TECHNICAL STANDARD L1.

MEASURING AIR PERMEABILITY IN THE ENVELOPES OF DWELLINGS

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This document provides the technical standard to be followed for the testing of dwellings as set out in Building Regulations and specifying documents around the world.

This Technical Standard is based on BS EN 13829:2001 - ‘Thermal Performance of Buildings - Determination of air permeability of buildings - Fan pressurisation method’ and ISO 9972:2015 Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method.

This Technical Standard sets out to provide detailed guidance and clarification of the above two listed standards in order to ensure consistency by testing companies.

Guidance for test procedures for the testing of Non-Dwellings is provided within companion reference document ATTMA Technical Standard L2.

Contents

Section 1 - Preambles

1.1 What is air leakage testing?

Air leakage testing, often known as air tightness testing, is the process of measuring the amount of conditioned (heated or cooled) air leaking from a building through uncontrolled ventilation. A fan is installed into the external envelope of the building and supply's air into, or extracts air out of, the property creating a pressure difference. The tester uses calibrated equipment and calculates an air flow into, or out of, the property. In simple terms, the amount of air going into, or out of the property when the building is subject to a pressure differential is the amount of 'air leakage'. The result can be described as the 'air permeability'. The process is known as 'air leakage testing'.

1.2 Who is authorised to test?

For a testing organisation to show compliance with this standard, they must have suitable 3rd party monitoring systems in place. This is demonstrated by either:

1. holding UKAS (or national equivalent) accreditation specifically for building air leakage testing in line with BS EN ISO/IEC17025:2005 (ISO 17025)
   or
2. having an active registration with a nationally recognised competent persons scheme (CPS).

1.3 Air Tightness & Ventilation

A common myth is that low air tightness levels can cause building sickness and poor air quality. It is important to match the air tightness testing targets and end result with adequate means of ventilation.

Low air permeability results (results typically less than 5 $m^3.h^{-1}.m^{-2}$ @ 50 Pa) will require an assessment of the ventilation strategy in order to achieve adequate air changes and therefore adequate air quality. Guidance can be taken from local Building Regulations.

High air permeability results (results greater than 5 $m^3.h^{-1}.m^{-2}$ @ 50 Pa) will allow much more freedom with the choice of ventilation. It should be noted however, advanced mechanical ventilation systems, such as heat recovery systems, may use much more energy than designed, and may not adequately heat a building. Mechanical ventilation systems, particularly those with heat recovery abilities, could require more maintenance and operate at an increased noise level as a consequence of high air permeability results.

1.3.1 What is good practice?

Table 1 gives guidance on what is considered to be 'good practice' for residential buildings.
It shall be noted however that the below figures may not apply to all situations. In the case of doubt, specialist advice shall be sought.

(i) Table 1 – Best Practice Air Leakage Against Ventilation Strategy

Ventilation Strategy	Best practice / Target Air Permeability *($m^3.h^{-1}.m^{-2}$ at 50 Pa)*	Best practice / Target Air Change Rate *(h^{-1} at 50 Pa)*
Trickle Ventilators and/or intermittent extractors	3.0 - 5.0	-
Passive Stack	3.0 - 5.0	-
Continuous Mechanical Ventilation	2.0 – 4.0	-
Continuous Mechanical Ventilation – with Heat Recovery	1.0 – 2.0	-
Other	Seek Specialist Advice	-
Passivhaus Standard	-	0.6*

* See guidance in 1.4 – Passivhaus Testing

1.4 Passivhaus Testing (Low air leakage buildings)

Passivhaus testing uses the same test method as ATTMA TSL1 but a different method of calculation and presentation of results.

Other than the test method, this standard should not be used to provide guidance on Passivhaus testing methods.

The Passivhaus Trust (http://www.passivhaustrust.org.uk/) can provide guidance when Passivhaus testing is required.

Section 2 – Approved Test Procedure

2.1 Pre Test Requirements

Liaison shall 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, however minor these are.

