CE248

Achieving airtightness in new dwellings: case studies

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Introduction

Home energy use is responsible for over a quarter of UK carbon dioxide (CO_2) emissions which contribute to climate change. To help mitigate the effects of climate change, the Energy Saving Trust has a range of technical solutions to help UK housing professionals build to higher levels of energy efficiency.

This guide outlines solutions for housing professionals to meet the energy efficiency requirements of level 3 of the Code for Sustainable Homes.

Addressing air leakage in new housing is key to reducing heat loss and associated CO_2 emissions. This guide is intended to show that raising standards of airtightness is possible in the UK. Three developments where airtightness has been achieved using different methods of construction, have been identified.. Each demonstrates how airtightness can be significantly improved with careful design and implementation.

Air leakage is the uncontrolled flow of air through gaps and cracks in the fabric of dwellings (sometimes referred to as infiltration, exfiltration or draughts). This is not to be confused with ventilation, the controlled flow of air into and out of the dwelling through purpose-built ventilators that is required for the comfort and safety of the occupants. Excess air leakage leads to unnecessary heat loss, discomfort from cold draughts and increased energy costs.

With more stringent building regulations requiring mandatory pressure tests on all newbuild dwellings, reducing air leakage, or improving 'airtightness', is an increasingly important issue. The aim should be to 'build tight – ventilate right'. Buildings should not be too airtight and it is, however, essential to ensure appropriate ventilation. More information on ventilation can be found in 'Energy-efficient ventilation in housing' (GPG268).

Whatever the construction method, care on site is important. However, the overall airtightness of the finished dwelling depends heavily on getting the original design and specification right. The designer's role is therefore critical.

Standards for air leakage

Air leakage is quantified as air permeability (q_{50} value). This is the rate of leakage expressed in cubic meters per hour per metre of envelope area ($m^3/(hr.m^2)$) in or out of the dwelling. It is measured at a reference pressure difference of 50 Pascals (Pa) by a fan pressurisation test.

See 'Further information', reference 1, for more detail about what is involved.

Advantages of airtight dwellings

CO_2 emissions

- An airtight dwelling will ensure lower carbon emissions.

Space heating

- The reduced heat loss will mean that a potentially smaller sized heating system may be able to meet the demand temperature and therefore decrease occupants' energy bills.

Comfort

- Draughts and localised cold spots can cause discomfort. In extreme cases, excessive infiltration may make rooms uncomfortably cold during cooler periods. An airtight dwelling will significantly improve occupants' comfort.
- An airtight dwelling will reduce the likelihood of interstitial condensation and improve building fabric lifespan.
- Joints between elements and unwanted gaps in the building fabric are sealed as a part of the airtightness requirements. This reduces sound transmission, both from outside to inside the dwelling and also across party walls between dwellings.

For new homes the Energy Saving Trust recommends that an air permeability of $3m^3/(hr.m^2)$ should be specified, in conjunction with a mechanical ventilation system. This specification is part of a wider range of Energy Saving Trust solutions to meeting the energy efficiency requirements of level 3 of the Code for Sustainable Homes. for more information, visit www.energysavingtrust.org.uk/housing

Table 1 compares a number of air permeability standards in the UK and abroad.

Basic principles
To achieve best practice levels of performance, airtightness has to be considered at every stage of a project's life, inclusive of design, procurement, construction and handover. At an early stage the designer should use construction drawings to identify a physical line through the envelope of the dwelling where the barrier to air leakage will be: this is the dwelling's air barrier. Details that are vital to achieving good airtightness need to be identified at this point. Careful thought must be given to ensure the continuity of the air barrier between all junctions, and that mechanical and electrical subcontractors' (M&E) details are also dealt with and provided in sufficient detail (scale of drawing) for interpretation onsite.

The airtight barrier should not place unreasonable expectation of workmanship, or be located where it is likely to be damage by follow-on trades. Where particular skill is required then training should be given. Next, ensure these details are carried over into the construction phase. It is far simpler to design and build an airtight dwelling than to carry out remedial measures in a draughty home.

For more details on adopting an airtight strategy please see 'Improving airtightness in dwellings' (GPG224).

Air pressure testing regime
Airtight dwellings rely on a robust design, but additionally the correct specification of materials in conjunction with adequate knowledge, skill and awareness of site staff, is just as important.

