AIRTIGHTNESS OF UK DWELLINGS: SOME RECENT MEASUREMENTS

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AIRTIGHTNESS OF UK DWELLINGS: SOME RECENT MEASUREMENTS

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ABSTRACT

This paper reviews the results of some recent measurements of airtightness that have been undertaken on a small number of UK dwellings, which were identified as being potentially very airtight. The purpose of these measurements was to illustrate the levels of airtightness that can be achieved in practice in the UK if consideration is given to airtightness at both the design and construction stage, and identify the lessons that can be learnt from constructing and testing these dwellings.

While the total number of houses involved in the work reported here is small, the results indicate that dwellings constructed with a wet plastered internal finish, can default to a reasonable standard of airtightness by UK standards (less than 7 $m^3/h.m^2$ @ 50Pa) and that it is possible to build very airtight construction in the UK (around 4 $m^3/h.m^2$ @ 50Pa), given a reasonable level of attention to design and construction. Nevertheless, the airtightness performance of these dwellings still falls short of best practice overseas.

Key words: Airtightness, air leakage, pressurisation testing.

INTRODUCTION

Airtightness is crucial to improving the energy performance of buildings. This was recognised in the June 2000 consultation paper on Part L of the Approved Document (DETR, 2000) which, for the first time, proposed a maximum air leakage target of 10 $m^3/h.m^2$ @ 50Pa for both domestic and non-domestic buildings. In April 2002, the amended editions of the Approved Document came into effect; Part L1 for dwellings (DTLR, 2001a) and Part L2 for buildings other than dwellings (DTLR, 2001b). These amendments were intended to be the first of a series of changes that are proposed to take place to the Building Regulations over this decade, with the next major review scheduled for 2005 (DTI, 2003). The 2002 amended edition of the Approved Document L1 (ADL1) requires that reasonable provision should be made to reduce unwanted air leakage, and suggests that this can be achieved by adopting the guidance given in the report on robust construction details (see DEFRA, 2001), or by pressure testing[1]. It is anticipated that, the consultation document (due to be published in July of 2004) for the 2005 review of Part L, will require the inclusion of airtightness as part of the calculation of the total carbon emission rate for a particular dwelling design. Compliance with regulation will be determined with respect to an emission rate target,

[1]A method for pressure testing of dwellings is outlined in CIBSE technical memorandum TM23 (CIBSE, 2000). The recommended good practice air permeability for naturally ventilated dwellings is given as 10 $m^3/h.m^2$ @ 50Pa, and 5 $m^3/h.m^2$ @ 50Pa for dwellings with balanced whole house mechanical ventilation.

which will be defined in regulation L1. In addition it is anticipated that all dwellings will have to achieve a value of less than 10 $m^3/h.m^2$ @ 50Pa irrespective of the carbon emission rate achieved. However in order to achieve a satisfactory carbon emission rate, the airtightness specification of many dwelling designs will have to be much lower than this and 5 $m^3/h.m^2$ @ 50Pa or less may become a common design requirement.

AIRTIGHTNESS OF NEW UK DWELLINGS

There is a commonly held perception that new dwellings in the UK are built to a high standard of airtightness (Olivier, 1999). This is not generally found to be the case. Cohort data contained within the Building Research Establishment's (BRE's) air leakage database[2] suggests that dwellings built between 1980 and 1994 are, on average, as airtight as those built at the beginning of the 20th century (see Figure 1). Whilst the air leakage data for the older dwellings is not likely to be representative of the airtightness of these dwellings when they were first built, the data suggests that the airtightness of new dwellings has not improved significantly over the last century.

Figure 1 Relationship between dwelling age and air leakage. After Stephen (2000).

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[2] The BRE's database of air leakage is the largest and most comprehensive source of information on the airtightness of UK dwellings (see Stephen, 1998 & 2000). This database contains information on some 471 dwellings of different age, size, type and construction. However, despite its size, this database is not the result of random sampling and cannot claim to be unequivocally representative of the UK housing stock.

