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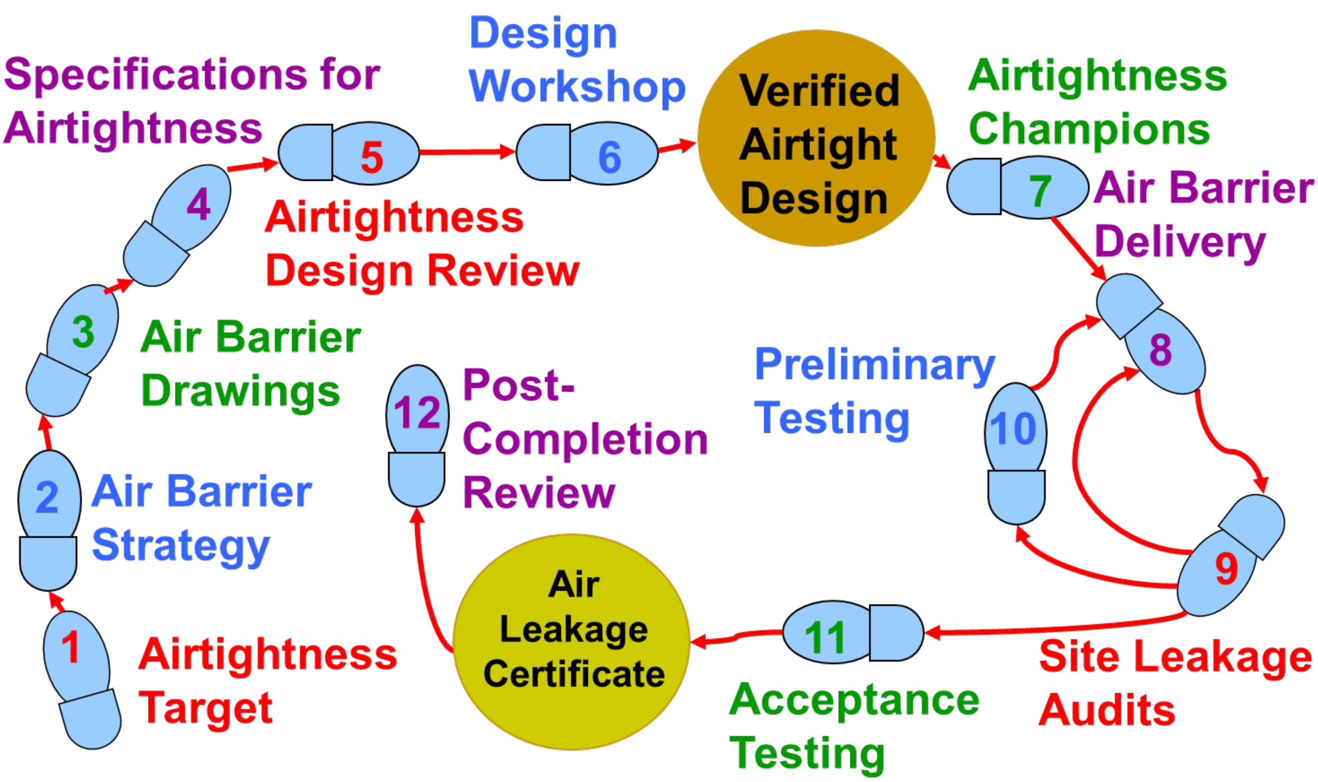
Delivering Airtight Buildings: A 12-Step Program

To effectively and efficiently deliver buildings to high degrees of airtightness, such as the AECB Building Standard or the Canadian Super-E standard (both ≤1.5 AC/hr @ 50 Pa), and particularly the German PassivHaus standard (≤0.6 AC/hr @ 50 Pa for newbuild, ≤1.0 AC/hr @ 50 Pa for refurbishment), the UK construction industry needs to adapt and develop, otherwise contractors and others will continue to face significant difficulties, delays and additional costs.

