 20,000 m^3 buildings one with an air permeability of 9.3 $m^3.h^{-1}.m^{-2}$ and the other with an air permeability of 23 $m^3/(h.m^2)$. The infiltration heat load from the first was 861 GJ p.a and the second was 2,439 GJ p.a. These are highly significant energy differences caused by ‘holes’ being left in the building structure. Such scenarios are no longer acceptable.

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 (m^3/hour) in or out of the building, per square metre of building envelope at a reference pressure of 50 Pascals ($m^3/(h.m^2)$@50Pa) 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 and all external doors and windows are closed. The test fans are switched on and the flow through them increased until a pressure of 50 – 60Pa is achieved. The total air flow through the fan and the building pressure differential (inside to outside) are recorded. The fan speed is then slowly reduced in steps down to around 20Pa with the fan flow and pressure differential data recorded at each step.

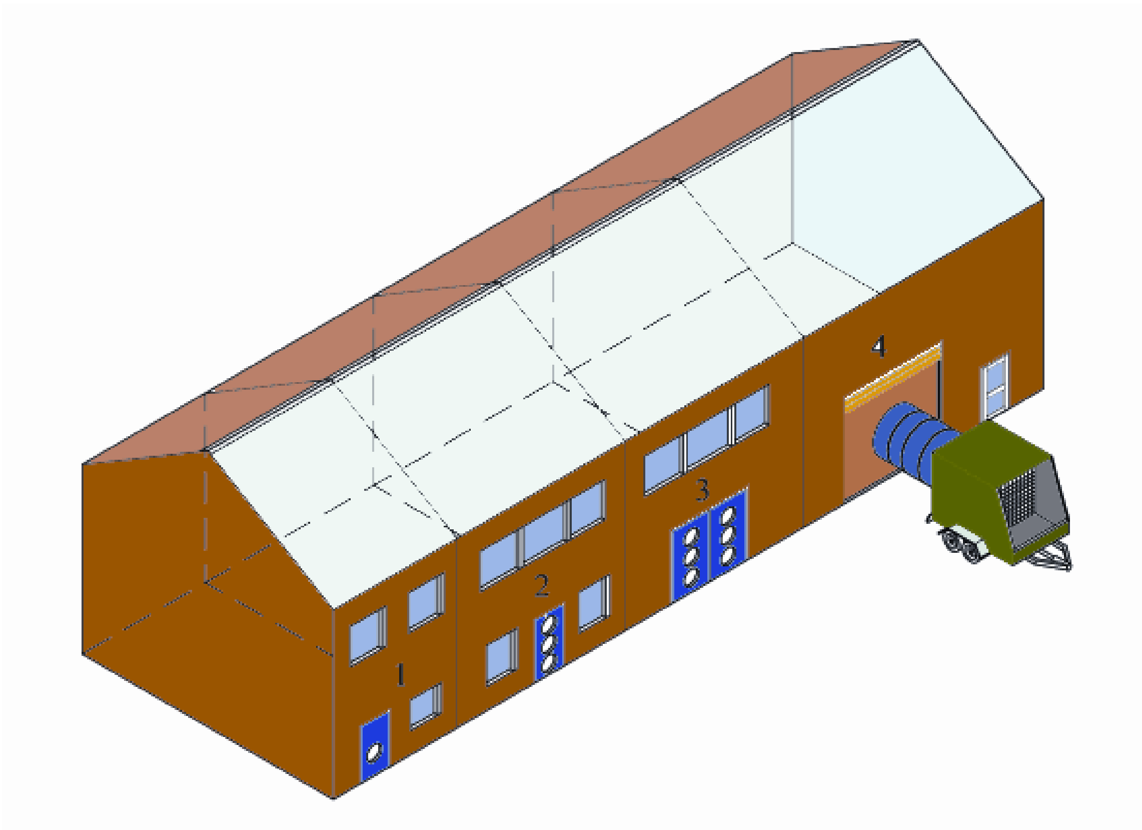
The recorded fan flow (Q) and building pressure differentials (Δp) data allow a relationship to be established. This can be defined in terms of the power law equation:

$$Q = C\,(\Delta p)^{n}$$

Where C and n are constants that are assumed to relate to the geometry of a single opening in the building envelope

The total air flow required to achieve a pressure differential of 50Pa can then be calculated from the equation. This is then divided by the total building envelope area to provide the leakage rate in $m^3/(h.m^2)$@50Pa.

Fan Pressurisation Systems



1. Single fan in single door used for dwellings and small buildings.
2. Multiple fans used in single door for small - medium buildings.
3. Multiple fans used in double door for larger buildings.
4. Trailer or lorry mounted fans for medium to large buildings - can be used in tandem for very large buildings

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. Airtightness standards up until the introduction of the 2002 Building Regulations were based on an air leakage index in which the envelope area was defined as the area of walls and roof. The airtightness of buildings as defined in the Building Regulations is based on air permeability where the envelope area is defined as the area of walls, roof and ground floor slab. For improved energy efficiency and much better control of the indoor environment better airtightness standards are required than the relatively relaxed standards required by the Building Regulations. The following table provides current normal and best practice airtightness criteria for different building types:

Type	**Air permeability**	
	$m^3/(h.m^2)$ at 50 pascals	
	Best practice	**Normal**
Offices		
Naturally ventilated	**3**	**7**
Mixed mode	**2.5**	**5**
Air conditioned/low energy	**2**	**5**
Factories/warehouses	**2**	**6**
Superstores	**1**	**5**
Schools	**3**	**9**
Hospitals	**5**	**9**
Museums and archival stores	**1**	**1.5**
Cold Stores	**0.2**	**0.35**
Dwellings		
naturally ventilated	**3**	**9**
mechanically ventilated	**3**	**5**

2.2 Building Regulation Requirements in the new Part L 2006

Building Regulations Part L requires reasonable provision to be made to limit heat gains and losses through the building fabric. This includes heat transfer by air leakage.

For new dwellings, as defined in *Appendix D* of this document, Building Regulations Approved Document L1A requires pressure tests to be carried out on a representative sample of dwellings.