Air leakage data on dwellings built from 1995 onwards is limited. Recent measurements undertaken by the BRE (see Stephen, 2000) on 32 post-1995 dwellings show that there is still a very wide range of airtightness observed within the sample (6.0 to 19.3 $m^3/h.m^2$ @ 50Pa), and that the average value is only marginally more airtight than the average for the stock as a whole (air permeability of 11.3 $m^3/h.m^2$ @ 50Pa as opposed to 11.48 $m^3/h.m^2$ @ 50Pa). This small difference indicates that there is unlikely to be any real improvement in the airtightness of buildings built post-1995. These results also suggest that a significant proportion of the post-1995 dwellings would fail to meet the Approved Document L1 (ADL1) air leakage target of 10 $m^3/h.m^2$ @ 50Pa (DTLR, 2001a). However, the size, structure and non-random nature of the post-1995 sample preclude certainty. It should also be pointed out that the data do not include airtightness measurements on any dwellings that have been constructed since the 2002 amendment to Part L of the Building Regulations.

In order to determine the levels of airtightness that could be achieved in new UK dwellings, air leakage measurements were undertaken on a small number of recently constructed dwellings that had been identified as being potentially very airtight. These measurements were undertaken using the fan pressurisation technique and were carried out in accordance with the method outlined in CIBSE technical memorandum TM23 (CIBSE, 2000).

DESCRIPTION OF THE DWELLINGS

In total, seven dwellings were pressure tested. In addition to the pressurisation tests, the main air leakage paths within all seven dwellings were identified by pressurising the building and locating the main areas of air leakage using hand held smoke generators. Although this technique enabled identification of all of the main air leakage paths within each dwelling, it was not possible to quantify the contribution that these leakage paths made to the dwellings overall air leakage.

Details of the dwellings that were tested are contained within Table 1. The dwellings varied in terms of size, built form and construction technique, and were completed between late 2003 and early 2004.

Dwelling	Construction type	Built form	Internal floor area (m^2)
A	Timber frame	Mid-terrace	98
B	Timber frame	Mid terrace	98
C	Timber frame	Mid-terrace	98
D	Timber frame	End-terrace	98
E	Masonry cavity	Detached	178
F	Masonry cavity	Detached	185
G	Masonry cavity	Detached	178

Table 1 Size, built form and construction type of the dwellings.

Timber Frame Dwellings

The timber frame dwellings formed part of a social housing development of 16 two-storey, two and three-bedroomed terraced houses. The houses were designed to achieve an enhanced energy performance standard proposed for 2008, which incorporated an air leakage target of 5 $m^3/h.m^2$ at 50Pa (see Lowe & Bell, 2001). This target was to be achieved by paying special attention during the design process to the creation of a continuous air barrier formed by the polyethylene vapour membrane. The 4 tested dwellings were all of the three-bedroom type. The units were constructed from a proprietary panelised timber frame system. The system used a breathable external sheathing board, cellulose insulation and an oriented strand board internal sheathing. A breather paper was installed over the internal sheathing, followed by wooden battens and an internal plasterboard finish, which formed a service void. A layer of closed cell rigid insulation was installed over the external sheathing, with a final timber weatherboard external finish. The ground floors were of suspended beam and block construction with an insulation layer and reinforced concrete screed top layer. The first floor was of suspended timber construction. The roof was of a traditional tiled pitched design with the loft insulation at ceiling level. Due to the expected high level of airtightness, all of the dwellings incorporated a mechanical ventilation system (continuous mechanical extract) in order to maintain adequate indoor air quality.

Masonry Cavity Dwellings

The three load bearing masonry cavity dwellings formed part of a private housing development of 9 two-storey 4/5 bedroomed properties. They were all constructed using masonry cavity external walls, which were fully-filled with 150mm of rigid resin-bonded glass wool insulation. A wet plastered internal finish was used. The ground floors were of pre-cast beam-and-block construction, whilst the upper floors were constructed using timber I-beams. The roof of dwelling F was constructed using trussed rafters, whilst timber I-beams were used for the room-in-the-roof designs of dwellings E and G. All of the roofs were insulated with 300mm of cellulose fibre. Due to the expected high level of airtightness, all of the dwellings incorporated a mechanical ventilation system with heat recovery, in order to maintain adequate indoor air quality.