Here we outline a 12-step program for contractors and design teams to consider for simple buildings. The diagram below summarises this approach, which is explained in more detail on the following pages:



This was originally developed more than a decade ago, in response to my continuing frustration at seeing the same mistakes and omissions giving rise to leakage issues and airtightness test values in a range of low energy buildings across the UK. There is an accompanying PowerPoint presentation, part of the training we deliver for those wishing to become Airtightness Champions. This was initially prepared in 2012, revised for a subsequent project in 2018 and then again in early 2022. Paul Jennings, Aldas, February 2022

Step 1: Determine the Air-Tightness Target

This may be expressed as an Air Permeability or as an Air Change Rate, or both. Air Permeability is the value used in the UK Building Regulations and relates to the surface area of the building. The Air Change Rate is a volumetric measurement and can therefore be considered more appropriate for buildings with Heat Recovery Ventilation systems. The AECB Building Standard and the Passivhaus Standards specify an Air Change Rate target. The Air Permeability is defined in $m^3/hr/m^2$ (of the total building envelope) @ 50 Pa, and the Passivhaus standard also applies an Air Permeability target for large buildings above 1500 m^3 volume.

Delivering best practice requires excellent levels of airtightness, primarily by effective management of the airtightness process, and harder targets have become more common in recent years as the Passivhaus standard has been more widely adopted. It is now usual to specify an airtightness target according to the ventilation strategy for housing. The table below is from ATTMA TSL1 (2016), the current UK standard for the airtightness testing of newbuild dwellings. New Building Regulations come into force in June 2022, which reference a new test standard, CIBSE TM23 (2022 edition).

Ventilation Type	***Best Practice Air Permeability Target ($m^3/hr/m^2$ @ 50 Pa)***
Trickle ventilators and/or intermittent extract fans	***3.0 – 5.0***
Passive stack ventilation systems	***3.0 – 5.0***
Continuous mechanical ventilation	***2.0 – 4.0***
Full mechanical ventilation with heat recovery (MVHR) systems	***1.0 – 2.0***

For non-domestic buildings, the ATTMA TSL2 standard (2021) adopts a different approach giving the following best practice airtightness targets for a range of building types:

Building Type	***Best Practice Air Permeability Target ($m^3/hr/m^2$ @ 50 Pa)***
Archive	***< 0.50***
Care Home	***< 3.00***
Cold Store	***< 0.30***
Community Building	***< 3.00***
Data Centre	***< 3.00***
Educational	***< 4.00***
Hospitals	***< 3.00***
Hotels	***< 4.00***
Laboratory	***< 3.00***
Leisure	***< 3.00***

Building Type (cont.)	*Best Practice Air Permeability Target ($m^3/hr/m^2$ @ 50 Pa)*
Medical	*< 3.00*
Modular Building	*< 3.00*
Museum	*< 1.00*
Office	*< 4.00*
Place of Worship	*< 4.00*
Prison	*< 3.00*
Retail	*< 3.00*
Student accommodation	*< 3.00*
Warehouse	*< 3.00*

Currently applied low-energy and/or sustainability airtightness standards:	*Air Change Rate Target (AC/hr @ 50 Pa)*		
	AECB Building Standard	*Super-E (Canada)*	*Passivhaus (Germany)*
Dwellings with MEV or DCMV	*1.5*	*n/a*	*n/a*
Dwellings with MVHR	*1.5*	*1.5*	*0.6*
Other buildings	*1.5/3.0*	*n/a*	*0.6*
Refurbished buildings	*1.5/3.0*	*n/a*	*1.0 (EnerPHit)*

MEV: Mechanical Extract Ventilation; DCMV: Demand Controlled Mechanical Ventilation; MVHR: Mechanical Ventilation with Heat Recovery

Note that the AECB Building Standard was originally specified as an Air Permeability standard, but then modified to use Air Changes. There is also the Passivhaus Low Energy Standard, which sets a target value of ≤ 1.0 AC/hr for newbuild properties. Current Best Practice for Passivhaus projects in the UK, including EnerPHit refurbishment projects, is ≤ 0.2 AC/hr @ 50 Pa, although the UK achieved its first “zero Passivhaus” early in 2019, achieving an acceptance airtightness test value of 0.048 AC/hr @ 50 Pa.