Staged pressure tests are not generally possible in routine testing but, as many air leakage paths are hidden by subsequent work, it is very useful to undertake this on a few houses to identify weak points in the design, or where very high standards of airtightness are required.

Table 1 Air permeability standards

	Maximum air permeability ($m^3/(h.m^2)$) at 50Pa*
Building regulations – poorest acceptable standard[2]	10
Building regulations indicative standard[2]	7
Part L 2010 target[2]	5
Netherlands[2]	6
Germany[2]	1.8 – 3.8
Energy Saving Trust best practice[3]	3
Super E® (Canada)[4]	1.5
PassivHaus Standard[5]	<1

* Some values are actually air changes per hour @ 50Pa. These differ slightly from the stated figure when converted to $m^3/(hr.m^2)$

Table 2 Phase pressure testing

Possible stages	Phase
Initial air pressure test	Upon completion of the structural frame and all windows and external doors installed
Second air pressure test	Upon installation of all internal finishes, service penetrations and ventilation
Final air pressure test	Final post completion test

Note: phases may vary depending on the construction type.

Case studies
The following case studies offer an insight into the challenges and key lessons learnt in meeting a high standard in airtightness. They are intended to assist designers and developers in saving time, money and achieving high levels of energy efficiency in dwellings.

Two of the case studies benefited from a phase pressure test similar to that shown in Table 2, whilst the Stamford Brook case study focuses on training, feedback and advice as core elements of their airtightness strategy.

Table 3 Case studies

Case Study	Construction Form	Air Pressure Result ($m^3/(hr.m^2)$)
1 Osborne demonstration house	Structural Insulated Panel (SIP) construction	2.89
2 Glaziers Lane, Guildford	Timber frame construction	2.52
3 Stamford Brook, Cheshire	Modern masonry construction (>700 dwellings)	Between 2 and 4.7

Key Factors

Design

The building form, location and types of opening, interaction of the structure and airtight layer all effect the air leakage performance.

Presence and line of the airtight barrier should be identified as soon as possible allowing examination of details at openings and junctions in the envelope.

Testing

Pressure testing should be carried out at the start of a development and at regular intervals during construction, in accordance with formal quality control programme, so as to provide feedback on performance.

Site manager to be present during pressure tests so that they are aware of the problem areas.

Specification

The components and systems that make up the external envelope such as insulation, windows, services etc. must achieve at least the specified level of airtightness, and materials used to form the air barrier should be carefully selected for the building. Responsibilities for dealing with coordination at junctions should be clearly spelled out.

Construction

All subcontractors and site staff should be adequately trained on the importance of maintaining the airtight barrier, quality control and reproduction of the building details and design.

Acknowledgements

The Energy Saving Trust would like to thank all those who provided assistance with the preparation of this guide.

Case study 1: Osborne Demonstration House, Watford

Osborne, a social housing provider with support from the Energy Saving Trust, set out to prove that it is possible to build affordable, sustainable homes that incorporate the latest thinking on energy efficiency and waste reduction by using modern methods of construction and design to achieve best practice airtightness standards.

The demonstration house was constructed on the Building Research Establishment's Innovation Park.

Windows and doors were sealed using fabric-reinforced, tear-resistant aluminium foil, and service entries were sealed using gaskets and polyurethane foam (see Figure 2).

A three-stage pressure testing regime was employed. An initial test was carried out on completion of the structural frame. A secondary test was performed upon installation of services and ducting for the ventilation system. A final third test to measure overall performance was carried out post completion.

Construction and strategy

The Osborne house uses Structural Insulated panels (SIPs), which are typically two sheets of lining material fixed to either side of a pre-formed timber frame. The lining material is usually oriented strand board (OSB), as used in this development, or cement-based boards. The benefits of using SIPs in construction are the relatively few studs/thermal bridges present and ease of use – the external wall shell system was erected in just two days.

The airtightness strategy was based upon using the OSB casing of the SIPs as the air barrier and creating a seal at the panel junctions using resin impregnated foam tape (see Figure 1).

Figure 1 Foam tape is applied to sole plates which expands in place to seal between joints

Figure 2 Sealing tape applied to window frame and wall junction

Initial test results

The initial air pressure test was carried out upon the completion of the structural envelope, a result of $3.5m^3/(hr.m^2)$ was achieved.