Considerable additional effort had been made by the construction team to reduce the air leakage of dwelling G. In addition to the use of a wet plastered internal finish, attempts were made to seal a number of leakage paths that had been previously observed within another house of the same type. For instance, silicone sealant had been used to seal all of the junctions between the floor and the skirting boards on the ground and first floor, as well as all of the service penetrations through the floors, ceiling and external walls.

RESULTS OF THE PRESSURISATION TESTS

The air permeability results for the seven tested dwellings are detailed in Table 2.

Dwelling	Pressurisation Test ($m^3/h.m^2$)	Depressurisation Test ($m^3/h.m^2$)	Mean ($m^3/h.m^2$)
A	7.64	7.42	7.53
B	8.58	8.14	8.36
C	9.45	9.46	9.46
D	7.95	7.69	7.82
E	6.71	6.30	6.51
F	4.92	4.64	4.78
G	3.81	3.78	3.80

Table 2 Air permeability results.

In the case of the four timber framed dwellings (A, B, C and D), the measured air permeability ranged from 7.53 to 9.46 $m^3/h.m^2$ @ 50Pa. These air leakage values all fall below the ADL1 maximum air leakage target of 10 $m^3/h.m^2$ @ 50Pa (DTLR, 2001). This range of values would place these dwellings in the top third of UK dwellings in terms of airtightness, as illustrated by the distribution of the air leakage data for UK dwellings in the BRE database (see Figure 2). However, the air leakage was not as good as would be expected from the adopted design approach, and fell short of the enhanced energy performance standard target of 5 $m^3/h.m^2$. The main air leakage paths that were identified within these dwellings were as follows: gaps around service penetrations through the external walls, floors and ceiling; poorly fitted and draught sealed doors, windows and loft hatch; junction between door/window frame and plasterboard drylining; and gaps between the upper floor and the external walls. These leakage paths rendered the designed air barrier ineffective. Photographs illustrating some of the identified air leakage paths (unsealed pipe penetrations and gaps around poorly fitting doors) are shown in Figures 3 and 4.

The air permeability of the three masonry cavity dwellings (E, F and G) ranged from 3.8 to 6.51 $m^3/hr.m^2$ @ 50Pa. These are well within the recommended ADL1 maximum air leakage target of 10 $m^3/h.m^2$ @ 50Pa (DTLR, 2001), and demonstrate the effectiveness of an internal wet-plastered finish as an air barrier. The very low permeability of 3.8 $m^3/h.m^2$ achieved by dwelling G shows the benefit of special attention to sealing problem areas such as service penetrations and gaps between floor and wall. For example, Figure 5 illustrates the use of clear silicone sealant to seal around the toilet soil pipe floor penetration. Dwelling G, with an air permeability of 3.8 $m^3/h.m^2$ @ 50 Pa, would be in the top 1% of in terms of airtightness when compared to the dwellings in the BRE database (see Figure 2).