Step 2: Define the Air Barrier Strategy

The Air Barrier Strategy is a summary of the building fabric choices which should facilitate the achievement of the Airtightness Target. The first principle is to adopt a single layer, with junctions between materials as necessary, as the air barrier throughout the building; having multiple layers as sometimes advocated merely increases the scope for divided responsibilities and failures in workmanship. As well as the airtightness layer, on the warm side of the bulk of the insulation, there should be a wind-tight layer on the outside of the insulation to prevent wind-washing that takes heat out of the insulation and cools the building down.

Photo: Mac Eye Projects Ltd

Certified Passive House

Passive House Institute

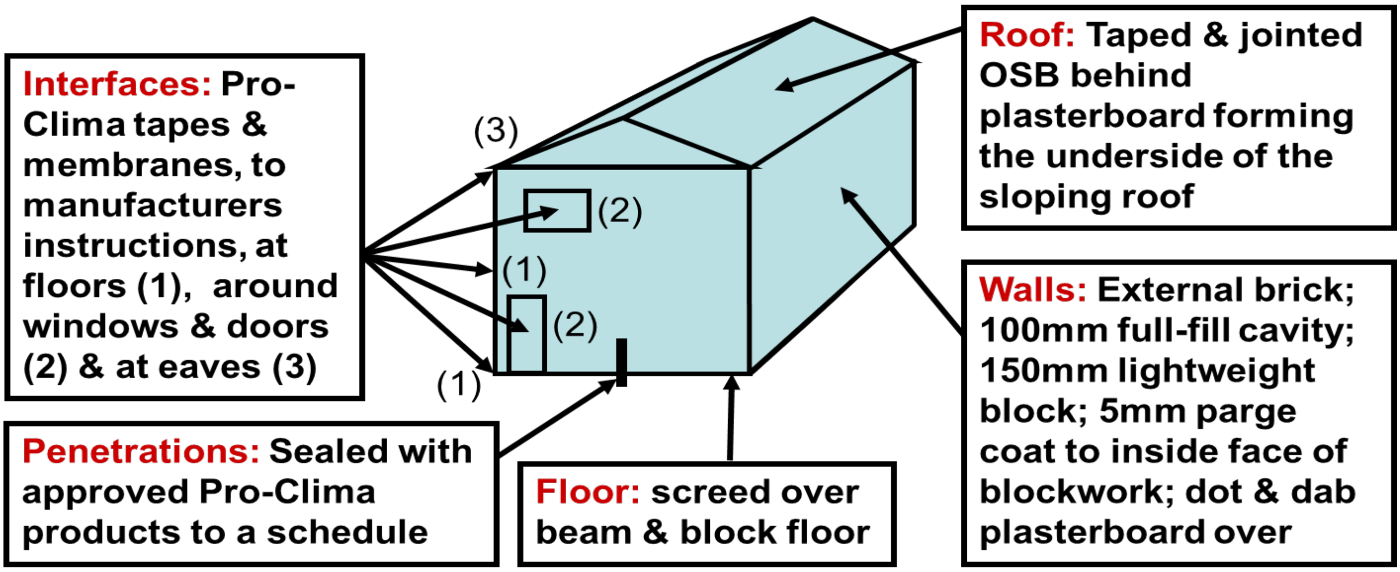
Larch Corner Passivhaus. The most airtight dwelling in the UK to date (May 2020). Achieved an air change rate of 0.048 AC/hr @ 50 Pa in March 2019. Since Passivhaus airtightness is quoted to 1 decimal place, i.e. 0.0, this cross-laminated Timber bungalow is the UK's first zero airtightness Passivhaus.