The test procedure can be significantly affected by extremes of weather (wind speed, internal/external temperature differential). 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 clearly identified 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 could exceed 5 Pascals making the test result invalid. In such circumstances, guidance should be taken as to whether or not the result is reflective of the buildings actual performance.

2.2 Building Envelope Calculations (A_E)

The Envelope Area Calculation, is defined as the sum of the area of the boundary walls, roof and floor. Internal walls are excluded unless they form part of the external barrier, for instance an integral garage wall or a plant room. 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.

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 directly heated or cooled.

The 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.

The dwelling envelope can be calculated from accurate dimensioned drawings. It must be verified on-site, using 2 or more 'reference check points' to confirm the scale used is accurate. The drawings used for the measurement must be current and reflect dimensions of the completed dwelling.

The envelope area of the dwelling should be measured along the line of the component to be relied upon for air sealing. Note that this is not always the 'thermal line' of the building.

For dwellings that do not require air tightness to be less than 5 $m^3.h^{-1}.m^{-2}$ @ 50 Pa, it is common that the internal plasterboard lining is used as the air barrier line. For dwellings that require less than 5 $m^3.h^{-1}.m^{-2}$ @ 50 Pa, the air barrier line shall be identified by the contractor. Failing to identify an air barrier line at the beginning of the project will likely lead to problems at the time of testing.

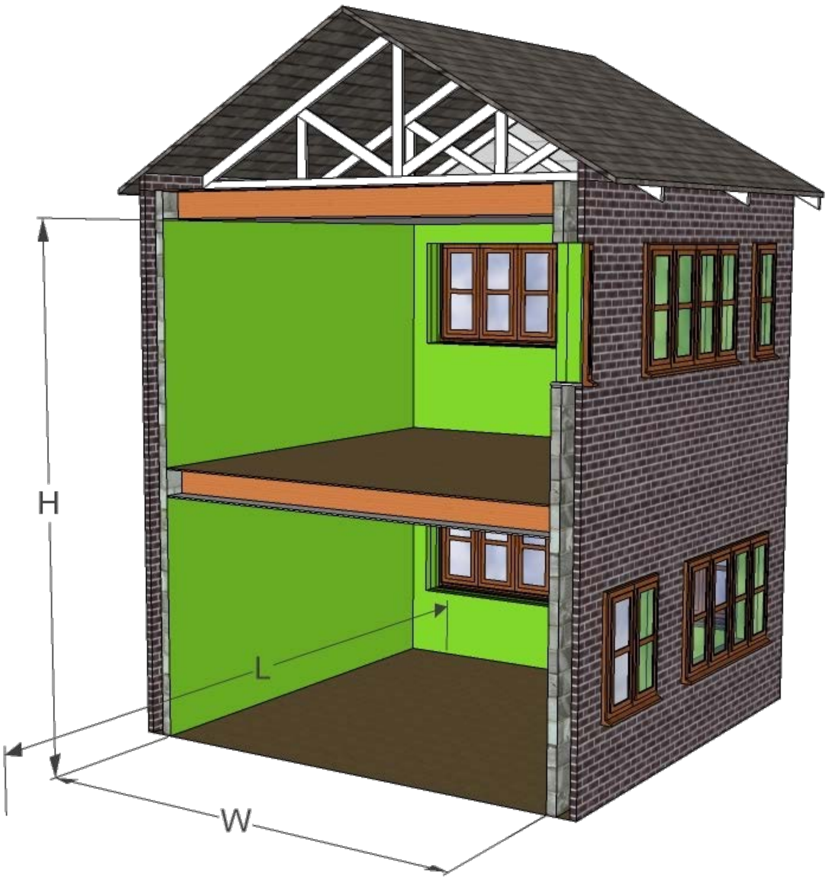
An accurate evaluation of the dwelling or test area envelope must be made prior to the test being undertaken. The necessary fan flow required to undertake the test shall be calculated from this figure.

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 and/or Lodgement Certificates.

2.2.1 Cold Roof Construction Envelope Area Calculation Example

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.