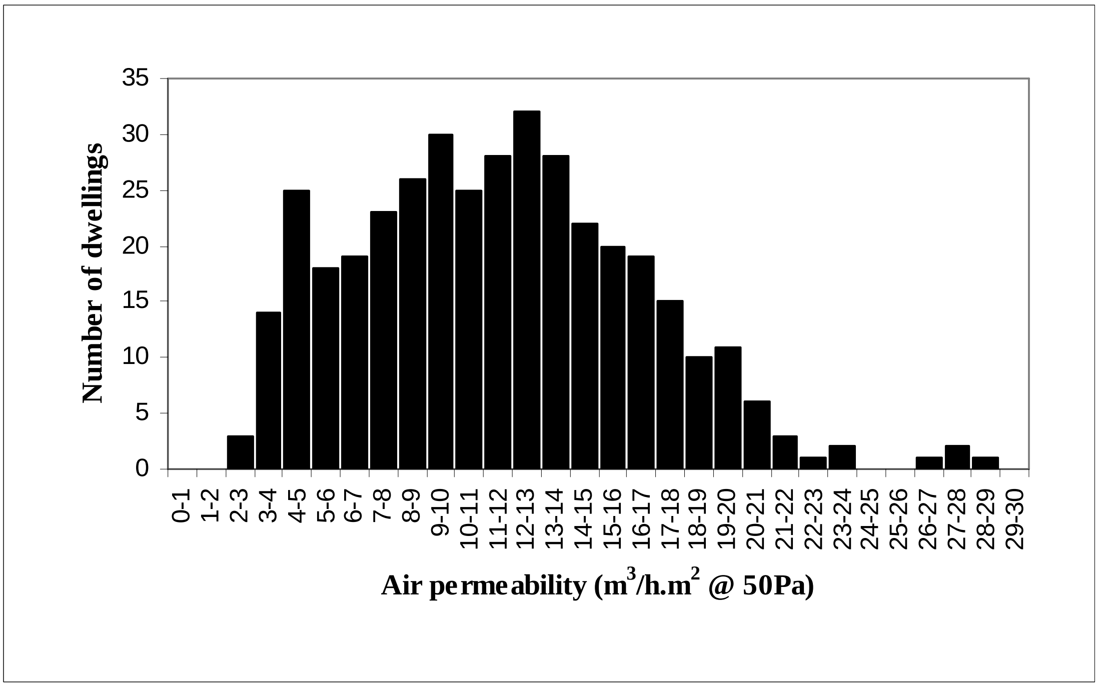

Figure 2 Distribution of air permeability for UK dwellings in the BRE database.

Figure 3 Air leakage around unsealed soil pipe penetration.

Figure 4 Air leakage through gaps around poorly fitting back door.

Figure 5 Use of silicone sealant to seal around toilet soil pipe penetration.

COMPARISON OF RESULTS WITH DATA FROM OTHER AIRTIGHT DWELLINGS

In order to place the air leakage results for dwellings A to G in context, the data have been compared against the results of some recent tests that have been undertaken on some ultra-low energy UK housing (Hockerton (Hockerton Housing Project 2000a & 2000b) and the Autonomous Urban House (Vale & Vale 2000)), and a range of airtight dwellings constructed in the UK and abroad that have been reported in the literature. The air leakage data, construction type and form of the dwellings incorporated within the comparison are listed in Table 3.

Dwelling	Construction Type and Form	Mean air change rate @ 50Pa (ac/h)
Hockerton Housing Project - Mean of 3 Dwellings	Single storey earth-sheltered masonry cavity terraced houses	1.26
Autonomous Urban House	2½ storey wet-plastered masonry cavity detached house	3.89
Lower Watts House, Charlbury, Oxfordshire (Olivier & Willoughby, 1996a)	2 storey wet-plastered masonry cavity detached house	3.60
Low Energy Housing, Stenness (Bullen, 2000)	Timber-frame semi-detached houses	1.00
Two Mile Ash, Milton Keynes (Bell & Lowe, 2001)	2 storey timber frame detached house	1.47
The Longwood House, Huddersfield (Lowe & Curwell, 1996)	2 storey wet-plastered masonry cavity detached house	3.00
Zero-Energy Timber-frame House, Brunnadern (Olivier & Willoughby, 1996b)	2 storey timber-frame detached house	0.17
The Passive Houses, Kranichstein (Passivhaus Institut, 2000).	2½ storey externally insulated masonry terraced houses	0.20
The Self-Sufficient Solar House, Freiburg (Voss, Stahl & Goetzberger, 1993)	2 storey externally insulated masonry detached house	0.30

Table 3 Air leakage data.

Due to data availability, it has only been possible to undertake a relatively crude air leakage comparison, using air changes per hour (ac/h) @ 50Pa, rather than permeability in $m^3/h.m^2$ @ 50Pa. The use of air changes per hour as a measure means that it is not possible to be able to take into consideration the effects of shape and size, and the results will favour those dwellings that have a low ratio of envelope surface area to volume. The results of the comparison are illustrated in Figure 6.