The following components worked well with little or no air leakage occurring:

- Good sealing between the windows and SIPs panels due to the use of sealing tapes.
- The bathroom pod showed no sign of air leakage.

The following areas of air leakage pathways were identified:

- Gaps at SIP junctions were beyond the tolerance of the resin impregnated foam tape.
- Air leakage was occurring around the floor perimeter where the damp proof course (DPC) had been damaged during construction.
- Due to constraints the depth of the ground floor made it impossible to fit the preferred option of gaskets around the service pipes, expanding polyurethane (PU) foam spray was used as the alternative.

The intermediate floor cassettes had open undersides, and the continuity of air barrier had not been considered (unlike the wall SIPs which were closed frame).

Second test result

A second pressure test result of $3.1m^3/(hr.m^2)$ was achieved on installation of the services and ventilation ducting.Further remedial sealing was carried out in accordance with recommendations highlighted by the pressure testing team. These were carried out to these areas using additional sealant tapes between the inner leaf of the SIPs panels, acrylic mastic and PU foam.

Final test result

Following the further remedial sealing works to the services the building was retested and achieved $2.89m^3/(hr.m^2)$.

Lessons learnt and recommendations

Airtightness did not meet the initial planned target for a number of reasons. Primarily, the proposed strategy of using resin-based impregnated open-cell tape to create an airtight barrier between the SIPs failed. This was due to the variation in tolerances between the wall panels and floor cassettes being too great for the tape to seal effectively. If panel tolerances cannot be improved adequately, a continuous airtight barrier would be more appropriate, such as an airtight membrane surrounding the house.

Additional factors to consider during construction also included the following:

- The intermediate floor cassettes needed to be wrapped to maintain continuity with the appropriate airtight barrier.
- Subsequent remedial strategies were limited due to access issues.
- No air leakage was detected around the bathroom pod, however, any air pathways behind this would have been impossible to assess post installation.

Finally, the project would have benefited from more rigorous monitoring onsite during construction to achieve the target set out in the airtight strategy.

Builder: Osborne Ltd
Architect: Baily Garner Ltd
Developers: Osborne Ltd
Baily Garner Architects
Energy Saving Trust

Case study 2: Dartmouth Avenue, Woking and Glaziers Lane, Normandy, Guildford

These two developments build on the experience Jon Broome architects have in 'green' building. The design and specification was based on the Energy Saving Trust's best practice standard incorporating low energy sustainable construction by using the lowest carbon performance and build methods available within a mainstream housing budget.

Construction and strategy

The Dartmouth Avenue and Glaziers Lane developments used a prefabricated timber frame panel construction with roof, ground and intermediate floor cassettes. An airtight vapour control layer (VCL) with taped joints was used for the interior, whilst a breather membrane was used externally.

The walls featured integrated service zones with cross battens on the inside of 140mm studs for pipes and cables. This significantly reduced penetration of the airtight layer as well as reducing any cold bridging.

Once the timber frame was erected and the VCL was stapled in place, the following work was carried out:

- All joints in the VCL were taped.
- VCL was carried into the window openings sealed around the windows.
- A polythene membrane was laid on top of the structural floor deck and lapped and taped to the VCL on the external walls. A hardboard temporary floor was laid on top to protect the membrane until the finish floor was laid on completion.

On all outer walls, OSB sheathing was installed to internal facades, and medium density fibreboard board was applied to all external facades.

Further airtightness works

The service zone was created and any incoming services were ducted through the construction and finally sealed with expanding foam. Sealing was applied internally between window and external door frames to the external walls with an acrylic sealant. This ensured any moisture that built up could pass to the outside without causing any problematic dampness. Finally the external finishes of lime render and timber cladding were applied over a ventilated cavity.

Services

All mechanical and electrical services were face-fixed to the walls and within the first floor void. Lighting was relocated to the walls rather than ceilings on the first floors as this maintained flexibility and airtightness.

All incoming services were brought in through ducts and sealed with tightly packed mineral wool and expanding foam. A second pressure test was carried out prior to fixing the plasterboard lining to confirm that the installation of services had not been detrimental to overall airtightness.

Pressure tests

Four pressure tests were carried out on the development in Dartmouth Avenue one per house type. The results were 2.96, 3.38, 4.40 and 3.97$m^3/(hr.m^2)$. Although the pressure tests were unsatisfactory it was not altogether unexpected.