Approved Document L2A relating to new buildings other than dwellings requires an air leakage test to be carried out on all buildings. There are only a few exceptions. One of the exceptions is where the new build is less than 500 m^2, then an airtightness of 15 $m^3/(h.m^2)$ may be assumed provided that the Target carbon dioxide Emission Rate (TER) is achieved using the National Calculation Methodology. However, it may be desirable to pressure test since the actual (lower) air permeability can then be used to calculate the Building CO_2 Emission Rate (BER). The other exception is where the building is extremely large or complex and this aspect is dealt with separately in section 5 of this document.

ADL2B applies to extensions to existing buildings and does not require the extension to meet a specific air permeability. However where there is an extension to a building with a usable area greater than 1,000 m^2 and the extension is greater than 100 m^2 and provides an increase in area greater than 25%, then the extension should be considered as a new building and ADL2A will apply rather than ADL2B. This will mean that the extension will require an airtightness target within the National Calculation Methodology. An airtightness test will therefore be required to demonstrate compliance, unless 15 $m^3/(h.m^2)$ can be shown to be adequate if the extension is less than 500 m^2.

Where the extension can be tested as a separate entity from the existing building, this will be relatively straightforward, except that the area of internal wall can not be used as part of the envelope area of the extension.

In some cases it will not be practicable to test the extension separately, for example an extension to the sales floor of a large retail outlet. Under these circumstances one approach would be for the existing building, or part thereof, to be airtightness tested before extension works commence in order to characterise the performance of the existing building. On completion of the extension, the building or section of the building will require to be airtightness tested again. The air quantity required to pressurise the existing part of the building including the new extension minus the air quantity required to pressurise the existing part of the building, divided by the envelope area of the extension will provide the air permeability of the extension. An airtightness test on the original building should be carried out before planning approval is granted for the extension. An alternative approach would be to follow the procedures for a large complex building as described in section 5 of this document.

The general requirement for domestic and non-domestic buildings is for the building to be tested to comply with a maximum air permeability of 10 $m^3/(h.m^2)$ at a test pressure of 50 pascals. However, in order to comply with the carbon emission target, a lower air permeability may be required by the Building Regulations and tested accordingly. The value for air permeability actually achieved will be used in the National Calculation Methodology (NCM) to assess the asset rating of the building as actually built. If the building fails to meet the carbon emission target, reducing and re-measuring the air permeability may be one of the few improvement factors practicable.

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 disruption that it may cause to construction works and/or operation of the building.

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

There may be occasions when the building needs to be tested in conditions that are less than ideal and under these circumstances this should be stressed in the test report. However, if tests need to be carried out during periods of 'fresh' (~6 $m.s^{-1}$) wind speeds, the zero flow pressures are likely to exceed 5 pascals. The correction procedures described in the appendix should be carried out. In windy conditions test procedures should be extended.

3.2 Building Envelope Calculations

An accurate evaluation of the building 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.

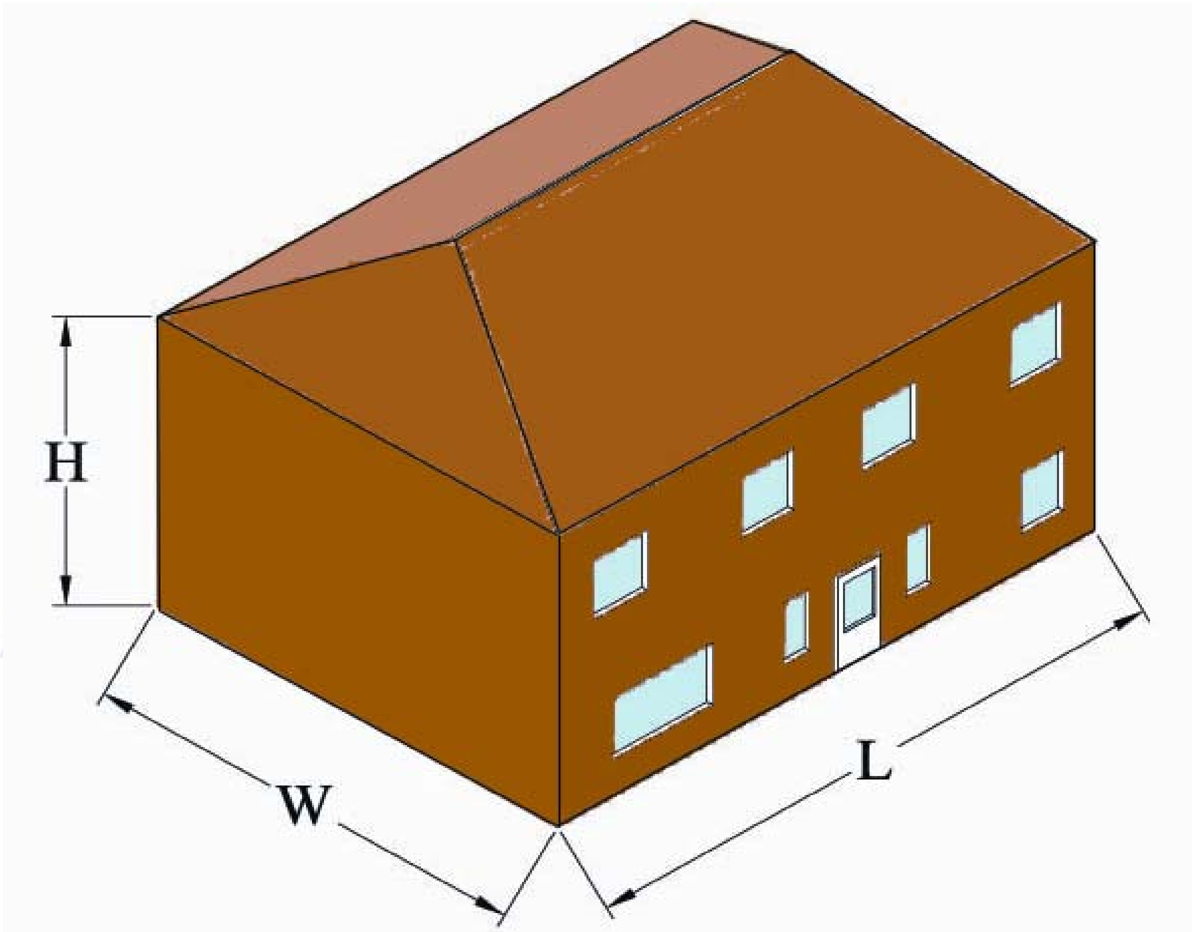
Air Permeability

For an Air Permeability envelope area ($A_{E\ permeability}$), all walls (including basement walls), roof and the floor slab of the lowest level are considered as part of the building envelope.

