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Version 1.0
June 2016

Passivehaus primer

Airtightness and air
pressure testing in
accordance with the
Passivhaus standard



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Background

This primer is an aid to understanding the key principles involved in achieving the airtightness performance required to meet the Passivhaus standard.

The primer also describes how to ensure that the building is correctly air pressure tested for compliance with Passivhaus certification (n50) pressure test requirements.

Unwanted air leakage significantly increases the space heating demand of a building, as well as causing occupant discomfort from cold draughts. Air leakage can also lead to long term problems in the building fabric where it is repeatedly damaged by the transmittance of water vapour which results in interstitial condensation. In areas affected by atmospheric pollution unwanted air leakage can contribute to reduced levels of Indoor Air Quality (IAQ). Achieving the advanced Passivhaus standard of airtightness (in conjunction with the use of appropriately designed ventilation systems) will help to eliminate these problems.



The 'Larch Passivhaus', under construction at Ebbw Vale, Wales. Source: R. McLeod

Air leakage – causes and affects

Air leakage through gaps in a building's envelope can be caused by either the buoyancy effect of air or by the pressure differential created by wind blowing on a building. Typically both of these factors will influence the total rate of air leakage at a given point in time.

Buoyancy: As air warms up within the building it expands and becomes less dense, causing it to rise upwards and leak out through gaps in the fabric at a higher level. The air that is lost from the building is then replaced by colder external air, which is drawn into the dwelling through gaps in the fabric at a lower level. This uncontrolled air leakage is experienced by the building occupants as cold draughts.

Wind: As wind blows against the building colder outside air will be forced under pressure through any gaps in the envelope. On the leeward side of the building the external air pressure is lower and will draw warmer air from inside the building out through any gaps in the envelope. The stronger the wind the greater this pressure differential is and the higher the resultant background air leakage rate will be (Figure 2).

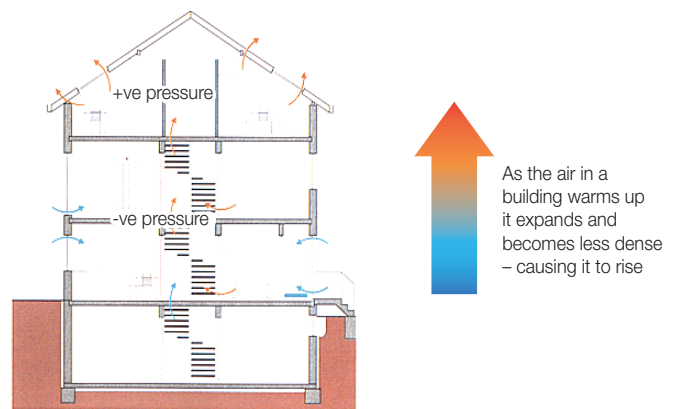


Figure 1 Buoyancy effect

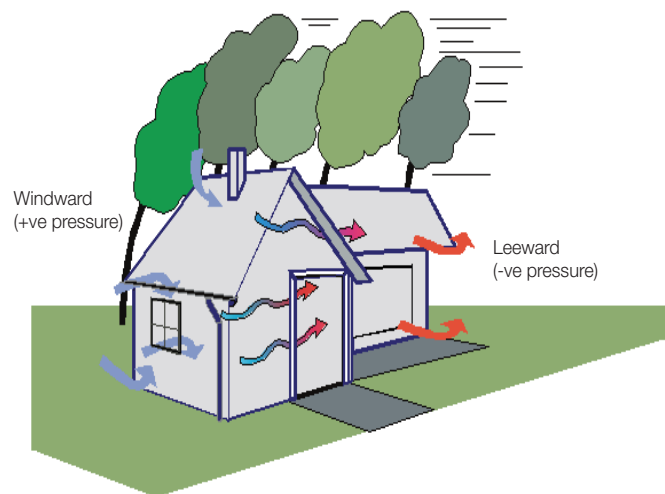
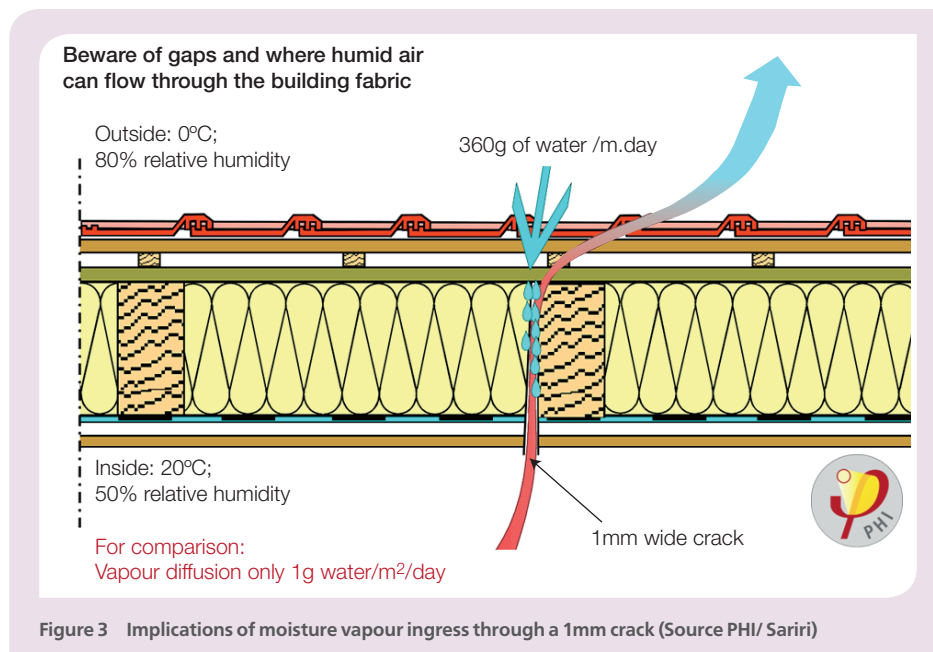


Figure 2 Wind driven air leakage (source: LTM GmbH)

Moisture ingress and interstitial condensation

When warm moist air flows out through a gap in the building fabric the air cools down and as the air cools its capacity to hold water vapour is reduced. When the warm air comes in to contact with a sufficiently cold surface the water vapour condenses to a liquid state (Figure 3). When condensation occurs within the build-up of the building fabric it is known as interstitial condensation. Over time, if the interstitial condensate remains trapped in the building fabric, it will lead to a deterioration in the fabric U-values and possibly structural damage and mould growth.



Airtightness requirement for Passivhaus Certification

Very low air leakage rates are required by the Passivhaus standard and must be demonstrated for each certified building by means of a “blower door” air tightness test. The air change rate must be less than or equal to 0.6 air changes per hour, under test conditions.

Passivhaus airtightness (n50) $\leq 0.6 \text{ h}^{-1} @ 50 \text{ Pa}$

Note: The limiting value of $0.6 \text{ h}^{-1} @ 50 \text{ Pa}$ should be used as the default design air tightness value in all preliminary Passive House Planning Package (PHPP) calculations until a verified pressure test reading is available.

It is important to note that achieving a heating demand of $15 \text{ kWh/m}^2 \text{ yr}$ or a peak load of $\leq 10 \text{ W/m}^2$ often requires the elemental specifications to be far better than the recommended Passivhaus limiting values. This is particularly the case for buildings that do not have an optimum form. Therefore the limiting value of n50 being $0.6 \text{ h}^{-1} @ 50 \text{ Pa}$ should be seen as the maximum air leakage

permissible. Attaining the Passivhaus standard of airtightness is challenging, but achievable when a clear and well thought out strategy is arrived at during the design stage. This strategy must be maintained and fully implemented during the construction phases. It is therefore imperative that the contractors clearly understand the airtightness strategy and are able to easily implement the sequence of work on site.