Examples of air barrier strategies might be:

Example A: The air barrier is formed by a thick, carefully applied, screed over a beam and block floor at ground floor level and a 5mm parge coat on the inside of the masonry inner leaf of the cavity external walls. Appropriate Pro-Clima membranes and tapes, applied according to the manufacturers' instructions, are used to (1) seal the interfaces between the parge coat on the external walls and the intermediate and ground floors; (2) seal around window, rooflight and door frames; and (3) at the eaves, sealing from the parge coat to the Duralis airtight OSB that forms the air barrier above the plasterboard finish to the underside of the sloping roof. All penetrations through the air barrier must be effectively sealed using approved materials, according to the schedule provided.

Example B: The air barrier is provided by: a cast in-situ concrete floor slab; Siga membranes and tapes (installed according to the manufacturers' instructions) at the back of the service void in the walls and the pitched (warm) roof. 12mm OSB forms the inner skin of the timber frame walls, providing the required racking strength. All penetrations to be effectively sealed with appropriate products.

Ideally, the Air Barrier Strategy will be summarised on a drawing to ensure that it is effectively communicated. This should be incorporated into site inductions and may be displayed in site canteens or welfare facilities. This is illustrated overleaf for example A.

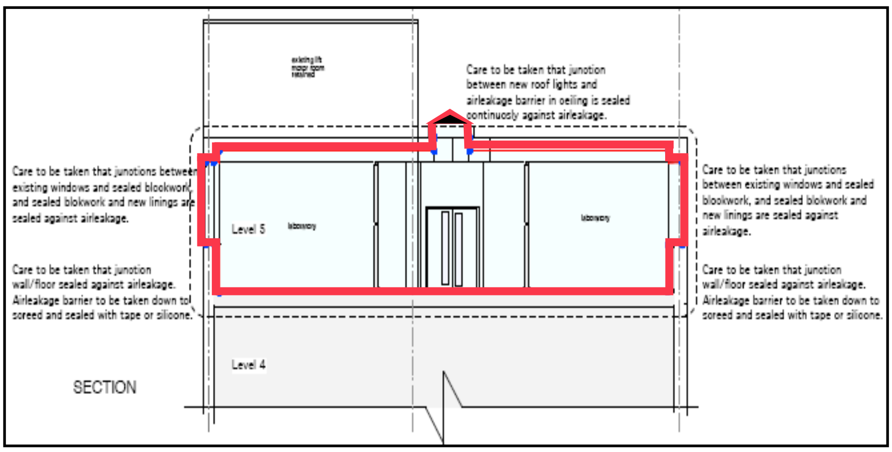


A more general additional statement for inclusion in any project specification might be: "All building elements and specialist components (such as curtain walling, roller-shutter doors, dock levellers etc.) must have a proven air leakage rate that is no more than 50% of the specified air-tightness for the whole building."

Step 3: Prepare a set of Air Barrier Drawings

These must (a) show the air barrier in plan and on sections and relevant details; and (b) provide notes identifying the material or product which forms the air barrier in each location, and particularly what forms the air barrier at interfaces between different sections and materials. May also record which work package includes each element of the air barrier. A3 close-up details should be provided for key interfaces and penetrations. Complex sealing details, such as joist ends built into a masonry wall, may require a 3-D diagram.

Normally prepared by the project architect, possibly with input from an air leakage specialist. This is the key opportunity to design out air leakage weaknesses and provide a robust solution for the builder to implement. The air barrier drawings constitute a controlled document which provides some protection against on site variations compromising the air barrier strategy by giving rise to additional holes through the air barrier plane without essential remedial sealing works then being undertaken. A common example would be to reposition extract or MVHR ducts without ensuring that redundant holes cut in the airtightness barrier are properly repaired. A sample drawing is provided here:



Air barrier section from a refit project in Scotland, courtesy of Howard Liddell at Gaia Architects