This is the method of envelope measurement referred to in Part L of the Building Regulations for England and Wales, and in Technical Booklet F of the Building Regulations (Northern Ireland) 2000.

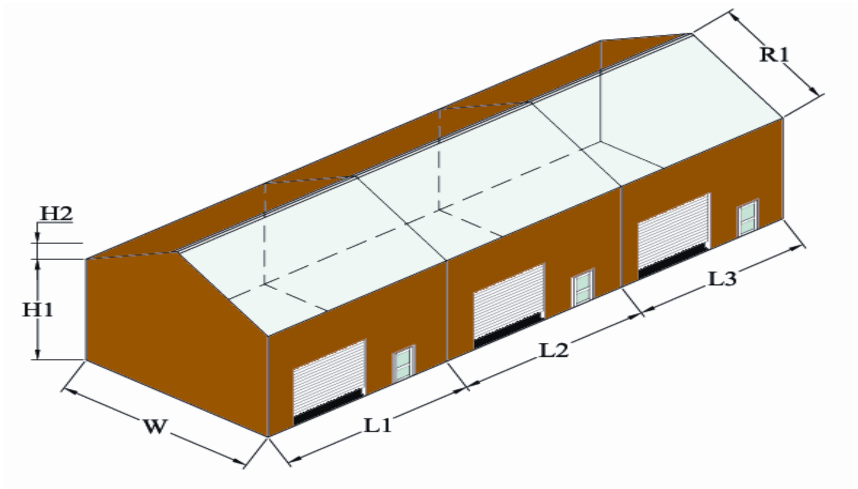
The envelope area of the building will need to be calculated using the dimensions in the following figure and table:

Cold Roof Construction



Cold roof construction - air barrier at first floor ceiling		
Area	Calculation (m^2)	Result
Floor area	L x W (8m x 5m)	40 m^2
Roof area	L x W (8m x 5m)	40 m^2
Wall area	2 x H x (W +L) 2 x 6m x (8m + 5m)	156 m^2
Total	236 m^2	

Interlinked Industrial /retail shed - air barrier between units

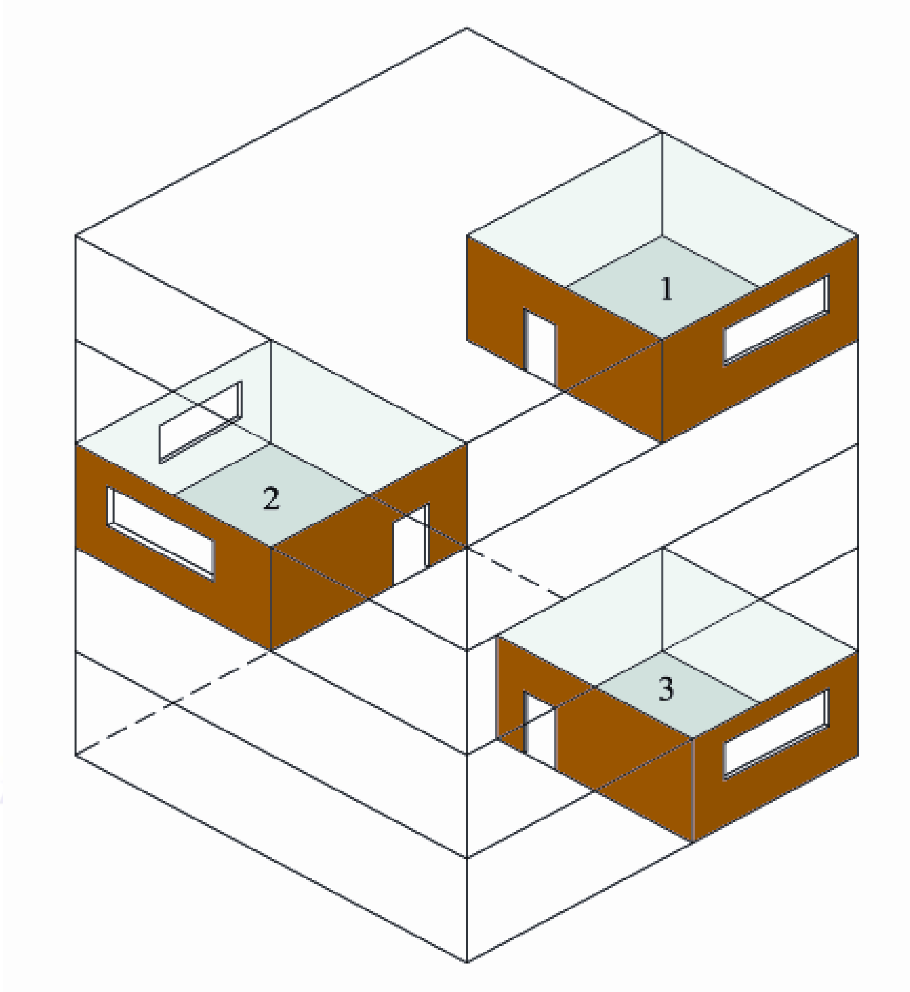


Where H1 = 12m, H2 = 9m, W =24m, R1 = 15m, L1 =20m, L2 = 25m, and L3 = 15m

Interior open to roof - air barrier at sloping roof			
UNIT 1			
	Area	Calculation (m^2)	Result (m^2)
	Floor area	W x L1 (24m x 20m)	480
	Roof area	2x R1 x L1 2x (15m x 20m)	600
	Wall area	2 x H1 x (W + L1) + 2 x (H2 x W ÷ 2) 2 x 12m x (24m + 20m) + 2 x (9m x 24m ÷ 2) = 1056 +216	1272
		Total	2352 m^2
UNIT 2			
	Floor area	W x L2 (24m x 25m)	600
	Roof area	2x R1 x L2 2x (15m x 25m)	750
	Wall area	2 x H1 x (W + L2) + 2 x (H2 x W ÷ 2) 2 x 12m x (24m + 25m) + 2 x (9m x 24m ÷ 2) = 1176 + 216	1392
		Total	2742 m^2
UNIT 3			
	Floor area	W x L3 (24m x 15m)	360
	Roof area	2x R1 x L3 2x (15m x 15m)	450
	Wall area	2 x H1 x (W + L3) + 2 x (H2 x W ÷ 2) 2 x 12m x (24m + 15m) + 2 x (9m x 24m ÷ 2) = 936 + 216	1152