It is worth noting that in practice an airtightness level of $n50 = 0.6 \text{ h}^{-1} @ 50 \text{ Pa}$ is roughly equivalent to having a hole in the envelope area of the building less than the size of a 5 pence piece for every 5 m^2 of building envelope (see Figure 4). In comparison a building that achieves the limiting figure for airtightness to comply with the Building Regulations Part L (2013) (Section 6 of the Building Standards, Scotland and Building Regulations Part F, Northern Ireland) will have an equivalent hole the size of a 20 pence piece for every 1 m^2 of envelope.



Figure 4 Building Regulations vs Passivhaus indicative maximum air permeability areas

UK Building Regulations and the Passivhaus Standard

Difference between AP_{50} , q_{50} and n_{50}

To comply with UK non-domestic Building Regulations (Part L2) it is necessary to carry out an air permeability pressure testing on all buildings with a usable floor area > 500m². Whilst for the domestic regulations (Part L1) a representative sample of dwellings on each new build site must be tested. The result of this test is expressed as the AP_{50} value. This is the measure of a volume of air (m³) that flows through the building fabric (m₂) every hour at a reference pressure of 50 Pascals (Pa) – hence the AP_{50} units are m³/(h.m²).

In order to calculate the air permeability the ATTMA (Air Tightness Testing and Measurement Association) TS1 standard defines the envelope air barrier line as being ‘along the line of the component to be relied upon for air sealing’. In practice this could be anywhere within the building envelope but typically measurements are taken up to the internal wall surface. The ATTMA AP_{50} test result is commonly referred to as the ‘air permeability’ however technically it is defined as the *rate of air flow* (m³/h) at a pressure difference of 50Pa (which is analogous to the v_{50} referred to in Passivhaus terminology). The 2010 Building Regulations state that the airtightness and the thermal line of a building should be contiguous. It is worth noting that a building regulations test can be either a

pressurisation or depressurisation test, but for Passivhaus both tests with the final result being the average of the two. The actual testing procedure is largely identical however and both the Building Regulations and Passivhaus compliance tests may be carried out at the same time.

For Passivhaus certification the airtightness target is expressed differently as n_{50} , which is defined as the number of air changes per hour in the building at a reference pressure differential of 50 Pascals. Since the result is calculated using the building’s internal air **volume** (m³), rather than using its envelope **area** (m²) the n_{50} units are expressed as m³/m³.h which may be simplified to h⁻¹ or ac/h.

Note: a standardised conversion between Air Permeability (AP_{50}) and Air Change Rate (n_{50}) values is not possible as they do not have a direct relationship with one another. Furthermore each test uses different measurement and testing protocols.



Taping of ‘intelligent’ airtightness membranes, Larch Passivhaus
(Source R. McLeod)

Achieving the Passivhaus airtightness standard in practice

1 Design stage – identifying the air barrier strategy

The key principle for achieving airtightness is to create a single, continuous and robust airtight layer (or air barrier). This layer surrounds the heated volume of the building and in general it should be located on the warm side of the insulation, therefore also fulfilling the requirements of the vapour control layer (VCL). It is important to define a single continuous air tight barrier – either it's a complete barrier or it's not! Having a secondary layer is often confusing and is unnecessary.

It is helpful to identify the location of the air barrier in the building's fabric by using the 'red line' method. To do this, simply mark the line of the air barrier using a red pencil onto a section through the building. It should be possible to trace the air barrier around the whole building envelope without any breaks in the line. If you need to lift your pencil from the paper then you must mark this area as a break in the air barrier, and provide a clear detail showing how the gap is to be connected and sealed. For example a gap in the barrier caused by a penetrating services pipe or window unit will need a robust detail to ensure an effective seal is achieved. For this reason it is recommended that multiple sections through the building fabric as well as each floor plan are assessed (including all service penetrations) during the initial design stages.

At the detailed design stage all complex junctions and air tightness details should be documented by large scale drawings (1:10) highlighting airtight barriers in a bright colour. At this level of detail it is common to show both the line of the internal air-tight barrier or VCL (red line) and also the line of the external wind barrier layer (WBL) (blue line), these barriers serve separate functions and should be clearly labelled to avoid confusion (Figure 7). It is important to note that the air-tight barrier may not always be a specialist membrane; at times it will be a rubber seal or a pane of glass or possibly a laminated timber board. When drawing connecting details it is important to understand precisely where the air-tight line is and how the various connecting elements will be joined together.