The first development suffered from problems with quality of construction of the timber frame and integrity of the airtightness membrane arising from damage from prolonged wetting.

Weaknesses in design and site practice exposed in the initial developments could then be addressed on the subsequent Glaziers Lane development.

Two of the 12 dwellings at the Glaziers Lane development of 12 in Guildford were tested. The first tests, after completion of the timber frame, achieved 1.17 and 1.37$m^3/(hr.m^2)$.

These dwellings were subsequently retested after the installation of services and the results were 2.73 and 2.31$m^3/(hr.m^2)$ respectively.

This is well within the Energy Saving Trust best practice target of 3$m^3/(hr.m^2)$ and consequently meets the energy efficiency requirements for level 3 of the Code for Sustainable Homes.

Identified air paths

One principal difficulty arose during the Dartmouth Avenue development; during the course of frame construction and installation, the airtight membrane was exposed to the weather for an extensive period and the sealing tape deteriorated.

The membrane was replaced in parts and the tape was reapplied generally to rectify the situation. Also the quality of fabrication and erection of the prefabricated timber frame, which included the air barrier, was below standard. The prefabricated timber frame was omitted on the Glaziers Lane development and instead built on site (see Figure 3).

Other areas where airtightness failings were exposed including the following.

- Incomplete seal between door or window casement and frame.
- Incomplete seal between window frame and opening in the timber frame structure.
- Incomplete seal around service pipe penetrations from waste stacks, flues or ventilation ducts.
- One instance of incorrect fitting of triple glazed sealed unit within its frame.

Figure 3 Timber frame construction on site, Glaziers Lane

The significance of services penetrations can be seen from air leakage rates. On the dwellings tested at Glaziers Lane, they doubled from an average of 1.27 to 2.52$m^3/(hr.m^2)$ once services were installed. Whilst the timber frame manufacturer on the Dartmouth Avenue development had a good appreciation of airtightness and took care to achieve a good result, the general contractor's site agent had more difficulty monitoring the M&E contractor's work, and remedial sealing after them.

Lessons learned and recommendations

It is crucially important to consider a sound airtightness strategy from the outset.

The first stage in air pressure testing of the envelope is essential and responsibility should lie with the initial structural contractor where one exists. The general site contractor will then become responsible for any further air pressure testing and the correct installation and sealing of services carried out by their M&E subcontractors.

More care during sealing and, where possible, avoiding service penetration, would significantly improve the results in future developments.

Most importantly assuring that the contractor or site manager has a comprehensive understanding and knowledge of all airtightness implications and strategy that is necessary in achieving the standard required.

It is also important that the contractor and most particularly, the timber frame and M&E subcontractors are aware of the implications of airtight construction and are committed to achieving the quality of construction necessary.

Architect: Jon Broome Architects
Client: Greenoak Housing Association

Case study 3: Stamford Brook, Cheshire

The Stamford Brook development of over seven hundred dwellings exemplifies energy efficiency in modern domestic masonry construction. To achieve this, Redrow and Bryant homes have worked in partnership with both Leeds Metropolitan University and the National Trust.

Construction and strategy

The Stamford Brook development demonstrates a best practice airtight standard using modern masonry cavity construction as part of a larger research project[6]. This was achieved by using the appropriate materials and due diligence on-site.

The airtightness strategy was developed at design stage as part of a wider energy standard[7]; the stated airpermeability target was 5m^3/(hr.m^2). It is very difficult to create a good air barrier using plasterboard on dabs due to the level of care required, the difficulty in checking, and the risk of damage by subsequent trades. Two options were investigated; traditional full surface plastering or applying a parge coat (rough coat of plaster to coat and seal external walls) prior to drylining. Of these two methods the parge coat and drylining solution was preferred, due to the extended drying times of wet plastering.

Additional air tightness measures were provided and these were specifically shown on design drawings. A comprehensive training package through the provision of workshops, formal training and continual feedback was put in place for all client, management and contractors.

Pressure tests

Due to the scale and diversity of dwellings built at Stamford Brook, there was a short window of opportunity for testing between construction and handover to the client. Owing to these constraints a representative sample of dwellings (35 out of 200 to date) were tested, and a predetermined pressure testing strategy was adopted.

The initial tests were primarily focused on the first phase of construction, from these tests it was possible to deduce whether the design strategy and site practice were performing as expected. Subsequent air pressure tests selected based on availability.