	Total	1962 m^2

Apartments

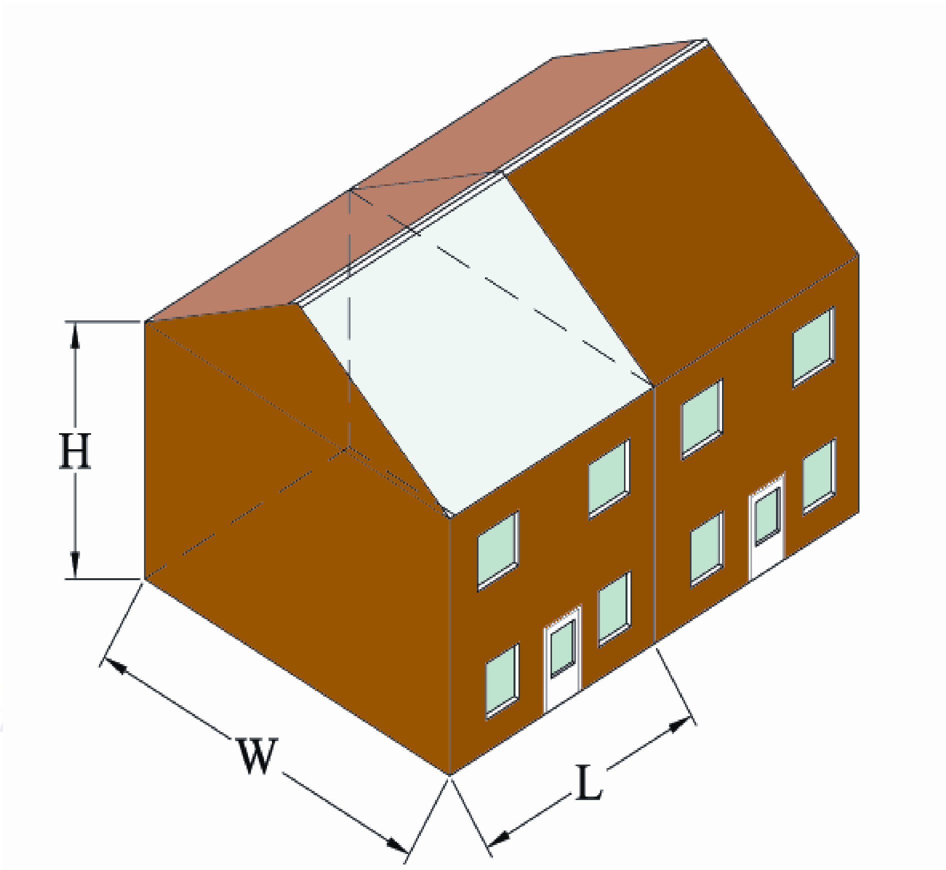


When testing flats you should aim to test a minimum of three flats:

1. Top floor
2. Intermediate floor
3. Ground floor

By testing flats across the building, as shown above, testing will include parts of the roof, ground floor and all four facades.

Semi-detached house



Cold roof construction - air barrier at first floor ceiling		
Area	Calculation (m^2)	Result
Floor area	W x L (8m x 4m)	32 m^2
Roof area	W x L (8m x 4m)	32 m^2
Wall area	2 x H x (W + L) 2 x 6m x (8m + 4m)	144 m^2
Total		208 m^2

The building 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 building.

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

In all buildings other than dwellings, areas heated or cooled in excess of $10W/m^2$ may be considered as conditioned. (Building Regulations [England and Wales] L2A)

Normally the air barrier line will closely follow the insulation to the external envelope, and if this is not clear from information issued this should be confirmed with the client.

Commonly plant rooms and unconditioned escape stairs may be excluded from the test procedure, again this must be confirmed with the client so that the calculation reflects the area of the building to be tested.

Whilst lift shaft vents to the outside remain open during the test procedure, the area of an internal lift shaft should not be included in the external envelope area for calculation of air permeability. Similarly, the area of an internal service riser open to the exterior should not be considered as part of the external envelope area for calculation of air permeability.

The area of the building 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.

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.

3.3 Fan System Selection

The fan system will normally consist of one or more units located within external openings to the building envelope. Adequate fan capacity must be available to undertake the test. This will be established from the target specification, and the envelope area calculations. The minimum equipment flow capacity should normally be no less than 80% of the required flow at 50Pa.

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:

a) Access for fan equipment to be delivered and installed.
b) Air flow restrictions in front and around fans. A clear door opening is preferred.
c) Any electrical power supplies which may be necessary.
d) Local restrictions, e.g. noise, working hours etc.

e) Acceptable route for the air to flow from the fans and pressure to equalise throughout the test enclosure.

The last issue is important in certain larger structures where sizeable volumes of air will be pushed into the building during the test. Ideally air should enter the building along routes without restrictions or sharp turns. Supply air forced through narrow corridors or stairwells should be avoided if at all possible.

If multiple fan systems are to be utilised, these should be located evenly around the building envelope whenever possible. This will allow a more even distribution of air around 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.

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 building must be prepared to allow effective pressurisation, and representative results to be obtained. The method of preparation referred to is generally compliant with BS EN 13829:2001 Method B – Test of the Building Envelope.

To allow pressure to equalise fully around the tested enclosure, all internal doors should be fully opened and restrained. All areas of the building 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:

- Internal doors to riser cupboards may be closed but should not be artificially sealed.