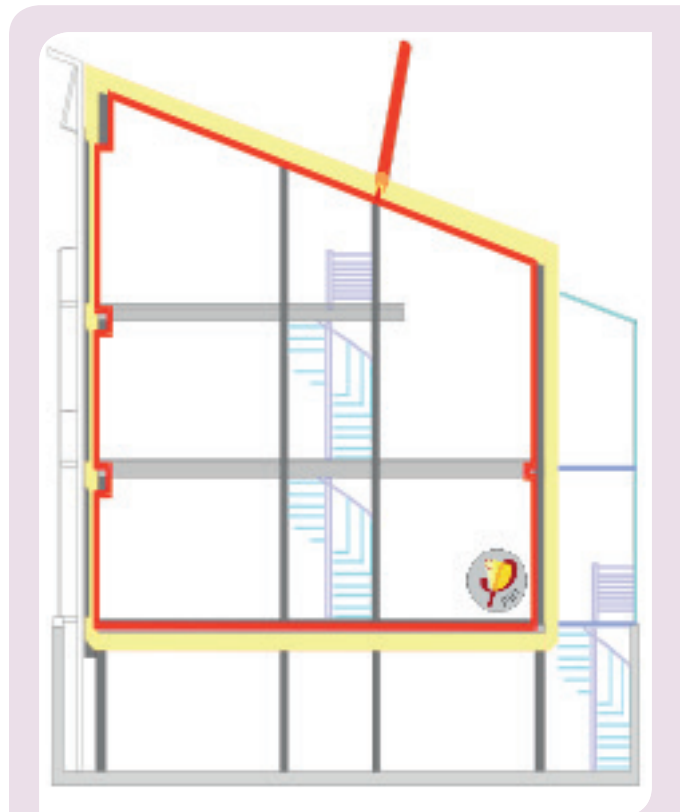


Figure 5 'Red line' technique used to define the air barrier

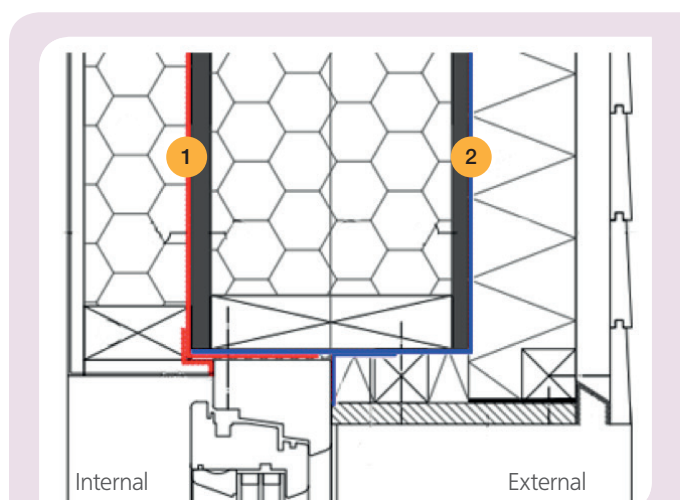
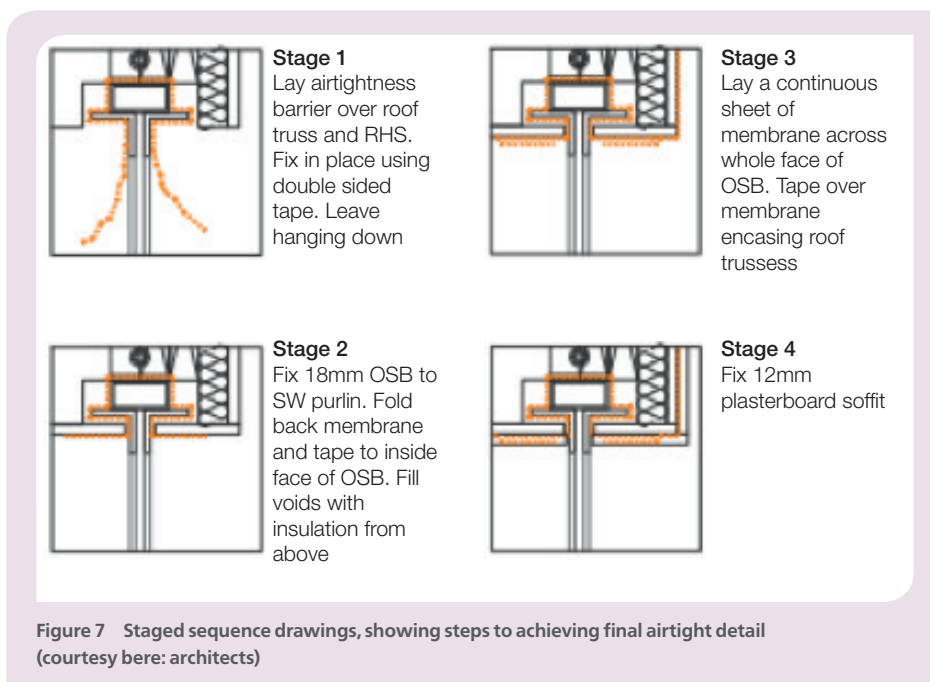


Figure 6 Detailed design – cross section through window head detail showing continuity of internal air tight barrier (No.1) and external wind barrier (No. 2) (image courtesy bere: architects)

2 Detailed Design/Production stage – installation sequence

Final production drawings should also contain sequenced illustrations of the key stages involved in installing the airtight barrier at complex junctions. Any careful sequencing needed to install a membrane or create an air-tight seal should be annotated on these drawings (below).



Types of air barrier

It is crucial to specify the appropriate materials that will be used to form the air barrier. An air barrier must be impermeable or virtually impermeable (i.e. not allow air to pass through them at 50 Pascals). Typical air barrier materials include:

- Vapour control layer membranes (used in timber frame construction)
- Concrete (but not unparged concrete blocks)
- Orientated Strand Board (used for SIPS panels and sheathing in timber frame)
- Cross laminated timber plate (used as structural panels)
- Parging coat (applied directly to masonry)

Do not use materials that are permeable such as fibrous insulation material. It does not matter how hard a permeable material is packed into a gap, air will still be able to pass through it.

Oriented Strand Board (OSB) class 3 (external grade) has been successfully used as an air barrier on a large number of Passivhaus projects however research shows that there is substantial variance ($<0.001 \text{ m}^3/\text{m}^2 \cdot \text{h} \cdot \text{Pa}$ - $0.01 \text{ m}^3/\text{m}^2 \cdot \text{h} \cdot \text{Pa}$) in the air permeability of OSB boards being supplied to the Western European market. As a result of detailed investigation it has been shown that OSB used as an airtight layer in Passivhaus construction should be quality controlled to a maximum air permeability $\leq 0.0018 \text{ m}^3/\text{m}^2 \cdot \text{h} \cdot \text{Pa}$ (Langmans et al., 2010). In response to these findings the Passive House Institute have advised that an elemental limit of $q_{50} \leq 0.1 \text{ m}^3/(\text{m}^2 \cdot \text{h})$ should be used when specifying OSB as the airtightness layer* (Peper et al, 2014).

Designers should be aware that at the time of writing this level of quality control is not mandated in Europe. It is therefore advisable to specify a minimum grade of 18mm OSB-3 and to either ask for evidence that substantiates the q_{50} or to test a sample batch of any boards prior to procurement to ensure that the air permeability complies with the above recommendation. Improved airtightness levels are likely if OSB class 4 is specified and or thicker boards (22mm) are used however there will be a cost implication associated

with the decision to specify a higher grade material. Other alternatives include options to use modified OSB sheet products, available from some manufacturers, incorporating a laminated airtight cellulose based layer. Given that the suppliers of these boards often have no access to information relating to the quality of airtightness of the OSBs they distribute, it is imperative that mandatory information is provided by manufacturers regarding airtightness. This information should feature on product agrément certificates and be imprinted on the boards.



Figure 8 Specialist air tight adhesive tape is used to seal gaps between OSB boards

Caution is similarly advised where cross laminated timber plate (CLT) (or other timber panel systems) are used as the airtight layer. Although such systems have been successfully used without additional membranes on a number of Passivhaus projects, the level of airtightness achieved will depend on the specific cross lamination method (i.e. whether the system is mechanically jointed and has a continuous glue layer between each layer of timber boards or not). Where data is not forthcoming sample tests should be carried out. It is particularly important to specify how junctions between components will be sealed. For example, tear resistant proprietary air tight tape should be used to seal gaps between OSB boards, and likewise to seal overlapping sheets of membrane material. Where a membrane or OSB boards are connected to a concrete slab or window reveal special attention should be given to cleaning and priming the concrete surface. This implies that a vacuum cleaner and proprietary priming materials will need to be on hand when sealing the air tight barrier layer to adjacent concrete or rendered elements. Additionally concrete and rendered surfaces must be completely smooth and dry before attempting to make an airtight seal.

Care must be taken to ensure that membranes and tapes are installed in such a way as to accommodate any movement between elements. Membranes that bond over their entire area are easier to seal than those that require edge sealing with tape.

*It should be noted that in Canada the requirement for areic airtightness (analogous to the AP_{50} value) of construction materials is much more severe where $q_{50} \leq 0.048 \text{ m}^3/(\text{m}^2 \cdot \text{h})$. It should be noted that the European q_{50} value is analogous to the ATTMA AP_{50} value.

Details and drawings must be clearly presented to ensure they can be understood and are able to be achieved on site. It is recommended that critical airtight details are prepared in large scale (1:10) and colour coded for clear reference. Consideration needs to be given to the sequencing and buildability of air tight junction details particularly around windows and doors and this should be clearly indicated on production drawings.

Try, where possible, to keep penetrations through the airtight envelope to a minimum. Take care when grouping services together (electrical cables, pipes and ventilation ducts) to ensure adequate space is left to seal around individual penetrations using proprietary seals (top hats and gaskets). Avoid services penetrations, MVHR units, boilers etc. being located too close to a corner or a wall as it may be impractical to access the gap for sealing. Ideally all penetrations are made as the building element is installed to ensure the seal is to the correct element of the wall. This may involve installing pipes or spigots to seal into the air line and then allowing the actual pipe or cable connections to be sealed to when subsequently installed. Select and specify materials that are robust and durable to form the air barrier. The objective is to achieve an airtight structure for the life of the building, not one which will be adequate for the air pressure test, but then degrade in a short space of time. Never try to make savings by specifying cheaper alternative materials (for example cheap building tapes), as these will not offer the robustness required to achieve a Passivhaus standard of airtightness. A review of the comparative performance of common European airtightness tapes can be found in the German 'Test' magazine (Stiftung Warentest, 2012).