Airtightness results below 3m^3/(hr.m^2) were achieved on a number of house types with the lowest being 2.1m^3/(hr.m^2) (five bedroom house). This shows that high levels of airtightness can be achieved with masonry construction. However, results over 3m^3/(hr.m^2) were recorded on several properties. Particular problems were found with the complex construction of two and a half storey units, where specific air paths where investigated.

Identified air paths

Overall service penetrations were well sealed, however exceptions to this were the boiler flue outlet situated behind the consumer unit, whereby difficulties arose in access to seal the joint closest to the wall. Other main points of air infiltration to note were as follows:

- Doors and patio doors were found to leak at unsealed thresholds (i.e. door to frame; wall to door frame interfaces).
- Rooflights had significant leakage between frame and ceiling joints, between window and frame and around the trickle vents.
- Preformed loft hatches had leakage observed between the frames and ceiling and also between the hatch and frame.
- Ducting around the soil and vent pipes (SVP) exhibited significant air leakage in comparison to other infiltration paths. This was primarily due to soil stacks terminating in the loft space or roof, therefore providing direct infiltration routes from inside the house. These were specifically at the kitchen and bathroom interfaces.

Lessons learned and recommendations

Analysis of air pressure test data highlighted assumptions made about hidden air leakage paths based on site observations and design CAD drawings. This was depicted in the two-and-a-half and three-storey dwellings, whereby design issues surrounding the continuous airtight barrier had to be revised. As part of the ongoing development at Stamford Brook, a series of in depth studies are being undertaken to better characterise airtightness. This will involve detailed monitoring of the construction process of several dwellings that include areas of difficult detailing, principally in the two-and-a-half storey designs. On completion of the dwellings, pressure tests will be carried out and the results related to the construction observations.

One of the developers is establishing a dedicated air pressure testing team to provide ongoing feedback on performance and continual improvement in airtightness measures.

A stringent airtightness quality system during design processes should be introduced for all new dwelling types as well as any major design changes.

There are a number of forgotten areas commonly overlooked when addressing airtightness, mainly service penetrations in concealed locations, such as airing cupboards or behind skirting at floor-to-wall junctions. Remedial sealing of these areas is very difficult due to access problems, so they should be dealt with early on or moved to a more accessible location.

One of the critical factors learnt during construction was the crucial need in maintaining a continuous air barrier. This was exemplified with top floor ceilings. Two differing approaches were adopted – Bryant Homes had internal partitions installed prior to applying plasterboard to ceilings and this led to breaks in the air barrier.

Changing the construction sequence so that ceilings were plasterboarded before constructing the partitions, allowed the air barrier to be continuous and made a significant improvement. The approach by Redrow was somewhat different; they concentrated on improving the quality of the plasterboard installation whilst paying particular attention to the critical junctions and air paths.

When combining these two approaches the average air pressure test results for two-and-a-half storey units improved from over 7 to under $3m^3/(hr.m^2)$. In addition, the use of joist hangers over built-in joists is likely to provide a more robust airtight solution.

Finally, more rigorous monitoring of work onsite during construction to achieve the airtight target set out.

Developer: Taylor Woodrow Ltd
Redrow Homes Ltd
In collaboration with the National Trust and Leeds Metropolitan University

References

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www.energysavingtrust.org.uk/housing/standards

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Further information

The Energy Saving Trust provides free technical guidance and solutions to help UK housing professionals design, build and refurbish to high levels of energy efficiency. These solutions cover all aspects of energy efficiency in domestic newbuild and renovation. They are made available through the provision of training seminars, downloadable guides, online tools and a dedicated helpline.

The following publications may also be of interest:

- Energy-efficient ventilation in housing: A guide for specifiers on the requirements and options for ventilation (GPG268)
- Improving airtightness in dwellings (GPG224)
- Post-construction testing – a professional's guide to testing housing for energy efficiency (GIR64)

To obtain these publications or for more information, call 0845 120 7799, email bestpractice@est.org.uk or visit www.energysavingtrust.org.uk/housing

Other publications

- BRE Guide BR 448: Airtightness in commercial and public buildings (2002)
- CIBSE TM:23 Testing buildings for air leakage (2000) (superseded by reference 1).
- BS EN 13829 Thermal Performance of Buildings – Determination of air permeability of buildings – Fan pressurisation method (2001).

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