- Lift doors should be closed (but not artificially sealed), Any external lift shaft vents should remain open.

- 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 artificially sealed). The exception to this will be apertures to which test equipment is connected.

- Trickle vents, smoke vents and all passive ventilation systems should be closed but not artificially sealed. 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.

Should only part of a building be subjected to the test, then doors bounding the test enclosure which will ultimately not fall on the external envelope, may be temporarily sealed.

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 test pressure.

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. As temporary seals may, in practice, be more airtight than the envelope element that they replace, results obtained with such temporary seals must be qualified accordingly.

It will normally be the responsibility of the client/main contractor to prepare the building prior to the test. 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. Temporary seals to incomplete components are not normally desirable; any such temporary seals must be recorded.

3.5 Further Test Equipment

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

The indoor/outdoor pressure difference is normally measured at the lowest floor level of the building or enclosure being tested. Measurements are normally obtained through small bore tubing (no greater than 6mm diameter). The internal reference tube will usually terminate near the geometric centre of the building. This must be located away from corridors or doorways where air movement (dynamic pressure) is likely to affect the readings obtained.

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 some distance away from the building envelope. This must terminate out of the air flows induced by the fan pressurisation system, and sheltered from any wind.

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

Suitably calibrated thermometers must be located both inside and outside the building, 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.

Anemometers are required to measure the wind speed, both before and after the test procedure.

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

Measurement of barometric pressure is also necessary.

3.6 Site Test Procedure

When the building 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.

Whilst it is safe for the test to be undertaken with people remaining inside the building, it is often easier for the site operatives/staff to evacuate the building for the period of the test. It is prudent for the client to position a number of people around the building to ensure that doors and windows remain shut, and that any temporary seals employed remain intact for the duration of the test.

Before the test commences, outside and inside temperatures shall be recorded (T_{o1}, T_{i1}). If the difference between these readings ΔT_1, multiplied by the height of the tested building in metres is in excess of 250mK, there is a significant risk that the static pressure (zero flow pressure difference) is likely to be excessive. This figure should be recorded and included in the test report.

The wind speed should also be recorded at this stage. If this is in excess of 6m/s there is again a significant risk that the static pressure (zero flow pressure difference) is likely to be excessive.

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 static pressure readings shall be recorded:

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

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

As noted, 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 the static pressure readings have been taken, air pressurisation equipment can be turned on to pressurise or depressurise the building/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 pressure difference must be the greater of 10Pa, or five times the static pressure measured prior to the test (the greater of $\Delta P_{0,1+}$, $\Delta P_{0,1-}$).

The highest pressure difference should ideally be no lower than 50Pa. If less than 50Pa is achieved this must be recorded within the final test report along with the reason why.

The test can be undertaken with the building 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 building does not become over pressurised (>100Pa) as this may present a risk to internal finishes and the fabric of the building.

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 10Pa. In windy conditions (wind speed >3m/s) a minimum of 10 pressures should be taken, but wherever possible 15 are recommended.

Adequate time must be allowed for induced pressures to stabilise throughout the building envelope, this is particularly significant in larger high rise buildings, and where many internal walls/corridors subdivide the internal space.

Once steady pressure (Δp) and flow (Q_t) 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 recovered. 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 +/- 5Pa, the conditions have not been suitable to undertake a valid test, and the client should be advised.

Should any test have been undertaken with static pressures (either before or after the test) in excess of +/- 5Pa, then any result obtained must be qualified accordingly. Whilst the test undertaken may provide a very approximate result, this should not be used to prove compliance with any specification.

Outside and inside temperatures should be recorded (T_{o2}, T_{i2}), where necessary an average reading may be taken.

The wind speed should be recorded at the end of the test.

Following the test it should be confirmed that the building conditions have remained stable during the test, and that temporary seals and external doors 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.

The final test result is expressed as a rate of leakage per hour per square metre of building envelope at a pressure differential of 50Pa ($m^3/(h.m^2)$@50Pa). This is calculated by dividing the total calculated leakage flow rate Q_{50} by the envelope area A_E.

Section 4 – Test Report

The report shall contain at least the following information:

a) all details necessary to identify the building/envelope tested; purpose of test (method A or B); post address and estimated date of construction of the building;

b) a reference to this standard and any deviation from it;

c) test object:
- description of which parts of the building were subject to the test; apartment number;
- optionally - net floor area and internal volume of space subject to the test ;
- envelope area;
- documentation of calculations so that the stated results can be verified;
- the general status of openings on the building 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;

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 pressurization and depressurization test;
- inside and outside temperatures;
- wind speed, barometric pressure if it is part of the calculation;
- 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 pressurization and depressurization tests determined by the method indicated.
- Air permeability result.

f) date of test.

Section 5 – Large and Complex Buildings

There will be instances where it is not feasible or practicable to carry out an airtightness test on an entire building or complex. The following sections detail various approaches to overcome these difficulties

5.1 Permanently Compartmentalised Buildings

It may be impractical to carry out whole building pressurisation tests on compartmentalised buildings which are divided into separate units having no internal openings to link them. In this case separate pressurisation tests should be carried out on each self contained compartment.

5.2 High Rise & Multi Storey Buildings

It can be difficult to achieve equal pressure across a high rise building and so it may be necessary to employ multiple fans at different points within the building. Approved Document B of the Building Regulations 2000 provides the requirements on the maximum area of multi-storey buildings (non-compartmentalised) at a height exceeding 18 metres and the number of stairwells required for evacuation. Within these restraints there is not normally a problem in pressure testing the entire building at less than 15 storeys. Floor levels do not need to be compartmentalised at and below 4,000 m^2 floor area and the number of stairwells is jointly fixed by the number of people to be evacuated, coupled with the number of shafts required for fire fighting.

Above twenty storeys the pressure loss up through the stairwells can become significant with respect to the requirement for all internal pressures to be within ±10%, unless there are light wells and/or an Atria - factors which would alleviate the testing situation.

For buildings well above fifteen storeys, the lift shafts could be deployed by opening doors at various levels - provided suitable safety precautions are deployed. This normally provides sufficient open area up through the building for the building to be pressurised as a complete unit.