Taping of window junction to airtightness membrane, Larch Passivhaus (Source R. McLeod)



Figure 9 A proprietary seal for a services penetration through a membrane

3 Delivering airtightness on site

It is essential that the construction team is fully briefed on the airtightness requirements of Passivhaus and receives clear, well laid out details in good time. It is advised that a clear communications plan and project delivery programme should be developed according to the RIBA Plan of Work 2013. The RIBA Plan of Work stages include sustainability checks/ audits that ensure that quality assurance and due diligence are carried out at each stage.

Effective project management is essential to ensure a high standard of construction. It is essential for site management to have some training on airtightness and for the site trades personnel to receive 'toolbox talk' training sessions prior to installing the airtight barrier.

Airtightness Champion

Appointing an 'airtightness champion' is a good way of ensuring that site operatives remain aware of the importance of the airtight barrier throughout the build. The 'airtightness champion' is responsible for maintaining the integrity of the air tight barrier throughout the build and reporting any issues back to the design team and project manager. This airtightness champion should be someone who will be on site throughout the build, but not the Project Manager or Clerk of Works as their time is often taken up with administrative tasks. The airtightness champion roles must be a good communicator and someone who takes pride in their work and has the authority to halt and change work if required. The airtightness champion must be thoroughly briefed by the design team and must be able to pass on that information to all of the sub-contractors and trades visiting the site.

Airtightness Champion – responsibility checklist

- 1 The role of air tightness champion must be separate from the foreman's role within the construction team. He/ she is likely to be a member of the builders team with a particular trade role throughout the construction but their main project responsibility must be that of air tightness champion, reporting regularly to the design team, site foreman and main contractor.
- 2 Understand & communicate the airtight/vapour control layer (VCL) and wind barrier layer (WBL) strategy. Ensure its adoption by all trades on-site (including scaffolders and sub-contractors).
- 3 Know where the VCL and WBL planes are and which materials form them. Supervise and inspect all relevant works affecting these internal and external planes.
- 4 Ensure that Site Inductions emphasise Air Leakage and the necessity to avoid damage to both barrier planes.
- 5 Manage relevant variations, which can often compromise the Air Barrier.
- 6 Operate an inspection checklist for key elements, interfaces and penetrations. Keep a camera on hand to take photographic evidence of any damage to the VCL and WBL.
- 7 Take regular temperature and humidity readings: some tapes seals and membranes will not cure or seal effectively if the atmospheric relative humidity is above 80%. Specialist briefing with the airtight membrane suppliers is advised, so that the airtightness champion knows the correct application conditions for each product.
- 8 Ensure all materials that form part of the VCL and WBL are correctly prepared and used and that proprietary products (including cleaning and priming materials) are available on site well before they are required.
- 9 Liaise with pressure testing specialists to organise visits for audits and tests, ensuring all necessary preparatory works are complete in time.
- 10 Verify that weather conditions are satisfactory for testing in advance of issuing a final test confirmation (using advanced Met Office and MetCheck advanced forecasts supported by any site anemometer readings on the day).
- 11 Determine how many dwellings need to be tested and prepared for testing prior to each audit or test.
- 12 Ensure that envelope area and volume for each dwelling unit is traceably calculated and confirmed with the ATTMA tester. V_{n50} reference volume to be determined in accordance with guidance issued in this document.
- 13 Ensure that recommendations from post-testing air leakage audits are acted upon.
- 14 Airtightness compliance logs for trades and domestic contractors: ensure records are up to date and any variations recorded/remediated (see Figure 10).
- 15 Use a leakage check kit to check the effectiveness of any remedial sealing works.

Achieving airtightness in practice comes down to attention to detail and common sense, for example making sure that surfaces are dry and dust free (and primed where necessary) prior to using adhesive tapes. Having extra rolls of tape, a vacuum cleaner and primer on hand is essential to ensuring the job is carried out thoroughly; as is a small heavy roller to ensure even pressure and adhesion over the entire length of tape.

Sites that have achieved very high standards of airtightness and satisfied Passivhaus Certification have found specific airtightness checklists and regular inspections of details helpful. The airtightness champion should keep a detailed logbook of the airtightness progression of each unit being tested. This log (or logs) should be stored on a clip board and kept in an easily accessible location within the site office or unit concerned. Ideally each trade would keep a separate log sheet (Figure 10) which should list the date, time and nature of any works carried out affecting the airtight layer as well as the contractor responsible for that element of the work. Interim pressure test results should also be recorded in the airtightness log.

Careful planning and sequential working are essential to achieving airtightness. A structured plan of work will ensure that the air barrier is sealed as the work progresses. Areas should be inspected before follow-on trades cover and hide crucial details to ensure the air barrier is continuous. For example, it will be necessary to check that any gaps left around a service pipe have been sealed prior to installing a bath, as once the bath has been put in place it may be very difficult to gain access to seal any remaining holes left in the air barrier.

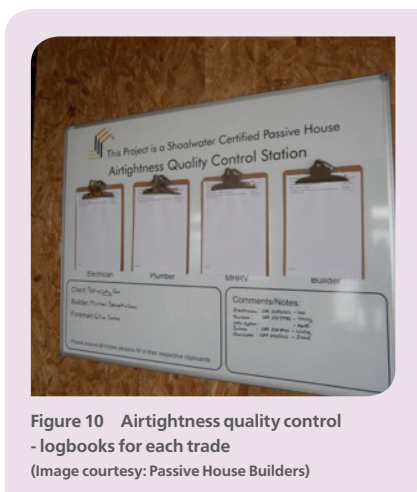


Figure 10 Airtightness quality control - logbooks for each trade
(Image courtesy: Passive House Builders)

Sequencing of air pressure tests

It is recommended that at least three air pressure tests are carried out during the construction phase. All tests should be comparable in terms of results i.e. the (Vn_{50}) volume used should be the same for all tests and is effectively the final volume of the finished building.

- 1 The first test should ideally be done as soon as the air barrier is complete, but before any services and/or appliances have been fitted. This allows the robustness of the air barrier to be assessed. Any defects (air leakage paths) can be easily identified and remedied at this point. This test can be carried out before all of the windows are installed by temporarily shuttering (and taping) any openings.
- 2 The second air pressure test should be carried out after services have been installed, but before fixtures and fittings (baths, shower trays, kitchen units etc.) have been installed. It is crucial to achieve an airtight seal around all services penetrations before they are hidden from view by follow on trades, and a test at this stage will ensure this has been achieved.
- 3 The third air pressure test must be carried out at practical completion for certification purposes. By checking the performance of the building through prior testing and remediation the result of this test should be confirmation of a well-sealed project. The final test result is the test result recorded for Passivhaus certification purposes.

Air pressure tests should always be accompanied by a thorough air leakage audit; so that any air leakage paths can be identified and remedied whilst the tester is on-site. This procedure may take some time and requires good diagnostic skills of the tester as well as trained operatives on hand - where for example poorly adjusted window gearing is a culprit. This time audit and remediation time must be factored into the programme from the outset as it is an essential requisite of achieving the Passivhaus standard.

It is worth noting that the additional expense to the project from a few extra air pressure tests is negligible in comparison to the potential extra costs that may be incurred by not achieving the air tightness standard on completion - resulting in extensive remedial sealing work. Because of the importance of repeated pressure testing many Passivhaus contractors own a small ('Wincon' type) blower unit and thermal anemometer that can be used for interim diagnostic testing.