Note how the red air barrier line follows the inside surfaces of the windows & rooflights. It links to the inside face of the blockwork walls at the window heads, cills and jambs (not shown) and to the floor screed and the underside of the roof deck

Step 4: Write Airtightness Requirements into the Project Specifications

The project specifications must detail: (a) the air leakage target and the air barrier strategy; (b) the requirements for various work packages to incorporate particular items of work that contribute to the airtightness of the building; (c) details of the project requirements for air barrier drawings, air leakage design checking, site air leakage audits and preliminary and acceptance air leakage testing; (d) requirements for Airtightness Champions and other management strategies to ensure that workmanship is satisfactory, sealing works are verified and that the Airtightness target is achieved; (e) responsibilities for works, particularly in the event that the result of the air leakage testing is unsatisfactory and remedial sealing and additional air leakage testing are required.

Step 5: Air Leakage Design Review

Normally undertaken by an airtightness specialist, a detailed design review is carried out to check all details relevant to the air barrier. All details and specifications are considered, particularly those details relevant to airtightness, such as sections through external facades. Relevant product information is also considered. For larger and more complex projects, the airtightness specialist typically prepares a report identifying actual and potential air leakage weakenesses, together with appropriate recommendations.

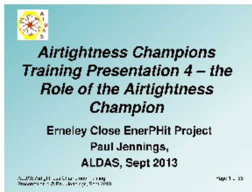
Step 6: Air Leakage Design Workshop

The air leakage design review is discussed by the design team, in a workshop facilitated by the airtightness specialist, and robust and cost-effective solutions are developed as necessary for the issues raised in the design review report. A schedule of penetrations and how they are to be sealed is commonly prepared. The project program is reviewed and hold points where airtightness of building elements must be verified are identified. An action plan with designated responsibilities relating to the prevention of air leakage issues must be prepared and implemented.

Step 7: Airtightness Champions Program

In order to deliver good levels of airtightness in UK projects, an Airtightness Champions Program is advisable, and is essential when UK contractors are aiming for Passivhaus accreditation of their buildings. The key role of an Airtightness Champion is to be continually aware of the position of the Air Barrier Plane and those materials and construction techniques involved in its formation. S/he must supervise and check all those works which are involved in forming a robust and continuous Air Barrier Plane, as well as those works which commonly compromise its effectiveness, such as the installation of plumbing and electrical services.

This role may be carried out by a Clerk of Works, or sometimes by a deputy site manager. On major projects there may be Airtightness Champions overseeing works for both Client and Contractor. Our suggested Airtightness Champions Program comprises three parts: (a) supply of an un-calibrated "Leakchecker" fan for leakage identification; (b) provision of a 2-day training course for 2 or more appropriately qualified and experienced staff to become Airtightness Champions for the project; and (c) provision of technical support for the Airtightness Champions for the duration of the project. A key part of the training program is an exhaustive in-depth review, normally held with the project architect in attendance, of the design details for the construction elements, and the interfaces between them, that will deliver the airtightness required for the project. There is an accompanying PowerPoint presentation, part of the training for the Erneley Close EnerPHit refurbishment back in 2013, which provides further details on the Airtightness Champions Program.



Step 8: Air Barrier Delivery

The relevant work packages by the main contractor and specialist sub-contractors, supervised by site staff and particularly by the Airtightness Champion(s). The Airtightness Champion will operate a leakage checklist to inspect key elements of the building process and ensure that sealing works are effective, for example by forbidding soil vent pipes to be boxed in before seals through floor and roof have been checked and approved. Normally a photographic record of key elements and locations is maintained for continual review.

Another key role of the Airtightness Champion is to ensure that manufacturers' requirements are adhered to for all materials used in the Air Barrier Plane by appropriate staff and/or contractors. This includes correct storage, timely ordering of product, and in particular that users of costly specialist sealing materials are properly trained and are demonstrably competent.