For buildings above 20 storeys it may be appropriate, under some circumstances, to test the building by floor level and the following logic would be recommended.

- Test the Ground floor and pressurise the First floor simultaneously to produce the same test pressures on both of those floors. The flow rates to the Ground Floor should be recorded and analysed in the usual way but taking the envelope area as that of the ground floor slab and external wall area of the ground floor only. If the first floor plan area is less than the ground floor then any ground floor roof areas may be included in to the envelope area.

- Test a selected intermediate floor at the same time as pressuring the floors above and below the test floor at the same test pressures. The data should be analysed in the usual way but the envelope area will be the area of the external walls of the test floor only.

- Test the top floor and pressurise the floor below it and take the envelope area as that of the external walls of the top floor and the roof area. Sufficient open area between the test floor and ground floor should be provided along with a route to feed the outside differential pressure tube. This aspect applies to all tests.

- The number of intermediate floors tested should be taken as 10%, unless there are substantially different methods of construction between floor levels

- If all of the above measured air leakage rates are less than the required specification then the building would have passed the air permeability criteria.

- If any of the building elements fail the required criteria then the Q_{50} for the ground floor plus the Q_{50} for the top floor should be summed with the highest Q_{50} for an intermediate floor multiplied by the number of the intermediate floors. This total air flow rate should then be divided by the envelope area of the building to produce a final value.

Most triple fan blower door systems will deliver a total of at 7.5 m^3/s. An intermediate floor area of 4,000 m^2 and a height between floors of 4 metres would require a flow rate of around 2.8 m^3/s per floor at an air permeability of 10 $m^3/(h.m^2)$. The top floor would require around 11.8 m^3/s and would therefore require two triple fan blower doors on the top floor with one double fan blower door on the floor below. Ground floors very often have a footprint greater than the main high rise portion of the building, but then normal large portable fans can be used at this level. Most high-rise buildings could therefore be tested with this methodology, but with the caveat that where the cross-sectional area changes dramatically after Second floor level and above, extreme care and diligence should be applied to the testing methodology and air flow testing requirements. More floor levels may need to be tested under these circumstances.

Tall buildings with intermediate floor areas greater than 4,000 m^2 would need to be compartmentalised for fire safety reasons and should be evaluated individually in terms of the above testing protocol, i.e. where a section of a building is to be evaluated then all surrounding internal zones (above, below and horizontally) should be pressurised equally.

5.3 Large and Complex Buildings

Large, in the context of this document, means buildings with an envelope area in excess of 60,000 m^2 with a target air permeability of 10 $m^3/(h.m^2)$ @50Pa or 120,000 m^2 with a target air permeability of 5 $m^3/(h.m^2)$ @50Pa. Complex and large buildings could encompass new District General Hospitals, Airport Terminals, Large City Shopping Centres and large developments where there is a phased hand-over spread over a significant time period.

It is expected that many of these building types can be broken down by Department or groups of Retail Outlets, for instance, which could facilitate part pressure testing.

There will no doubt be some, albeit few, buildings where none of the above approaches would be practicable and in such instances the following approach is recommended:

- The local Building Control Authority and/or ODPM should confirm that none of the above is practicable and that this is therefore to be treated as a 'Special Case'.

- The local Building Control Authority and/or ODPM should approve the approach to ensure that the development will be constructed to the required airtightness standard (no less than 5 $m^3/(h.m^2)$ @50Pa) taking due cognisance of air sealing details and component testing where necessary.

- A thorough quality management procedure is required. An ATTMA member should oversee the project with regard to airtightness issues, inspect detailed air sealing drawings, inspect the building at intervals during construction, recommend full-scale mock-ups of sections of the building be tested and/or recommend air tightness testing of components.

- Detailed specifications and drawings with regard to air sealing must be collated and reviewed, particularly where different trade contractor 'packages' need to be air sealed to each other. Where there is likelihood that these sealing details can not be inspected progressively before such details become concealed, a system, such as photographic records, should be put in place so that there is comprehensive assurance that the building is built to the design criteria.

- Contractor's tradesmen should be given demonstrations of what the goals are and what to watch out for in their work to avoid defects.

- Contractors may be required to remove items which conceal air sealing details for inspection.

- Feedback from the results of mock-up or component testing should be implemented in the general design.

- An audit trail should be kept and, at handover, be handed to the client for archiving.

Zone/Sample Testing

Phased handover or occupancy of a building may preclude the testing of a whole building in practical terms. If such situations exist, a test to a representative sample may be deemed reasonable. This should represent at least 20% of the building envelope area and the areas tested must be representative of the external envelope construction for the building as a whole. Where samples are used to prove compliance of larger areas of the building, it is necessary to achieve a test result 10% below the target specification, thereby giving some comfort that workmanship and detail issues elsewhere may not compromise the envelope air leakage performance when considered for the whole.

Testing of sample areas can prove problematic as inevitably internal walls or temporary screens isolating test zones will also be tested. Leakage through these elements will impact upon the result for the sample in question, although ultimately they may not form part of the building envelope. Such walls must be constructed as air barriers as tightly as possible. **Their area should not be considered in calculation of the air permeability of the tested sample.**

•

Appendices

Appendix A – Equations and Corrections

A1.0. Equations

A1.1. Corrections for zero flow pressure differences

Zero flow pressure difference corrections should be applied to the observed building 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:

$$\Delta p_{env} = \Delta p_{\mathrm{m}} - (\Delta p_{0,1} + \Delta p_{0,2})/2$$

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.

A1.2. Calculation of air density

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

$$\rho = (p_{\mathrm{bar}}/287.055\ (\theta + 273.15)$$

The above is slightly out by the equivalent of 5 mbar.

$$\rho = (\mathrm{p_{bar}} - 0.37802\mathrm{p_v})/(287.055\ (\theta + 273.15))$$

where $\mathrm{p_v} = \varphi \exp\{59.484085-(6790.4985/(\theta + 273.15)) - 5.02802(\ln(\theta + 273.15))\}$

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

A1.3. Correction for actual and observed airflow through the measuring device

The actual flow rate through the fan is a function of the measured values at the last fan calibration and measured values during the air test. This is calculated by equation:

$$Q_m = Q_c\,(\rho_c/\rho_m)$$

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 (kg/m^3) and ρ_c is the air density recorded during fan calibration.