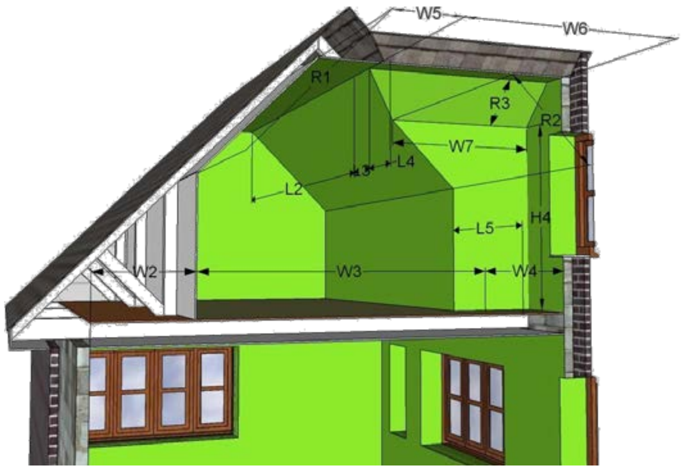


Where: Length (L) = 7.40 m Width (W) = 4.40 m Height (H) = 5.30 m

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

2.2.2 Warm Roof Construction Envelope Area Calculation Example

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 (m²)
Floor area	L1 x W1 (7.40 x 4.40)	32.56
Roof area	(((2 x L1) – L5) x W2) + (L1 x W5) + (L4 x W6) + (L1 x R1) + ((L1 – L5) x R1) + ((R1 – R2) x L3) + ((W6 + W7) x R3) (((2 x 7.40) – 1.30) x 0.85) + (7.40 x 0.58) + (0.50 x 1.91) + (7.40 x 1.50) + ((7.40 – 1.30) x 1.50) + ((1.50 – 0.93) x 0.40) + ((1.91 + 1.51) x 0.57)	39.15
Wall area	(2 x (W1 +L1) x H1) + (((2 x L1) – L5) x H2) + (2 x W3 x H2) + (W5 x H3) + (W3 x H3) + (L5 x H4) + (((L4 + L5)/2) x (H2 + H3 – H4)) + (2 x W4 x H4) + ((W7 – W4) x (H4 – H2)) (2 x (4.40m +7.40m) x 5.10m) + (((2 x 7.40m) – 1.30m) x 1.44m) + (2 x 2.70m x 1.44m) + (0.58m x 1.06m) + (2.70m x 1.06m) + (1.30m x 2.10m) + (((0.50m + 1.30m)/2) x (1.44m + 1.06m – 2.10m)) + (2 x 0.85m x 2.10m) + ((1.51m – 0.85m) x (2.10m – 1.44m))	158.15
	Total	*229.9m²*

2.3 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 which will be established from the target specification, and the envelope area calculation. The fan flow rate must be in excess of that required to pressurise or depressurise the building to greater than +/-55Pa and never less.

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. This is particularly important when testing large dwellings (dwellings with an envelope greater than 750 m^2 envelope area). 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 as this may affect temporary sealing methods and locations.

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

2.4 Building Preparation

Prior to the test being undertaken, the dwelling must be prepared to allow effective pressurisation or depressurisation and representative results to be obtained.

Testing for this standard is carried out using Method B. Method B tests the building fabric excluding the ventilation and therefore ventilation is excluded from the test by being temporarily sealed. Only the ventilation designed within the energy model where the purpose of the ventilation is to provide air into the dwelling shall be sealed for the test.

For the result of the test to be representative, the external envelope should be in its final completed state. All penetrations that will break through the air tightness barrier must be have already been made. It is not acceptable to test a plot, unless in exceptional circumstances, where penetrations are not yet made.