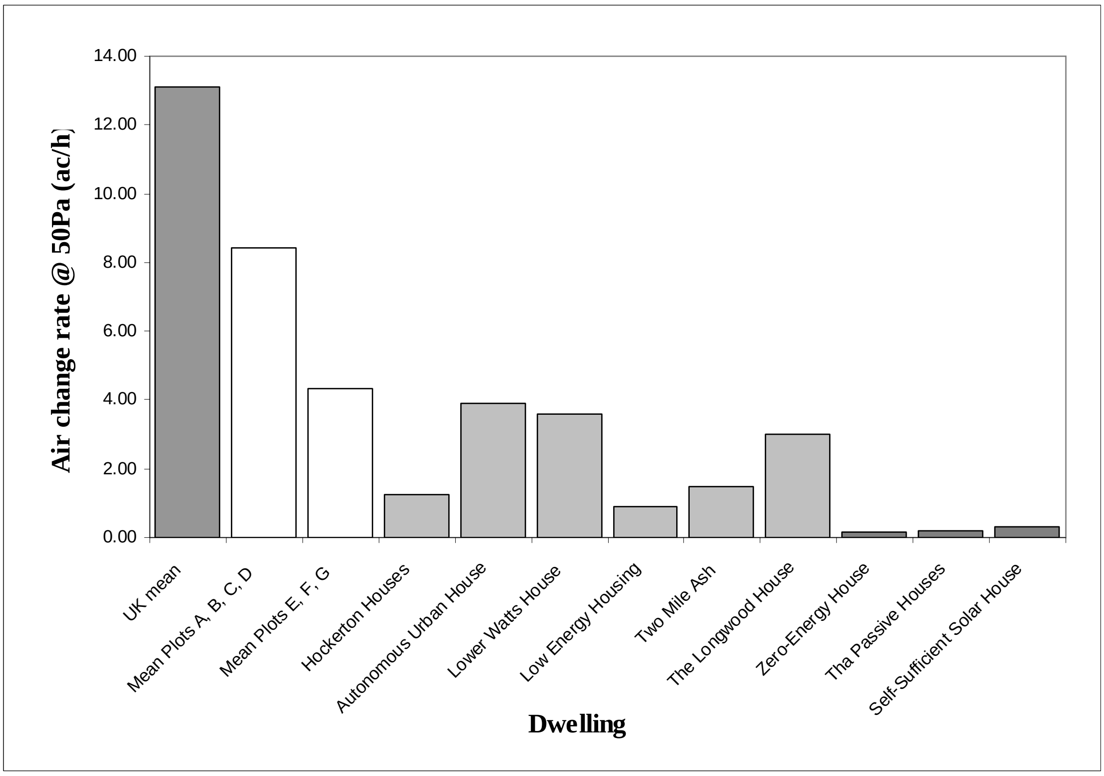

Figure 6 Comparison of results with state of the art UK and European dwellings.

The tested dwellings (A to G) have measured air leakage values ranging from 3.17 ac/h to 9.57 ac/h, which makes them all better than the UK mean (13.1 ac/h). The masonry cavity dwellings (E, F and G) have levels of air leakage that are comparable with the Autonomous House, Lower Watts House and Longwood House. This puts these dwellings amongst the most air tight traditional masonry dwellings yet recorded in the UK. Dwelling G, with an air leakage of 3.17 ac/h, is only bettered by one other traditional cavity masonry dwelling in the UK, namely the Longwood House with an air leakage of 3.0 ac/h. The four timber framed dwellings (A, B, C and D), with a mean air leakage of 8.44 ac/h, do not fare as well when compared to state of the art timber frame dwellings in the UK, falling well short of the 1.0 ac/h and 1.47 ac/h recorded by the Stennes and Two Mile Ash timber frame houses.

The results suggest that, in the UK, relatively airtight dwellings can be built using both timber frame and wet plastered masonry. However, there is still a considerable gap in airtightness between the best performing dwellings constructed in the UK and those constructed abroad. The lowest recorded airtightness readings for UK dwellings are from the Low Energy Dwellings at Stenness and the Hockerton Houses, but these fall short of the best performing houses overseas, such as the Brunnadern house. This indicates that the design approach and construction techniques must be improved further if the UK is to match the airtightness performance of the best overseas dwellings.

DISCUSSION AND IMPLICATIONS

The results of airtightness measurements and air leakage path identification for the four timber framed dwellings (A, B, C and D) indicate that the quality of workmanship and level of site supervision can have a significant influence on the airtightness of dwellings. The lack of attention during construction to details such as the sealing of service penetrations and ensuring that doors and windows were properly fitted, meant that these dwellings failed to achieve the expected level of airtightness. This is probably due to a combination of factors such as a lack of understanding by the workforce of the importance and significance of these issues and inadequate supervision. These failings could be addressed by better training and the use of improved quality control systems.