Calculating the pressure test reference volume (Vn_{50})

Airtightness performance of a Passivhaus is measured in air changes per hour at a 50 Pascal pressure difference between the inside and outside of the building. This is referred to as the n_{50} value, and is determined by calculating the volumetric flow of air (m^3/h) required to maintain a pressure difference of 50 Pascals (v_{50}) divided by the internal (heated) air volume (m^3) (Vn_{50}). It should be noted that the v_{50} (volumetric flow rate at 50Pa) value is the same as the ATTMA q_{50} value.

$$n50 = \frac{v_{50}}{Vn_{50}}$$

The Vn_{50} volume is the conditioned volume of the building in normal operation with measurements taken from the visible wall, floor and ceiling finishes.

This is not the same as the air permeability envelope area ($A_{E \text{ permeability}}$) approach generally used in the UK, which ignores internal walls and floors and is measured to the air barrier element. This means that voids between the ceilings and floors, internal wall voids are not included in the Passivhaus volume calculation (room by room volume calculation will naturally exclude these). Beams and visible rafters are not typically deducted from the volume of the building however.

The loft space is generally excluded (in cold roof constructions) as it is not conditioned and in such cases the loft door has been designed to be airtight. The opening for stairs should be calculated and included, while the solid element of the actual stairs should be ignored such that the entire stair volume is included in the Vn_{50} . Internal wall voids, floor voids and ceiling voids are excluded from the Vn_{50} . In practice this may require detailed plans of the final construction to be issued to the person carrying out the calculations, since some of these volumes may not be enclosed or formed at the time of the initial pressure test. Measurements should therefore be taken off drawings to allow direct comparisons between different people's calculations in a way that is not affected by different individuals measuring different lengths etc. Dimensions used should be checked on site to ensure that the calculation of volume is reliable, and that the built form complies with the plans. Window reveals are not normally included but external door reveals (which are 13cm deep or deeper are included). Hidden risers, wall and floor voids are not included in the volume but any large store cupboards inside the finished surface (e.g. containing MVHR etc.) are included.

The calculated $V_{n_{50}}$ volume is critical to the final test result. Should the calculated volume be overestimated at any time, it will result in an under estimate of the airtightness result, so it is imperative that it is agreed upon as early as possible in the build and design process. Having to downward revise the calculated volume at a late stage of the design could jeopardise compliance with Passivhaus certification criteria. It is therefore imperative that the $V_{n_{50}}$ volume used to calculate the airtightness result is checked by a competent third party and this calculation must be documented within the Passivhaus certification folder. Where there is any uncertainty/ discrepancy over the interpretation of the $V_{n_{50}}$ dimensions the lower figure should be used (until further clarification has been provided by the Passivhaus certifying body). Figure 10 and Figures 11a-b provide an illustration of the volumes which are to be included (blue) and excluded (yellow) from the $V_{n_{50}}$ calculation. In general the $V_{n_{50}}$ should be calculated on a room by room basis by measuring the room volume from the finished floor/wall/ceiling surface. In general all conditioned air spaces within the thermal envelope are included in the $V_{n_{50}}$ however enclosed air spaces behind partitions or above suspended ceilings are excluded, as are window reveals and door reveals (if less than 13cm deep). Full height reveals greater than 13cm deep should be included in the $V_{n_{50}}$. A summary table of volumes to be included and excluded from the is provided in Table 1.

Table 1 Air volumes and solid elements to be included and excluded from the calculationTest method

Object	Volume included / excluded from
Stairs	Include the volume of air displaced by the stairs (unless the stairs are of monolithic stone or concrete construction without any air void or cupboard beneath them)
Stair void in floor plate	Include the air volume of the stair void in the floor plate
Window reveals	Exclude (unless full height window with reveal depth \geq 13cm)
Door reveals	Exclude (unless door reveal depth \geq 13cm)
Columns	Include the volume of air displaced by any columns (unless the cross sectional area of an individual column is greater than 0.1m ²)
Beams	Include the volume of air displaced by any beams (unless the cross sectional area of an individual beam is greater than 0.1m ²)
Attic/ loft space	Include if warm roof construction with openable loft hatch. Exclude if cold roof construction or not accessible via loft hatch/ internal opening.
Ductwork and flues	Include the volume of air displaced by ductwork and flues (unless the duct or flue is room sealed and the cross sectional area is greater than 0.1m ²)
Cupboards	Include the air volume displaced by all wall mounted cupboards and shelving units. For walk in wardrobes sand large services cupboards measure internal volumes as per a room.
Storage cylinders and appliances	Include the air volume displaced by all hotwater storage cylinders, header tanks and building services (unless the total air volume displaced by an individual appliance is greater than 1% of the net internal air volume)
Skirting boards, architrave etc.	Include the air volume displaced by skirting board, architrave etc

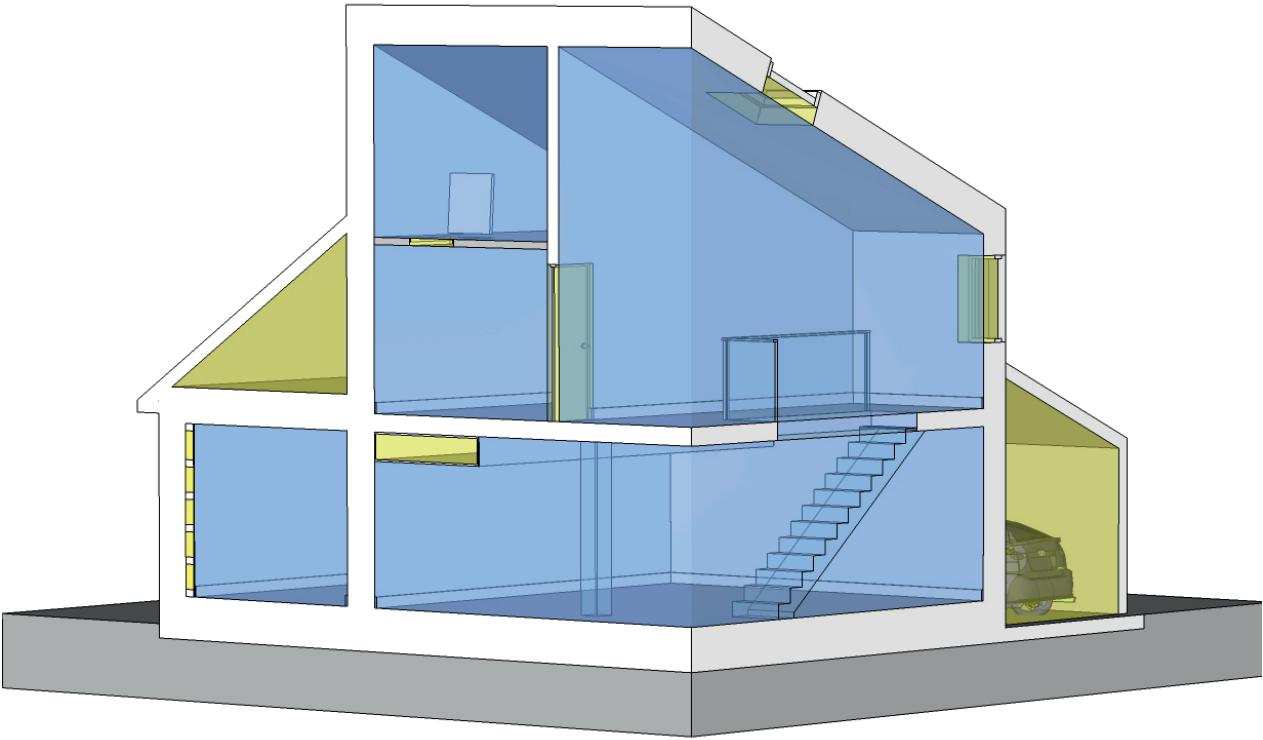


Figure 10 3D view of Passivhaus air pressure test volume (V_{n50})