Table 2 provides a checklist for work that is required to be completed before a test can be conducted:

(i) Table 2 – Building Condition Requirements

Step	Description	Completed?
1	Drainage traps in toilets, sinks, showers and wet rooms are filled with water.	
2	Incoming or outgoing service penetrations have been made and have permanent sealing works completed around the penetrations.	
3	External Doors, including integral garage doors, are fitted with seals and closed as necessary.	
4	External Windows are fitted with seals and closable as necessary.	
5	Plug, television, data, satellite and shaver sockets must be fitted to the wall without items plugged in, other than for the operation of the air tightness equipment.	
6	Light switches shall be fitted to the wall.	
7	Internal Doors are restrained open and remain open for the test.	
8	Power is available to the plot in order to power the fan	

2.5 Temporary Sealing

2.5.1 Mandatory temporary sealing

Air permeability testing to Method B tests the building fabric and not the designed ventilation. It is therefore mandatory to temporarily seal designed ventilation, including:

- Mechanical ventilation - (Extractors, MVHR, Air Handling)
  - Mechanical ventilation systems such as bathroom, kitchen and cooker hood extracts must be switched off before being temporarily sealed for the test.
- Trickle ventilators
  - Trickle ventilators shall be closed for the test and may be temporarily sealed in some countries, depending on national guidance.*
- Air conditioning
  - Air conditioning grilles can be sealed internally or at the intake/outlet of the AHU. It is important to check and confirm that the air conditioning is switched off during the test.
- Passive ventilation
  - Passive Ventilation, such as air bricks to outside, acoustic vents and passive stacks should be temporarily sealed for the test. The air leakage should be measured by relying on the damper. Sub-floor ventilation shall not be sealed as the air seal is the floor itself.
  - Internal transfer grilles (leading from a hallway into a boiler cupboard, for example) should not be sealed.
- Chimney flues
  - Flues should ideally be blocked using an expandable balloon rather than the front of the chimney being sealed. It is not always practicable to block the flue directly, in which case the seal should be against the fireplace. The fireplace should not be sealed to the wall or floor as this is not designed ventilation.

*This is currently the case in England and Wales only. Note that if the trickle vents are not factory fitted, it is often easier to temporarily seal the gap for the trickle vent rather than trying to seal around the trickle vents once installed.

Temporary seals employed during the test (including the method of closure of mechanical ventilation systems) must be checked and recorded for inclusion in the test report.

The application of the temporary seals shall be agreed between the tester and the client before the test takes place.

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

2.5.2 Additional Temporary sealing (Deviations)

Temporarily sealing items is not a method of compliance. Temporary sealing items not listed in 2.5.1 may result in the report being rejected by the Competent Person's Scheme and/or building control.

It is never acceptable to temporarily seal the following items:

- Sockets (Electrical, Switches)
  - Electrical sockets should never be temporarily sealed. Any test that has temporary sealing on sockets will be immediately rejected.
- Downlights
  - Downlights may be designed to draw in air and must never be temporarily sealed for an air test. Selection of downlights should be considered as part of the overall design of the building.
- Bath panels & shower trays
  - Bath panels and shower trays are not the air barrier line of a property and must never be temporarily sealed. Areas behind bath panels and shower trays should be permanently sealed before, or during fitting.
- Loft hatches & access panels
  - Loft hatches and access panels shall be fitted before the test is conducted. It is never acceptable to temporarily seal a mal-fitting loft hatch or access panel
- Doors
  - Doors to unconditioned storage areas should be closed and not temporarily sealed. This includes doors to garages.
  - It is never acceptable to temporarily seal a cupboard door, including boiler / water tank cupboard or kitchen cupboard doors. Doing so and declaring the result as final may result in your competence being questioned by your competent person's scheme.
- External doors and window frames
  - External doors and window frames shall have seals fitted before the test is conducted. It is never acceptable to temporarily seal a mal-fitting door or window, even if the seal has not yet been fitted.

The above list is not exhaustive. If the item to be sealed is not 'designed ventilation' it shall not be sealed.

Temporary sealing a broken or missing component can only be carried out as an exception and only where it is not possible to fix or install a single broken or missing component (i.e. a single missing downlight or a single ill fitting light switch) and never 'gaps and cracks'.

Components that are not going to be fixed that are sealed for the purpose of the test (such as bath panels, gaps in external doors) will result in the report being rejected.

Building Control shall seek an explanation from the testing company should any deviations be present.