Some other recent measurements undertaken as part of the Building Operational Performance Framework Project have shown that, even when dwellings have been constructed using the "Robust Standard Detail" approach, air leakage can be very high. For example, tests undertaken on four drylined cavity masonry terraced houses (Building Sciences Limited, 2004) showed air permeability values ranging from 29.7 $m^3/h.m^2$ @ 50Pa to 33.75 $m^3/h.m^2$ @ 50Pa.

It is also important to note that, even when levels of workmanship on site are high and dwellings are constructed that are very airtight, airtightness is likely to degrade over time. Work undertaken by Elmroth & Logdeberg (1980) and Warren & Webb (1980) on a small number of Swedish and UK dwellings found that the majority of the increase in air leakage occurred during the first year of occupation, where it was observed to increase by 70% and 83% respectively. This suggests that the majority of the increase in the air leakage of these dwellings was attributable to shrinkage cracks caused by drying out and settlement of the foundations. A number of other factors are also known to contribute to increased air leakage over time. These include: wear-and-tear of construction materials, particularly window and door seals; and changes carried out by the occupants, such as poorly sealed penetrations through the air barrier. A number of these factors have been observed within the Hockerton houses (see Johnston, Wingfield & Bell 2004). These include, for example, leaks through the opening casements of the windows and the French doors (attributed to worn or damaged seals, warped casements and doors, and 'dropped' casements and doors) and a number of poorly sealed service penetrations that had been made through the building fabric after the dwelling had been occupied.

The implication of these findings, along with the importance of achieving a high level of airtightness in order to satisfy the total carbon emission requirements expected for the 2005 review of Part L of the Building Regulations, means that architects and contractors will need to think much more carefully about airtightness standards when making design and construction process choices for new dwellings. For example, architects may consider specifying a wet-plastered internal finish in preference to plasterboard dry-lining, as this is more likely to achieve a higher level of airtightness. Such changes could transform the way dwellings are constructed in the UK.

CONCLUSIONS

- All the tested dwellings were found to be relatively airtight by UK norms, and were all within the target of 10 $m^3/h.m^2$ @ 50 Pa given in Approved Document L1 of the Building Regulations. The air permeability of the four timber dwellings ranged from 7.53 to 9.46 $m^3/h.m^2$ @ 50 Pa whilst the permeability of the three wet-plastered masonry cavity houses ranged from 3.8 to 6.51 $m^3/h.m^2$ @ 50 Pa.
- The results suggest that wet-plastered masonry cavity construction can default to being airtight when compared to typical UK construction, with little attention being given to airtightness. Where additional consideration is given to airtightness during construction, for example by ensuring that all service penetrations are properly sealed, and that gaps between floors and external walls are sealed, then permeability can be improved further to a level that is comparable with some of the most airtight houses measured in the UK.
- The air permeability of the four tested timber frame dwellings was not as good as expected, falling short of the design target of 5 $m^3/h.m^2$ @ 50 Pa. This was attributed to poor attention to sealing of service penetrations, absence of any seal between floor and external walls, and poorly fitted and sealed doors, windows and loft hatches. These failings rendered the designed air barrier ineffective.
- The air permeability of all of the dwellings could be improved by undertaking a number of relatively simple and inexpensive measures. For instance, sealing service penetrations, sealing junctions between floors and external walls, doors are correctly fitted and adjusted, sealing the junction between door/window frame and plasterboard drylining and ensuring that doors, windows and loft hatches are adequately draughtsealed.
- These results indicate that, in the UK, relatively airtight dwellings can be built using both timber frame and wet plastered masonry. However, there is a still significant gap in airtightness between the best performing dwellings constructed in the UK (around 1 to 1.5 ac/h at 50 Pa) and the most airtight dwelling constructed abroad (less than 0.3 ac/h @ 50Pa).
- The results of air leakage path identification suggest that the quality of workmanship and level of site supervision can have a significant influence on the airtightness of dwellings.

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