A1.4. 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 building envelope. The correction to be applied depends on whether the building is being pressurised or depressurised.

A1.4.1. Corrections to airflow rate for pressurisation tests:

Convert the measured airflow rate, Q_{m} , to airflow through the building envelope, $Q_{\mathrm{env(out)}}$, for pressurisation using equation:

$$Q_{\mathrm{env(out)}} = Q_{\mathrm{m}} \left(\rho_{\mathrm{e}}/\rho_{\mathrm{i}}\right)$$

where $Q_{\mathrm{env(out)}}$ 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).

A1.4.2. Corrections to airflow rate for depressurisation tests:

Convert the measured airflow rate, Q_{m} , to airflow through the building envelope, $Q_{\mathrm{env(in)}}$, for depressurisation using equation:

$$Q_{\mathrm{env(in)}} = Q_{\mathrm{m}} \left(\rho_{\mathrm{i}}/\rho_{\mathrm{e}}\right)$$

Where $Q_{\mathrm{env(in)}}$ 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).

A1.5. 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 building differential pressures (ΔP_{env}) and corresponding fan flow rates (Q). 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. For this, the straight line

$$y = mx + b$$

should be fitted through the given points $(x_1, y_1),\ldots,(x_n, y_n)$ so that the sum of the squares of the distances of those points from the straight line is minimum, where the distance is measured in the vertical direction (the y-direction). 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 pressurisation test are as follows:-

$$dSumXY = \sum(\text{In } \Delta P_{env} * \text{In } Qc)$$

$$dSumXX = \sum(\text{In } \Delta P_{env} * \text{In } \Delta P_{env})$$

$$dSumX = \sum(\text{In } \Delta P_{env})$$

$$dSumY = \sum(\ln Q_C)$$

m = (dSumX * dSumY - Numpnts * dSumXY) / (dSumX * dSumX - dSumXX * Numpnts)
b = (dSumX * dSumXY - dSumXX * dSumY) / (dSumX * dSumX - dSumXX * Numpnts)

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

$$C_{env} = \exp^{b}$$

$$m = n$$

A1.6. Correction of airflow rates through the envelope to STP

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

$$Q_{env} = C_{env} (\Delta p_{env})$$

where Q_{env} is the air flow rate through the building envelope (m^3/h) and Δp_{env} is the induced pressure difference, in Pascal.

The air leakage coefficient, C_L , is obtained by correcting the air flow coefficient, C_{env} , to standard conditions (i.e. 20 ^{o}C and 101325 Pa) for pressurisation using equation.

$$C_L = C_{env} (\rho_i / \rho_s)^{1-n}$$

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

The air leakage coefficient, C_L , is obtained by correcting the air flow coefficient, C_{env} , to standard conditions (i.e. 20 ^oC and 101325 Pa) for depressurisation using equation:

$$C_L = C_{env} (\rho_e / \rho_s)^{1-n}$$

where 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 , for a given building differential pressure, Δp_{env} , can be calculated using equation:

$$Q = C_L (\Delta p_{env})^n$$

where C_L is the air leakage coefficient, in m^3/(h·Pa^n), Δp_{env} is the induced pressure difference (Pa) and n is the air flow exponent.

A1.7. Air permeability

The air permeability, Q_{50}/(S+F), is the air leakage rate at a pressure difference of 50 Pa, divided by the building envelope area S + F (m^2). Units are m^3 h^{-1} per m^2 of envelope area. The air permeability is calculated from

$$Q_{50} = C * (\Delta P)^n$$

$$\text{Air Permeability} = 3600 * Q_{50} / (S + F)$$

where S is the exposed surface area of the walls and roof, and F is the area of the solid ground floor

A1.8. 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.

Correlation coefficient = $S_{xy} / \sqrt{(\sigma^2)}$ where;

σ^2 = (Numpnts * dSumXX - dSumX * dSumX) * (Numpnts * dSumYY - dSumY * dSumY)

S_{xy} = Numpnts * dSumXY - dSumX * dSumY

A2.0. Essential parameters (r^2 and n)

Assessment of building airtightness using a steady state technique relies on the premise that an equal pressure difference is maintained across the whole of the building 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.

A2.1. 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 building pressurisation test with a minimum of 5 building envelope readings typically taken in the range 20 to 60 Pa, 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.

A2.2. Air flow exponent (*n*)

The fortuitous air leakage paths through a building 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 0.5and 1.0. If the value of n is not within these limits ± 0.01, 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 building elements and represents air flow through rather large apertures, which tend to be indicative of rather leaky structures. n values which approach 1.0 will have approached laminar flow through the building elements and ~~are~~ generally represent very tight structures or those with a myriad of very tiny holes.

A3.0. Limiting factors

A3.1. Windspeed

The meteorological wind speed should ideally not exceed 6 m s^{-1}. Due to commercial pressures and characteristic British weather, it may sometimes be necessary to carry out tests in conditions outside of this parameter. To minimise the negative effect of wind pressures on test accuracy it is advisable to aim for a maximum building differential pressure of 100 Pa, with no readings taken below 35 Pa. Readings should be taken for 15 fan speeds. This increased sample size should ease the identification of outlying results.

A3.2. Static pressures within tall buildings

Buildings with large internal/external temperature differences are subject to stack pressures. These may be more pronounced in tall buildings. If the product of the temperature differential across the building envelope (Δt), multiplied by the building height (m) is greater than 250mK, it is likely that the stack pressure is too great to maintain an equal pressure difference across the whole of the building envelope.

A3.3. Uniform pressures across the building envelope

In multi cellular buildings all internal doors should be opened, so that a uniform pressure is maintained across the whole of the building envelope. This may entail using a number of fans strategically located in various doorways or other openings around the envelope. Two differential pressure measurements should be made at separate locations at the maximum required building differential pressure. Uniform pressure should be maintained within ±10%.

A3.4. Zero-flow pressure differences

Temporarily sealing is applied to the fan(s) at the start and end of the test. Readings for building 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.