2.6 Test Equipment

Equipment	Description	Calibration Required?	Calibration Frequency
Blower Door Fan	Fan used to create a pressure difference within the tested property.	Yes	Annually Appendix B gives calibration requirements.
Manometer	Pressure differential measuring device(s) employed to measure the indoor/outdoor pressure difference.	Yes	Annually Appendix B gives calibration requirements.
Thermometer	To allow temperatures to be recorded before and after	Yes	Annually Appendix B gives calibration requirements.
Barometer	To measure barometric pressure	Yes	Annually Appendix B gives calibration requirements.
Anemometer	To make an approximate assessment of wind speed.	No	N/A
Laptop or tablet	Laptop or tablet with the latest version of the software installed. Calibration details including exponents and coefficients for the fan shall have been added in advance.	No	Not required, though calibration details for the fan will need to be updated as per the calibration.
Ancillaries	Blower door frame and fabric, pressure tubing, sealing tape, power invertors (if required),items for health and safety reasons	No	N/A

2.7 Site Test Procedure

2.7.1 Checklist

A summary of the site procedure is described below. Each point has accompanying text following the table.

Step	Description	Completed?
1	Blower door fan installed in appropriate doorway. The fan shall be covered.	
2	Heating systems are turned off or are not actively heating the building	
3	Laptop and approved software is loaded or a site sheet is available.	
4	Temporary sealing is completed as per Section 2.5. Temporary sealing is recorded.	
5	Internal tube is run to the geometric centre of the building and connected to manometer. Location is recorded.	
6	External tube is run outside away from flow of the fan. External tube distance and location is recorded.	
7	All external doors and windows are closed. Doors to adjacent properties are open where possible.	
8	'Pre-test' External temperature is measured.	
9	'Pre-test' Internal temperatures are measured.	
10	'Pre-test' Barometric pressure is measured	
11	'Pre-test' Zero Flow pressures are measured with the fan covered.	
12	The fan is started. A check is carried out to ensure you can reach a minimum of 50Pa. For tall buildings, check pressure is uniform across the building.	
13	Fan readings and building pressures are measured over varying pressures.	
14	The fan is switched off and covered. A period of at least 60 seconds shall pass before the next step.	
15	'Post-Test' Zero Flow pressures are measured with the fan covered.	
16	'Post-Test' Internal temperature is recorded	
17	'Post-Test' Barometric temperature is recorded	
18	'Post-Test' External temperature is recorded.	
19	The results are verified using approved software.	
20	The test is completed	

2.7.2 Test procedure detail

1. Installation of blower door

The blower door may hinder the exit point(s) from the building. 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.

The blower door must be set up in a location that will not hinder airflow from or to the fan. For example, it is often required to set the blower door fan up in a rear door of a dwelling to avoid the air flow being directed against a wall. For instances such as this, consider using the depressurisation method.

There should also be an adequate air supply to the fan, for example if the equipment is located within a door to a garage, the external garage door should be open.

It is acceptable to apply temporary sealing around the blower door should the doorframe hinder the blower door frame from achieving a reasonable seal.

2. Heating systems are turned off

Heating systems are to be switched off from source before the test is conducted.

3. Approved Software

It is mandatory that the latest version of the approved software is used to achieve the correct result. Software can either be proprietary software, typically from equipment manufacturers, or a spreadsheet type software which has been created by the testing company.

All software should be verified against Appendix 4 – Software verification to ensure compliance.

Coefficients and exponents from the fan calibration must be used.

4. Temporary Sealing

Temporary sealing shall be completed and recorded in accordance with Section 2.5.1.

5. Internal Pressure Tube

The indoor pressure difference is normally measured at 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.

Pressure tubes should be kept away from locations where they may be trapped, or may become heated or cooled excessively.

For dwellings greater than 3 stories, or 10 metres in height, a second internal tube should be run to the centre of the top floor. See Point 12 for further details.

6. External Pressure Tube

The external reference tube should preferably be located away from the building envelope and not in direct sunlight. 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 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.
The location and approximate distance of the external tube shall be recorded.