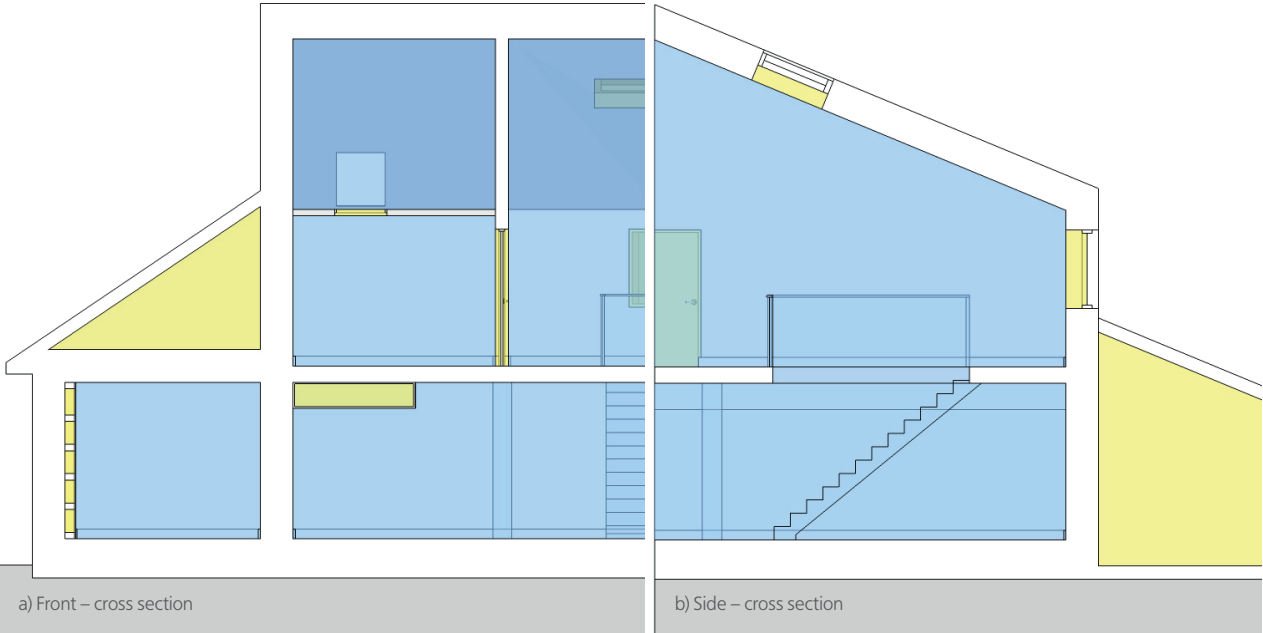


Figure 11

The airtightness performance of a building is measured by an 'air pressure test' (often referred to as an 'airtightness test' or 'blower door test'). To achieve a result that is compliant for Passivhaus Certification the test must conform to BS EN 13829 (2009) 'Thermal Performance of Buildings – Determination of air permeability of buildings – Fan pressurisation method'. Both pressurisation and depressurisation tests must be undertaken for Passivhaus certification purposes, with the combined result of both demonstrating that an air change rate of less than or equal to $0.6h^{-1}$ @50Pa being achieved. For final testing the building should be prepared in accordance with BS EN 13829 Test Method A (test of a building in use), with all external doors and windows closed (except the one being tested from) and water in traps. The only temporary seals to be applied should be to **designed** ventilation which in most cases will just mean sealing the inlet and exhaust of the MVHR for the test. Other temporary seals to non-designed ventilation (i.e. around door frames, any holes in the fabric) will lead to the test result being

invalid. Note that this only applies to the **final test**, for pre-tests sealing incomplete or missing elements is acceptable to gain a benchmark for that which has been completed. Table 3 (below) provides a Passivhaus n_{50} pressure test openings protocol checklist.

To demonstrate competency for airtightness testing in the UK the air pressure tester should either be accredited by the British Institute of Non-Destructive Testing (BINDT) for 'air pressure testing dwellings' or be a member of the Air Tightness Testing and Measurement Association (ATTMA) for testing dwellings and non-dwellings and be fully versant with the Passivhaus n_{50} test procedure, as described in this document.

Preparation for the test

Maximum acceptable wind speed

In preparation for the air pressure test the local weather conditions must be observed; in particular the mean wind speed and any gusting. **Testing should not be undertaken when wind speeds are above 6m/s** (i.e. above Beaufort Force 3). Even wind speeds above a light breeze (Beaufort Force 2) will begin to introduce an element of error into the test results (Table 2). When wind speeds exceed 3 m/s caution is needed since the risk of error rises significantly, particularly for exposed buildings (Table 2). This error can be reduced by using four reference tapping points around each side of the building, to more accurately gauge the mean internal/ external pressure differential (Table 2). The effect of wind is effectively measured by the fan off pressures taken at the start of the test – they must be within +/- 5Pa. Higher building differential pressures (above 50 Pa) should also be achieved – up to 80-90 Pa (with 10 measurement points taken as a minimum). Care must be taken to ensure these higher pressures do not affect the seals and/or fan in the doorway.

Beaufort force	description	wind speed ¹ (m/s)	land conditions	max error due to wind flow					
				[%] ²			[%] ³		
				A	B	C	A	B	C
0	calm	< 0.45	Calm. Smoke rises vertically.	0	0	0	0	0	0
1	light air	0.45 - 1.34	Smoke drift indicates wind direction and wind vanes cease moving.	0	0	0	0	0	0
2	light breeze	1.8 - 3.1	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.	1	2	3	0	1	2
3	gentle breeze	3.6 - 5.4	Leaves and small twigs constantly moving, light flags extended.	2	9	11	4	5	6
4	moderate breeze	5.8 - 8	Dust and loose paper raised. Small branches begin to move.	8	24	27	5	20	23
5	fresh breeze	8.5 - 10.7	Branches of a moderate size move. Small trees in leaf begin to sway.	15	40	50	10	35	40
			This is applicable for single or multi family houses up to 2.5 floors and row houses						
			A very sheltered building						
			B partly exposed building						
			C very exposed building						
			¹ meteorological wind speed (open land); the wind speed measured with anemometer is approximately half						
			² a reference pressure tapping point, ca 10m distance from building, sheltered from direct flow (fan)						
			³ four measurement points around the building with pipes of same lengths; measuring points measure velocity pressure						

Table 2. Influence of wind speed and number of pressure tapping points on max error margin (source Dr.-Ing. Achim Geißler)

Preparing the building

In preparation for the pressure test the building's ventilation system must be closed and sealed. In residential buildings this will involve sealing the MVHR inlet and extract ducts from the external air. The inlet and exhaust ducts should be sealed at their external ends to avoid testing the MVHR unit or internal ductwork. Note that in non-residential buildings using intermittent ventilation strategies (e.g. schools) where the ventilation system is turned off during evening and weekend periods (to save energy), the inlet and exhaust must have tightly shutting flaps to ensure that additional heat is not lost from the building (as air leakage) when the ventilation system is turned off. When testing Passivhaus buildings with intermittent ventilation systems the sealing flaps must be closed during the pressure test but must not be sealed over.

All water traps must be filled, or if no water is present in the building these traps must be temporarily sealed. Other openings in the external envelope like doors, windows and loft hatches must be closed for the duration of the test, and must not be temporarily sealed. All sealed openings must be noted and recorded in the test report. Internal doors must be wedged open for the duration of the airtightness test to ensure an even distribution of air pressure throughout the building.



