Delivering Airtight Buildings: A 12-Step Program

To effectively and efficiently deliver buildings to high degrees of airtightness, such as the AECB Building Standard (≤1.5 ACH\(^{-1}\) @ 50 Pa), the Canadian Super-E standard (also ≤1.5 ACH\(^{-1}\) @ 50 Pa), and particularly the German PassivHaus standard (≤0.6 ACH\(^{-1}\) @ 50 Pa for newbuild, ≤1.0 ACH\(^{-1}\) @ 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. The diagram below summarises this approach, which is explained in more detail on the following pages:

1. Airtightness Target
2. Air Barrier Strategy
3. Air Barrier Drawings
4. Airtightness Design Review
5. Design Workshop
6. Verified Airtight Design
7. Airtightness Champions
8. Preliminary Testing
9. Site Leakage Audits
10. Post-Completion Review
11. Acceptance Testing
12. Air Leakage Certificate

Specifications for Airtightness

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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 Passivhaus system specifies an Air Change Rate target.

The Air Permeability is defined in m$^3$/hr/m$^2$ (of the total building envelope) @ 50 Pa. Normally we would expect a goal of the AECB Silver Standard (≤3.0 ACH$^{-1}$ @ 50 Pa when Mechanical Extract Ventilation is fitted) if the desire is to achieve a low-energy and sustainable building.

The table below (primarily from the Green Building Bible) summarises generally agreed good and best practice air-tightness targets for a variety of building types. It is clear that delivering best practice requires good levels of airtightness, and more onerous targets have become more common since this table was originally prepared, particularly for housing where higher CSH levels and Passivhaus projects are increasingly popular.

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Air Permeability Target ($m^3$/hr/m$^2$ @ 50 Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good Practice</td>
</tr>
<tr>
<td>Dwellings</td>
<td>10.0</td>
</tr>
<tr>
<td>Dwellings with mechanical ventilation</td>
<td>5.0</td>
</tr>
<tr>
<td>Naturally ventilated offices</td>
<td>7.0</td>
</tr>
<tr>
<td>Mechanically ventilated offices</td>
<td>3.5</td>
</tr>
<tr>
<td>Superstores</td>
<td>3.0</td>
</tr>
<tr>
<td>Low energy offices</td>
<td>3.5</td>
</tr>
<tr>
<td>Industrial</td>
<td>10.0</td>
</tr>
<tr>
<td>Museum &amp; archival storage</td>
<td>1.7</td>
</tr>
<tr>
<td>Cold storage</td>
<td>0.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Air Change Rate Target (ACH@ 50 Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwellings with MEV</td>
<td>AECB Building</td>
</tr>
<tr>
<td>Dwellings with MVHR</td>
<td>1.5</td>
</tr>
<tr>
<td>Other buildings</td>
<td>1.5/3.0</td>
</tr>
<tr>
<td>Refurbished buildings</td>
<td>1.5/3.0</td>
</tr>
</tbody>
</table>

Note that the AECB Building Standard was originally specified as an Air Permeability standard, but then modified to use Air Changes.
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 Air Tightness 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. Examples of air barrier strategies might be:

Example A: The air barrier is formed by a 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, where they must be mechanically trapped; and (3) at the eaves, sealing from the parge coat to the OSB that forms the air barrier above the plasterboard finish to the underside of the sloping roof. All the penetrations through the air barrier shall be effectively sealed using appropriate approved materials, according to the schedule provided.

Example B: The air barrier is provided by: a cast in-situ concrete floor slab; Pro-Clima membranes and tapes (installed according to the manufacturers’ instructions), beneath plasterboard internal lining to the timber frame walls and the pitched (warm) roof. All penetrations to be effectively sealed with appropriate products.

An additional statement that could be included in the 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.”

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 below.
Step 3: Prepare a set of Air Barrier Drawings

These must (1) show the air barrier in plan and on sections and relevant details; and (2) 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. Normally prepared by the project architect, possibly with input from a specialist air leakage consultant. 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.

Step 4: Incorporate 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/or other management strategies to ensure that workmanship is satisfactory and 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 a specialist air leakage consultant, 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. The consultant prepares a report identifying actual and potential air leakage weaknesses, 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 specialist air leakage consultant, and robust and cost-effective solutions are developed as necessary for the issues raised in the design review report. A clear action plan with designated responsibilities relating to 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: (1) supply of an un-calibrated “Leakchecker” fan for leakage identification; (2) provision of a 2-day training course for 2 or more appropriately qualified and experienced staff to become Airtightness Champions for the project; and (3) 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.

**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 have completed all necessary training and are demonstrably competent.

**Step 9: Site Leakage Audits**

A series of site air leakage audits are undertaken during the latter stages of the project, typically by the specialist air leakage consultant in co-operation with the Airtightness Champion. The purpose is to determine actual and potential air leakage weaknesses and determine any remaining or additional works that need to be carried out before the acceptance air leakage testing as the project nears 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 verbal report is provided immediately after each audit, with a photographic record of all identified actual and potential leakage being supplied in a written report only if warranted.

**Step 10: Preliminary Air Leakage Testing**

This may be (a) element testing of particular components or sample sections of the building envelope; (b) sample testing of smaller sections of a whole building (e.g. one wing of a new school); and/or (c) preliminary testing of the whole building, typically for dwellings built to advanced and onerous airtightness requirements, such as the Passivhaus standard. This may 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 buildings are pressurised simultaneously, so that the significance of leakage occurring through party walls or floors can be assessed.
In complex projects, particularly those with innovative materials or construction practices, preliminary air leakage testing of sample sections of the building envelope may be undertaken, either on or off 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 particular 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 subcontractors, 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.

Preliminary whole building testing is commonly undertaken on smaller projects, both newbuild and refurbishment. On the latter, leakage sites identified in a preliminary test before works commence will inform the design of improvements, for example establishing 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 Silver 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 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 should be the responsibility of the specialist airtightness consultant or the airtightness test engineer to calculate the values for the building envelope and volume prior to the test. These are essential to calculate the final 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.

Note that the volume calculation for Passivhaus and AECB Silver 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 15% or more 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 and potential leakage sites, whether internally (when the building would normally be depressurised) or externally. Where time and access constraints permit, temporary and/or permanent sealing of significant leakage sites may be undertaken immediately and a further air leakage test carried out during the same visit to site. Non-toxic smoke, air velocity meters and thermographic cameras may be used to identify and assess varying leakage sites.

A san 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 ACH$^{-1}$ @ 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 ACH$^{-1}$ @ 50 Pa) during finishing works before the final acceptance test, normally because of leakage around services.

**Step 11: Acceptance Air Leakage Testing**

For the acceptance air leakage test the building should be essentially complete, and any areas of temporary sealing must be noted in the test report. Testing shall be carried out by a recognised specialist contractor in accordance with ATTMA TSL1 (2010) for dwellings and ATTMA TSL2 (2010) for non-domestic buildings. 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.

It shall be the responsibility of the 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. Details of any leakage inspection would typically be included.

**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 thread 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.