7. External doors and windows closed, adjacent property doors and windows open.

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.

8. 'Pre-Test' External temperature is measured.

External temperature shall be recorded (T_{e1}). For multiple story buildings, the temperature is taken from the location the air is drawn for the fan. Temperature should be taken to the closest single decimal place, e.g. 12.2°C

External temperature shall not be taken in direct sunlight.

9. 'Pre-Test' Internal temperature is measured.

Internal temperature (T_{i1}) shall be recorded. For dwellings up to 2 stories tall, this may be a single measurement in the geometrical centre of the building. For dwellings taller than 2 stories, measurements shall be taken once for every two stories and averaged e.g. in a 4 storey dwelling, 2 measurements shall be taken.

10. 'Pre-Test' Barometric pressure is measured

Barometric pressure is measured.

11. 'Pre-Test' Zero Flow pressures are measured

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. Record the zero-flow pressure differences over a period of at least 30s ideally recording a minimum of 10 values. The following zero flow pressure difference readings shall be calculated:

$\Delta P_{0,1+}$ *The average of positive values recorded*
$\Delta P_{0,1-}$ *The average of negative values recorded*
$\Delta P_{0,1}$ *The average of all values recorded*

If any individual measurement of $\Delta P_{0,1+}$, $\Delta P_{0,1-}$, $\Delta P_{0,1}$ is 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.

12. Fan on test

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 fan shall be turned on and a pressure difference of 50Pa (positive or negative) slowly applied to the building, starting at ~20Pa (or 5 times the highest zero flow reading) and working up to 50Pa to ensure that you can achieve the required pressure and to ensure the integrity of the temporary sealing. It is recommended that fan 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, the fabric of the dwelling and temporary seals applied.

Where dwellings are more than 10 metres tall in height, a separate building pressure measurement shall be taken and recorded on the highest floor level of the dwelling tested. 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. Where uniform pressure cannot be achieved, the fan installation may need to change, for example moving the fan onto a higher floor, or adding a second fan.

13. Fan readings and building pressures are measured.

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 maximum zero flow pressure difference measured prior to the test (the greater of $\Delta P_{0,1+}$, $\Delta P_{0,1-}$).

The highest pressure difference (measured and corrected) must be greater than 50 Pa. If less than 50 Pa 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.

Measured and corrected readings shall be taken both above and below 50Pa.

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.

A minimum of 7 measurements must be taken, with intervals between pressures being no greater than 10 Pa. It is recommended that 10 pressure differences are recorded. Measurements should be recorded over a minimum range of 30 Pa building pressure.

Readings should not be taken above 90Pa induced pressure.

Adequate time must be allowed for induced pressures to stabilise throughout the dwelling envelope for each measurement. Larger buildings, or buildings subject to a high wind load may take longer to settle, whereas a smaller building will settle very quickly. Dwellings with an extremely low air leakage may take a long time (>60s) to stabilise.
Measurements shall be stable for 30 seconds before the reading is taken.

Testers that use automatic software may need to amend their settings in order to take measurements over an increased period of time. Manufacturer's instructions shall be followed if required.

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.

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

14. The fan is switched off and covered

When a full set of data has been recorded, the pressurisation system should be switched off and the fan opening re-covered. A period of 60 seconds shall be allowed before part 15 commences.

15. 'Post-Test' Zero Flow (Static) pressures are measured

Record the zero-flow pressure difference over a period of at least 30s recording a minimum of 10 values. The following shall then be calculated:

$\Delta P_{0,2+}$ *The average of positive values*
$\Delta P_{0,2-}$ *The average of negative values*
$\Delta P_{0,2,}$ *The average of all values*

If any of $\Delta P_{0,2+}$, $\Delta P_{0,2-}$, $\Delta P_{0,2}$ measurements 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.

16. 'Post-Test' Internal temperature is measured.

Internal temperature (T_{i2}) shall be recorded. See advice in part 9.

17. 'Post-Test' External temperature is measured.

External temperature shall be recorded (T_{e2}).