Figure 11 Air pressure testing fan installed in the entrance doorway of a building

Testing protocol

Passivhaus guidance recommends that the air pressure testing fan equipment should be fitted into a window opening rather than an external door opening; this is because an external door may have a letter box, key holes and potential air leakage issues, particularly where there is a level access threshold. However, as most testing bodies in the UK use fan testing equipment that is designed to fit into a door frame it is usually more practical to adopt this more conventional method of testing. If there are doubts about a door's air tightness separate tests should be conducted using front and rear doors, or a window test may be commissioned.

For Passivhaus Certification it is compulsory to carry out both a **pressurisation** test and a **depressurisation** test on the building. The depressurisation test can be particularly revealing of leakage paths around window casement seals, where inadequate or poorly tuned gearing mechanisms fail to hold the window casement tightly in the frame.

A series of pressures between 10 to 60 Pascals are used for the test, this corresponds to the pressure generated by wind speeds of 4-10 m/s on a building. The results of the pressurisation and depressurisation tests are averaged and the resultant figure is valid for demonstrating compliance with Passivhaus requirements. This is different to compliance testing for UK Building Regulations, where either a pressurisation or depressurisation test is required (but not both) - so it is important that the person undertaking the test is aware of this additional requirement.

BS EN 13829 'Thermal Performance of Buildings – Determination of air permeability of buildings – Fan pressurisation method' provides the overarching testing protocol which needs to be followed to ensure a valid test result is achieved. This testing methodology is also provided in the UK via ATTMA Technical Standards TSL1 (for dwellings) and TSL2 (for non-dwellings). It is important to note that the existing procedure for measuring the volume of a building in the ATTMA guidance documents does not comply with the requirements of Passivhaus certification, see 'Calculating the V_{n50} volume of a Passivhaus' (above). It should be noted that with respect to the sealing of openings in preparation for the test that neither BS EN 13829 Method A or Method B can be directly followed. A summary table below has therefore been provided (below) for the purposes of carrying out a Passivhaus compliant n_{50} test. The air pressure test report must document the condition of every opening. Furthermore, in accordance with the standard, the person carrying out the test must comprehensibly document the net interior volume and the net floor area, either based on the production drawings (final plans) or on-site measurements. If the net volume and net area are provided by another consultant, the pressure tester must independently verify these values.

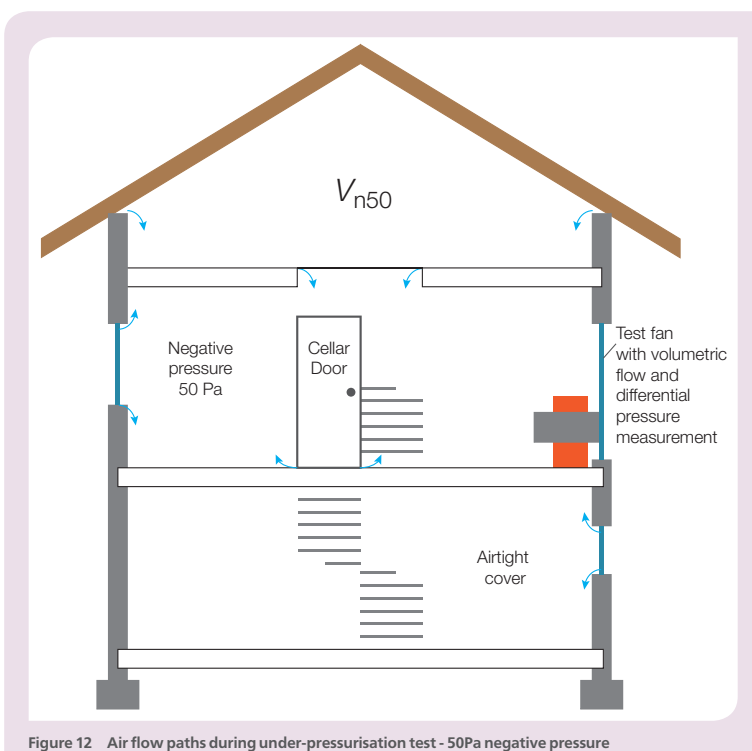


Figure 12 Air flow paths during under-pressurisation test - 50Pa negative pressure

Table 3 Checklist for preparing the building openings for the n₅₀ Passivhaus test

	Building component/opening/ fitting	Guidance notes
1	External door	Close doors; may be locked
2	Internal door	All doors open
3	Closet doors	No action
4	Hatch/trap door to unheated attic	Close door and latch; do not seal. Leave open if attic is within airtight envelope
5	Basement door leading to unheated cellar/cellar corridor (within envelope)	Close door
6	Open fire place - NOT ADVISED FOR PASSIVHAUS	Decommission; remove ashes; close inlet air
7	Built in (tiled) or free standing solid fuel stove (or boiler) with independent external supply air*	Decommission; remove ashes; close air inlet
8	Room air dependent (gas) fire within heated building space - NOT ADVISED FOR PASSIVHAUS	Decommission; no action
9	Solid fuel stove etc. which is dependent on room air - NOT ADVISED FOR PASSIVHAUS	Decommission; no action
10	Gas fired boilers (non- room air dependent) in heated building space (e.g. condensing boiler with balanced flue)	Turn off no action
11	Hatches/doors/ access to unheated building spaces (garages, storage rooms) combine with 5	Close door; may be locked
12	Key hole	No action; do not seal
13	Air release valve duct in unheated building space	Seal
14	Kitchen hood *	Decommission; no action
15	Ground source heat exchanger (inlet air duct/ plenum from EAHE)	Seal
16	Fixed vents in window/ skylights (trickle vents) - NOT ADVISED FOR PASSIVHAUS	Close; no action.
17	Additional vents or supply air openings	No action.
18	Air inlet and exhaust valves (external air supply/exhaust ducts to MVHR).	Seal**
19	Letter box door flap (Not advised for Passivhaus doors unless airtight!)	Close; do not seal
20	Cat door flap	Close; do not seal
21	Opening "inlet air or vents" in boiler room/oil storage room - NOT ADVISED FOR PASSIVHAUS	No action
22	Laundry dryer in heated building area with exhaust air to the outside*- NOT ADVISED FOR PASSIVHAUS	Close; no action
23	Laundry chute to unheated building area - NOT ADVISED FOR PASSIVHAUS	Close; no action
24	Central vacuum cleaner facility	Close; no action
25	External roller shutter (shutter belt conduit)	No action; do not seal
26	Top cover of (access) shafts with pumps/ installations in unheated building area	Close; no action
27	Side access hatches to the attic eaves combine with loft hatch – same thing	Close; no action (leave open only if attic eaves are within air tight envelope)
28	Missing window/door handle	Seal; (add note in testing protocol log sheet)
29	Empty conduit (or ducting) to unheated building area (e.g. due to posterior installed solar panels)	No action; do not seal (add note in testing protocol log sheet)
30	Air grilles/air bricks (existing openings for background ventilation of an existing chimney void)	No action
31	Suspended ceiling	No action
32	Windows in unheated spaces	Close

* If equipment is missing (not yet installed) then these items should be temporarily sealed and the sealing procedure should be noted in the air pressure testing protocol log sheet

** in non-res buildings with intermittent ventilation systems - sealing flaps must be closed during the pressure test but must not be sealed over.