Step 9: Site Leakage Audits

A series of walk-around site air leakage audits are undertaken throughout the project, typically by the Airtightness Champion or the Airtightness Specialist. The purpose is to determine actual and potential air leakage weaknesses and determine any remaining or additional works that need to be carried out as the project proceeds completion. Depending upon the scale of the project, two to four Site Leakage Audits would normally be undertaken, with the final one typically taking place a week or so before the acceptance testing. A short report is provided after each audit, with photographs all actual and potential leakage identified being supplied in a detailed report only if warranted.

Other leakage audits are undertaken following an unsatisfactory preliminary airtightness test, when the air leakage tester and/or the airtightness specialist, in consultation with appropriate site staff, shall inspect the building envelope to identify and record leakage sites. These are then detailed in the airtightness test report.

Step 10: Preliminary Air Leakage Testing

10.1 Partial Preliminary Testing

This may be:

(a) Localised leakage checking using acoustic devices or hand-held air moving devices to check that individual sealing works are effective – such as running a hairdryer around the perimeter of a newly installed window to check that draughtseals work and that tape seals between the frame and the adjoining wall are effective;
(b) Leakage investigations using uncalibrated fans to check the effectiveness of localised sealing works, such as around a waste pipe through a floor slab;
(c) Element testing of specific components or sample sections of the building envelope;
(d) Testing sub-sections of a whole building (e.g. one wing in a new school, or one floor in a multi-storey office).

Much of the partial testing that can be carried out will require experience testers and often the guidance of an Airtightness Specialist to ensure that it is both appropriate and effective. In complex projects, particularly with innovative materials or practices, preliminary air leakage testing of sample sections of the building envelope may be undertaken, either on or off site. This may be a requirement for sealing contractors to demonstrate competence before starting on site.

This is known as element testing and is commonly carried out using a small test kit ducted from a temporary enclosure which isolates a known area of a specific material, or perhaps a known length of a key interface. By undertaking a series of comparative tests with temporary sealing of actual or potential leakage sites, by subtraction the leakage rate can be ascertained per square metre or per metre length of the particular element causing concern.

Another application of this technique is to check the workmanship of particular contractors or sub-contractors, for example by testing the first wing (or even the first classroom) completed in a new school and carrying out a detailed inspection and quantification of any significant leakage sites identified. This approach provides confidence that a satisfactory airtight design will be realised on site – or perhaps early warning that contractors' skills and/or application need to be improved to avoid potential problems as the build nears completion.

10.2 Preliminary Whole Building Testing

Just carrying out an acceptance airtightness test is risky, particularly for dwellings and other buildings built to increasingly onerous airtightness requirements, such as Passivhaus. Hence it has become usual practice to carry out at least one preliminary whole-building airtightness test, to provide security that a satisfactory result in a final acceptance test will be achieved. This may even be pre-improvement testing of a building to be refurbished, to identify key air leakage issues and weakness to inform the design process. This can even extend to co-pressure testing, where two or more adjoining dwellings are pressurised simultaneously, so that the extent of leakage occurring through party walls or floors can be assessed.

Preliminary whole building testing is now commonly undertaken on both newbuild and refurbishment projects, sometimes with a more stringent airtightness requirement to allow for the increased leakage that commonly occurs as building services are installed and the fundamental fabric airtightness is degraded. On refurbishment projects, leakage sites identified in a preliminary test before works commence will inform the design of improvements.

This might, for example, establish whether installing mechanical ventilation with heat recovery (MVHR) would be worthwhile. If the building is too leaky initially, especially if the extent of the refurbishment is limited by planning or financial constraints, opting for mechanical extract ventilation (MEV) and a target of the AECB Building Standard may be more realistic. Pre-improvement preliminary testing also provides a benchmark for comparison against after the final acceptance test, enabling a more robust calculation of energy and emissions savings.