18. 'Post-Test' Barometric pressure is measured

Barometric pressure is measured.

2.8 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 ($m^3.h^{-1}.m^{-2}$ @ 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 3 - Test Report

3.1.1 Companies operating within a competent person's scheme

Companies that operate within a recognised competent persons scheme may demonstrate competence by using a Lodgement certificate only as evidence of a test being conducted.

Whilst Lodgement certificates are not fully compliant test reports, they provide a sufficient amount of information required for the assessor or Building Control to make a decision about the validity of the test.
Lodgement certificates shall contain the minimum of:

a) Plot number
b) Site address
c) Tester name
d) Tester unique identifier / registration number
e) Testing company
f) Level of compliance within the CPS scheme
g) Temporary sealing applied
h) Deviations
i) Contact details of CPS scheme, including address, contact number and email address
j) Unique certificate reference number (UCRN)
k) Building envelope area
l) Date of test
m) Test standard and method adhered to
n) Result
o) Flow Exponent (n)
p) Correlation (r^2)

A full, compliant report in accordance with Section 3.1.2 may be sought by any industry stakeholder (Client, Building Control, EPC Assessor etc.) and must be created if a request for the full report is made, subject to confidentiality clauses as necessary.

3.1.2 Companies that do not operate within a Competent Persons Scheme

For companies that do not operate within a Competent Persons Scheme, the report shall contain at least the following information:

a) All details necessary to identify the dwelling tested; purpose of test (Method 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 $\Delta P_{0,2}$;
  - Displayed to 1 decimal place
- internal and external temperatures before and after the test;
  - Displayed to 1 decimal place
- barometric pressure before and after the test;
  - displayed to 0 decimal place in Pa, 2 decimal places in hPA.
- differential pressure on ground and top floor at highest flow rate achieved (if required);
- table of induced pressure differences and corresponding air flow rates;
  - To 1 decimal place
- air leakage graph, with value of correlation coefficient r^2;
  - to 4 decimal places
- the air flow coefficient C_{env},
  - to 3 decimal places
- the air flow exponent, n,
  - to 2 decimal places
- the air leakage coefficient C_L, for both pressurisation and depressurisation tests determined by the method indicated;
  - to 3 decimal places
- Air permeability result.
  - To 2 decimal places

f) Date and time of test.

g) Name and address of organisation/individual carrying out the test and details.

Appendices

Appendix A – Equations and Corrections

Appendix B – Test Equipment and Calibration Requirements

Appendix C – Equivalent Leakage Area (ELA)

Appendix D – Software Verification Process

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*: (The plus or minus signs should be included when undertaking this calculation)

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

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 kg/m^3, at a temperature, θ, in °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.

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

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.

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

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 (kg.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*:

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

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*:

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

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),….,(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:-

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

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

$$d\sum YY = \sum\left(\ln[Q_m] \times \ln[Q_m]\right) \tag{9}$$

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

$$d\sum Y = \sum ln[Q_m] \tag{11}$$

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

where i = number of data points

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

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

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

and

$$m = n \tag{15}$$

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:

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

where Q_{env} is the air flow rate through the dwelling envelope ($m^3.h^{-1}$) 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:

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

For **depressurisation** use equation:

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

where ρ_i is the indoor air density (kg/m³), ρ_e is the outdoor air density (kg/m³), 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:

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

where C_L is the air leakage coefficient, in m^3.h^{-1}·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 (m²). Units are m³.h^{-1}.m^{-2}. The air permeability is calculated using equation *20*:

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

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 (m³). It defines the length of time required to completely change the volume of air within the dwelling, and has the units 1/h. The air change is calculated using equation 21:

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

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 (Δp_{env}) and corresponding fan flow rates.

$$r = \frac{S_{xy}}{\sqrt{\sigma^2}} \qquad 22$$

where

$$\sigma^2 = \left[\left(i \times d\sum XX\right) - \left(d\sum X \times d\sum X\right)\right] \times \left[\left(i \times d\sum YY\right) - \left(d\sum Y \times d\sum Y\right)\right]$$
$$S_{xy} = \left(i \times d\sum XY\right) - \left(d\sum X \times d\sum Y\right)$$

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 0.9800 must be obtained. It is not uncommon for greater than 0.9900 to be achieved. 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 minimum pressure of at least 50 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 90 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’.