Note: The above guidance has been translated and compiled from Appendix 3 'Checklist for approved measurement Method A' as presented in Fachverband Luftdichtheit im Bauwesen. V.(FLIB, April 2008)

Testing different building formats in accordance with the Passivhaus standard

Detached buildings

These are tested as a whole unit. Every part of the internal volume that is surrounded by the air barrier and within the thermal envelope will be subject to the test, therefore it is essential to make sure internal doors are wedged open to ensure the free flow of air around the building. Loft hatches should be closed (but not sealed) if the insulation and VCL are located at joist level (cold roof), but left open if the insulation and VCL are located at the rafters (warm roof). Note, if there is no loft hatch the volume of the air in the loft is not included in the $V_{n_{50}}$ even if it is a warm roof construction.

For large buildings it will be necessary to make sure that fan equipment used to pressurise and depressurise the internal volume is adequately sized to achieve the pressure differentials required for the test (i.e. > 50 Pa). Conversely for small units (dwellings) it is important to make sure that fans are not oversized as over pressurisation (> 100 Pa) may cause damage to the building's fabric. Competent air pressure testers will have experience in calculating the fan capacity requirements for different sizes of buildings.

Terraced / semi-detached houses

Partitioning walls between individual terraced and semi-detached houses need to be airtight, and therefore terraced and semi-detached houses must be tested separately. The windows in the adjoining houses should be open during the airtightness test to make sure the air pressure in these adjacent dwellings equalises with the outside. If this is not possible (e.g. if the adjoining dwellings are occupied) then the tester should note this in the test report. A terrace of five houses is illustrated in figure 13, each of these houses would be tested individually.



Figure 13 Testing terraced houses

Flats

If the communal and circulation areas (foyer, corridors and staircases) in a block of flats are all within the thermal envelope (built to Passivhaus standard) then the block will be tested as a whole building (all doors to individual flats and all internal doors must be wedged open); the fan testing equipment will be installed into the main entrance door and must be appropriately sized to ensure pressure differentials are maintained equally throughout the whole building. For UK Building Regulations compliance it will then be necessary to carry out further air pressure tests on a sample of individual flats (in this case the flats to be individually tested will be determined by the Building Control Body).

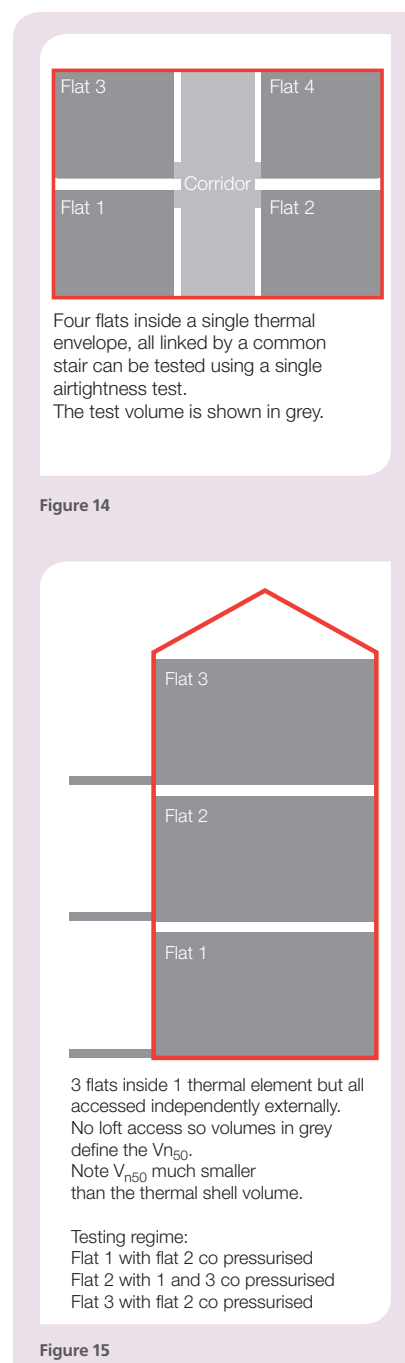
When communal circulation areas (foyers, staircases and corridors) are outside the thermal envelope and therefore not heated, it will be necessary to test each flat individually; however it is important to note that Passivhaus Certification requires the tester to balance the pressures (i.e. co-pressurise) between the flat being tested and adjacent dwellings (i.e. flats that adjoin the flat being tested - including flats that are directly below, to each side and directly above). This method of testing is often complex and can be costly. An alternative to this approach may be to test an entire group of flats at the same time by ducting air flow into each flat, but again this method of testing is complex and should only be attempted by a competent air pressure tester.

Co pressurisation - general note:

If one overall thermal element is split into separate units which are not linked via a passivhaus standard common area then co pressurisation tests should be carried out to each unit with each unit separately achieving the required standard.

Multi residential units with commercial units

If the commercial unit is separated from the domestic units by a thermal break and an air barrier then it will be necessary to air pressure test these areas separately. Where there is no thermal separation, such as in a single live-work unit, then the block would be tested and certified as one unit.



Air leakage audits – leak detection

An air leakage audit is helpful when carrying out an air pressure test to identify any air leakage paths that may need to be sealed to improve airtightness performance, and also to provide helpful guidance on areas to tighten up in future projects.

Smoke pencils, thermo-anemometers and infrared thermographic cameras and even the back of a hand can all be helpful to identify air leakage paths in the building's fabric.

While the building is being pressurised smoke pencils can be used to release small controlled quantities of dense white smoke that allows air to be visualised as it leaves the building through gaps in the envelope. Not all gaps will necessarily result in an air leakage path; the air barrier may be robust inside the fabric even if there is a large gap visible in the finish layer inside the building. If smoke moves quickly through a gap it indicates that the opening is connected with a lower pressure zone (i.e. it is connected to the outside).

For very leaky buildings, or a preliminary air leakage audit prior to an EnerPHit refurbishment project it can sometimes be helpful to use larger scale smoke machines that can fill large voids with smoke. Standing outside of the building it will be possible to see smoke emanating from the fabric through gaps, which can then pinpoint where remedial sealing is necessary.

Thermo-anemometers are able to detect localised air movement by inserting an electrically heated probe element into an airstream. The air speed is then inferred from the increase in heating power necessary to maintain the probe at a given temperature. These devices can pinpoint fine air leakage paths, and can be used over and over again, which is an advantage over smoke pencils - which can only be used once.

Infrared thermographic cameras can also be used to identify internal cold patches in the fabric caused by air leakage paths and heat being lost externally by warm air escaping through

an air leakage path. Care must be taken when using infrared thermographic cameras to ensure the inside of the building has been heated to a temperature that is at least 100C above the external temperature. If taking external images it is necessary

to avoid sunshine on the fabric and rain/dampness which will show as hot and cool patches respectively, and do not necessarily correspond to heat loss paths or air leakage. Some high quality infra-red cameras are capable of photographing laminar air flow through door and window seals. These cameras are expensive and must be used by a competent person, their use is not typically required if the building has been pressure tested and thoroughly audited at the first fix stage.



Figure 16 Smoke pencil used to identify air leakage path

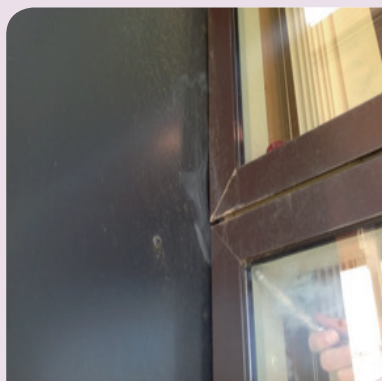


Figure 17 Thermo-anemometer used to detect air leakage paths



Figure 18 Infra-red thermographic image of air leakage between window casement and frame