A preliminary airtightness test should be undertaken on a newbuild project as soon as is feasible. This will establish confidence that the acceptance test will be satisfactory, or less ideally, will identify air leakage problems that must be tackled, and will allow sufficient time for effective remedial sealing works to be carried out before the final acceptance test. It is preferable that such a preliminary test is carried out as soon as soon as the building is weathertight, and the primary air barrier is largely complete. It is permissible for considerable temporary sealing to be in place to facilitate the earliest possible test, for example to have selected window openings temporarily sealed with polythene and tape because the window has not yet been delivered, or is faulty in some way. Commonly most services will be incomplete – e.g. waste and soil vent pipes taped over – and holes through the building envelope for some services, such as ventilation inlet and exhaust ducts, may not even have been cut at this point.

It is commonly the responsibility of the airtightness specialist or the airtightness testing organisation to calculate the values for the building envelope and volume prior to the test. These are essential to calculate the results of the testing.

The details and sources of these calculations shall be recorded in a traceable manner, and for complex building forms, it is advisable that these calculations are checked by a third party. With larger buildings and many Passivhaus projects, SketchUp modelling is commonly used to calculate the building envelope and volume and derive the values used in the Passivhaus Planning Package (PHPP) modelling required for Passivhaus certification.

Note that the volume calculation for Passivhaus and the AECB Building Standard testing is on a room-by-room basis, rather than the gross internal dimensions used by ATTMA. Hence the overall volume for such tests may be between 10% and (an extreme example) 25% less than the volume if calculated according to ATTMA guidance for standard Building Regulations testing

For buildings aiming to achieve Passivhaus certification, particularly if timber frame, it is advisable to budget for three air leakage tests. In the event of an unsatisfactory result, the specialist testing contractor, in consultation with appropriate site staff, shall inspect the building envelope to identify and record leakage sites. It is the responsibility of the main contractor to provide safe means of access to inspect actual or potential leakage sites, either internally (with the building normally depressurised) or externally.

Where time and access constraints permit, temporary and/or permanent sealing of significant leakage sites may be carried out immediately, and a further air leakage test carried out during the same visit to site. Non-toxic smoke, air velocity meters and thermographic cameras are used to identify and assess varying leakage sites. Acoustic devices may can also be utilised to find key leakage paths

As an example, two preliminary tests of a timber-frame Passivhaus newbuild might be undertaken (1) at the completion of the timber framing, when the building fabric is largely complete and most of the windows and doors are installed; then (2) after the completion of first fix, when all the penetrations through the building envelope (walls, floor and roof) have been installed and sealed back to the primary layer forming the air barrier layer in each element of the building envelope.

At this point the air change rate should be significantly better than the 0.6 AC/hr @ 50 Pa final airtightness target, since considerable experience suggests that the leakage of the building will increase somewhat (by between 0.05 to 0.2 AC/hr @ 50 Pa) during finishing works before the final acceptance test, normally because of leakage around services.

This process is illustrated in pictures below, from a series of tests I carried out upon Bere Architects' Ebbw Vale Larch House, an early demonstration Passivhaus. The text beneath each image provides test details and the result achieved. This series illustrates the variation in the Air Change Rate that can occur during a project.

Initial test, April 2010
At completion of timber frame
Achieved 0.29 AC/hr @ 50 Pa

Post 1st-fix test, May 2010
After wall penetrations sealed
Improved to 0.20 AC/hr @ 50 Pa

Final acceptance test, July 2010
Passivhaus certification test
Worsened to 0.23 AC/hr @ 50 Pa – damage to floor membrane

Step 11: Acceptance Air Leakage Testing

For the acceptance air leakage test the building should be essentially complete, and the only permissible temporary sealing (which must be detailed in the test report) is to exclude the ventilation systems so as to provide a true evaluation of the building fabric. Testing shall be carried out by a recognised specialist contractor in accordance with the applicable standards:

- ATTMA TSL1 (2021) for dwellings;
- ATTMA TSL2 (2021) for non-domestic buildings;
- ATTMA TSL3 (2021) for high-rise and complex buildings;
- ATTMA TSL4 (2021) for Passivhaus and other low-energy projects

Note that the range of ATTMA Airtightness Testing Standards were revised in late 2021, and that the new Building Regulations Part L (England & Wales), which comes into force on June 15th 2022, references the CIBSE TM23 standard (2022 edition) as the primary airtightness standard for Building Regulations Parts L and F compliance after that date.