All instrumentation must be annually calibrated to the following specification by UKAS, or the nationally recognised accreditation body for the country that the testing is being conducted. All calibration certificates must bear the logo of the national accreditation body, with laboratory number, and ILAC logo to be considered an equivalent calibration to UKAS. Any testing carried out without calibrated equipment shall be rejected.

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 Pascals in the range of 0 to 100 Pascals, 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 ±1.0C within the range of -20.0 to + 40.0 ^{0}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 requirement for companies accredited through UKAS to calculate estimates of uncertainty 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:

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

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 Pascals, and Q_{50} is in $m^3.s^{-1}$, which allows equation to be simplified and rearranged to:

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

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.

Appendix D – Software verification process

D.1.0 Introduction

In order to verify custom test software, the following readings and calibration data have been provided, along with the result. This can provide a method of checking that the software is working, particularly after software upgrades, this data shall be entered and the result verified. If this test data is inappropriate for checking new/upgraded software, then the software algorithms should be checked manually using a different method such as a spreadsheet or by hand.

D.2.0 Data - Calibration

Static Pressure (Pa)	Flow Pressure (Pa)	Volume Flow (m^3/s)	Exponent	Coefficient (m^3/s)
-50.5	216.8	1.1723	0.482069	0.087706
-50.5	175.4	1.0589		
-50.6	133.3	0.9278		
-50.2	90.9	0.7713		
-50.3	50.4	0.5803		

Air Density (kg/m^3)
1.200

D.3.0 Data – Positive Test

Test Details

Envelope Area	367.0 m^2
Volume	332.0 m^3
Type of Test	Pressurisation
Operator Location	Outside

Reading	Building Pressure (Pa)	Flow Pressure (Pa)	Corrected Flow (m^3/h)
1	57.4	245.0	4470
2	56.9	232.0	4354
3	52.6	227.0	4308
4	50.6	211.0	4159
5	49.5	201.5	4068
6	46.1	187.0	3924
7	40.6	153.0	3562
8	34.7	130.0	3293
9	30.7	108.0	3011
10	25.1	91.0	2773

Environmental Readings	Before	After
Temperature Internal (°C)	15.0	13.0
Temperature External (°C)	10.0	10.0
Barometric Pressure (Pa)	99400	99400
Zero Flow Pressure (Pa)	0.17	1.38

Results

Air Flow Coefficient	452.51
Air Leakage Coefficient	426.02
Air Flow Exponent	0.581
Correlation Coefficient	0.9929
Flow at 50 Pa	4141

Air Permeability	11.28
Air Changes Per Hour	12.47

D.4.0 Data – Negative Test

Test Details

Envelope Area	667 m^2
Volume	618 m^3
Type of Test	Depressurisation
Operator Location	Inside

Reading	Building Pressure (Pa)	Flow Pressure (Pa)	Corrected Flow (m^3/h)
1	-74.0	252.1	4473
2	-69.2	240.5	4373
3	-64.3	220.0	4189
4	-59.7	195.0	3952
5	-56.2	172.4	3724
6	-50.7	162.0	3614
7	-45.3	123.0	3165
8	-41.4	124.0	3177
9	-36.1	100.7	2852
10	-32.9	87.0	2689

Environmental Readings	Before	After
Temperature Internal (°C)	18.0	19.0
Temperature External (°C)	16.0	15.0
Barometric Pressure (Pa)	101200	101300
Zero Flow Pressure (Pa)	2.77	0.51

Results

Air Flow Coefficient	255.71
Air Leakage Coefficient	257.07
Air Flow Exponent	0.664
Correlation Coefficient	0.9886
Flow at 50 Pa (m^3/h)	3457

Air Permeability	5.18
Air Changes Per Hour	5.59