A3.5. Minimum acceptable building differential pressures

The building differential pressures induced during an air test should be greater than those occurring naturally to minimise the influence of wind and stack effects. A pressure of 20 Pa must be established across the envelope, with readings typically taken up to between 60 and 100 Pascals. 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 should therefore be avoided.

In exceptional circumstances, e.g. when a large building is unexpectedly leaky, it may not be possible to achieve a pressure difference of 50 Pa. In this case, a minimum of 35 Pa must be achieved, with no readings taken below 10 Pa, or 5 times the zero flow pressure difference, whichever is greater. 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

B1.0 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.

The primary measurements for this type of work are clearly pressure differentials and air flow rate measurement. Measurements of wind velocity, air temperature and barometric pressure do not require such a high accuracy level since they are used as corrections to the primary air flow measurements and are of second order. All instrumentation, whatever required tolerance, does need to be UKAS certificated and calibrated at regular intervals. UKAS Certification is an ATTMA mandatory requirement for all members.

B2.0 Accuracy

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

B2.1 Pressure Differential Measurement (micromanometer)

An instrument capable of measuring pressure differentials with an accuracy of ±2 pascals in the range of 0 to 60 pascals.

B2.2 Air Flow Rate Measurement

A device to measure the air flow rate to within ± 7 % of reading. The reading of the air flow rate shall be corrected according to air density. Calibration issues will be dealt with in Section 3.2, but this is a wide and sometimes confusing issue. Care should be taken when choosing a measurement system 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 together need~~s~~ to be verified and UKAS accredited.

B2.3 Temperature Measurement devices

The accuracy of temperature measurement should have an accuracy of ±1K.

B2.4 Wind Speed - Anemometer

The device for measuring wind speed should be horizontally omni-directional such as a cup anemometer. The accuracy of measurement should be ±1 m/s in the range 3 to 6 m/s. This is a nominal accuracy since the recommendation is to undertake air leakage measurements at wind velocities less than 6 m/s. Wind speed indicators tend to have poor accuracy at these low velocities and in any case accuracy at low level in the environs of buildings can give misleading results. Reliance should be placed on the measured fan-off pressure difference in deciding whether the test conditions are suitable, i.e. less than 5 ±1.0 pascals between inside the building and outside.

B2.5 Barometric Pressure

A barometer should have an accuracy of ± 5 mbar in the range 950 - 1050 mbar. The barometer is used for correcting air flow rates and has a small effect on the measurement accuracy. As with wind speed the European and International standards do not impose a measurement accuracy on these parameters but are imposed within the ATTMA requirements.

B3.0 Calibration

All measurement equipment used will need to be regularly calibrated by a UKAS accredited organisation. This will apply to micromanometers, thermometers, anemometers and barometers and will normally be an annual 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 BS1042 : Section 2.1 : 1983 (ISO 3966-1977) - 'Measurement of Fluid Flow in Closed Conduits' and the other is ANSI/AMCA Standard 210-85 (ANSI/ASHRAE 51-1985) - 'Laboratory Methods for Testing Fans for Rating'.

It will also be a UKAS requirement and therefore 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 equivalent leakage area, 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:

$$Q = A.C_d\{2\Delta p/\rho\}^{0.5} \quad m^3.s^{-1}$$

Where the discharge coefficient, C_d for a sharp edged orifice can be taken as 0.61 and if ρ is taken as 1.2 $kg.m^{-3}$ this can be simplified to:

$$Q_{\Delta p} = 0.788.\ A\ (\Delta p)^{0.5} \quad m^3.s^{-1}$$

or at a test pressure of 50 pascals:

$$A = Q_{50}/5.57 \quad m^2$$

Most buildings 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.

However, if for example one takes a 6,000 m^2 gross footprint area warehouse building (15,600 m^2 envelope area), the current Building Regulations require a maximum air permeability of 10 $m^3/(h.m^2)$ and at that performance there would be about 7.8 m^2 of 'holes' left in the structure. If the building failed the air tightness test at an air permeability of 14 $m^3/(h.m^2)$, then there would be about 10.9 m^2 of 'holes' left in the building. There would be little point in re-testing the building until well over 3 m^2 of 'holes' had been identified and sealed. This gives a useful 'feel' for the scale of the problem.

The above should be treated with extreme caution since 'holes' in buildings 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.

Appendix D Definition of *Dwelling Types*

Approved Document L1A demands testing of selected samples of dwellings by "type". This Appendix to ATTMA TS1 defines these "Dwelling Types"

Various generic forms of dwelling are considered as separate discreet types. Examples include:

- Detached
- Semi detached
- End-terrace
- Mid-terrace
- Ground-floor flat
- Mid-floor flat
- Top-floor flat

The number of storeys will also define different dwelling types, i.e. 1, 2, 3, etc.

For dwellings to be considered to be of the same type:

- They must contain the same construction details for each of the main elements, i.e. walls, floors and roofs.

- They must have similar floor areas. Small variations in gross floor area do not constitute a different dwelling type. For the purposes of this Technical Standard the difference in gross floor area between the largest and smallest within a dwelling type should be no greater than 15%.

- They must have a similar number of significant penetrations (SP) defined as the sum of the total number of window frames and entrance door frames (including patio door frames) in the external façade. Flues are also counted as significant penetrations. A dwelling can't be considered as the same dwelling type if the total number of significant penetrations varies by more than ±1. *(For example, if a dwelling type contains 6 SP's then dwellings with 8 or more SP's can not be considered as the same dwelling type neither can 4 or less SP's be considered as the same dwelling type).*

- For the purposes of this Technical Standard a cold roof construction will be considered as a different dwelling type from a warm roof construction, since in the latter case the loft space will be included in the airtightness tests. Similarly a cold floor, flat above an access road will be considered as a different dwelling type.

- Where there are a number of dwellings within a dwelling type, there may be variations in their design air permeability due to SAP calculation differences. In order for all those dwellings within that type to conform to Part L1A then the lowest dwelling design air permeability must be used as the acceptance criteria, regardless of which plot is tested. Alternatively, the dwelling type should be subdivided according to their design air permeability resulting in more dwellings of that type being tested

Appendix E

ATTMA information - See website: www.attma.org

Appendix F

List of members - See website: www.attma.org