In particular the maximum permitted existing pressure differential (before the test equipment is operated) shall be ±5 Pa. Testing for Passivhaus certification has more onerous requirements, in particular both pressurisation and depressurisation testing are required, rather than either one for conformance with ATTMA. TSL4 (2018) applies for Passivhaus and the AECB Building Standard.

All airtightness test results, both preliminary and acceptance, should be lodged on-line with the ATTMA Lodgement system to facilitate robust quality assurance on the airtightness process. This will help to ensure both that properly calibrated test equipment is utilised and that the test engineers are suitably experienced and reliably competent.

It shall be the responsibility of the airtightness testing contractor to issue an Air Leakage Certificate once testing is complete and the building has met the required standard. This would normally be incorporated in a full report detailing the test methodology, measurements recorded and the results, as well as any temporary sealing undertaken. The sample certificate shown is from the Cannock Mill Cohousing Passivhaus development.


Air Leakage Certificate

In accordance with BS EN 13829 and ATTMA TSL1 (2016) & TSL4 (2018)

Building Tested:	Plot 14, Block B, Cannock Mill CoHousing, Old Heath Road, Colchester CO2 8AA
Test Date:	26th November 2019
Test Engineer:	Paul Jennings, Aldas
Certificate No:	P3755-14-C01

This is to certify that the above-named dwelling has been tested for air leakage in accordance with the BS EN 13829:2001 methodology and the requirements of ATTMA as specified in TSL1 (2016) & TSL4 (2018). The additional requirements of the Passivhaus Institute when Passivhaus Certification is required were also met. The average Leakage Characteristics of the dwelling were recorded as follows:

Airflow @ 50 Pa:	91.8 m^3/hr
Air Permeability @ 50 Pa:	0.27 m^3/(hr.m^2)
Air Change Rate @ 50 Pa:	0.57 AC/hr
Data consistency, r^2 (requirement, r^2 > 0.98):	0.998
Slope, n (requirement, 0.5 < n < 1.0):	0.70
Intercept, C_{env}:	5.96 m^3/(hr.Pa^n)

Test Parameters

Envelope, A_E:	342.0 m^2
Volume, V:	274.0 m^3
Env. Calc. prepared by:	Paul Jennings, Aldas & Junko Suetake, Anne Thorne Architects

Initial Offset Pressure	- 0.10 Pa	Final Offset Pressure:	- 0.06 Pa
Initial Inside Temperature:	12.3°C	Final Inside Temperature:	12.1°C
Average Outside Temperature:	12.2°C	Barometric Pressure:	99.6 kPa

This certificate should be read in conjunction with the full airtightness test report P3755-23 and associated test method statement.

Signed: Paul Jennings Name: Paul Jennings Date Issued: 2nd December 2019
Position: Air Leakage Specialist

Deviations from Deviations from TSL1 & TSL4 methodology: None

Step 12: Post Completion Air Leakage Review

Carrying out a review of what worked and what didn't work with regard to the design and implementation of airtightness on a project can significantly improve the performance of the design team and contractors on future projects, which are likely to entail more onerous airtightness requirements. This is particularly so when the newly completed project is innovative or significantly in advance of previous design and/or construction practice.

There has been some discussion about undertaking repeat air leakage testing at the end of the defects period, particularly if the acceptance test result is marginal and/or there is evidence from users of the completed building of excessive fuel consumption or discomfort from draughts. These two threads could be merged by specifying a post-completion repeat Air Leakage test, to be carried out one month or so before the end of the defects period, after which a review meeting is held.