AIRTIGHTNESS OF UK DWELLINGS

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This paper presents the results and key messages that have been obtained from Phase 1 of a participatory action research project that was undertaken with 5 developers to investigate the practical design and construction issues that arise in making improvements to the airtightness of speculatively built mainstream housing. Two construction types were represented in the project, masonry cavity and light steel frame. Phase 1 of the project sought to assess in detail the design, construction and air permeability of 25 dwellings that were constructed to conform to the requirements of Approved Document Part L1 2002. While the total number of dwellings reported here is small, the results suggest that there is not a consistent approach to the way in which developers present information on air leakage to those on site, a mixture of approaches are utilised on site to achieve the same specification and there appears to be a lack of foresight in the detailed design stage, resulting in specifications that are practically very difficult to achieve. Despite this, the air permeability results suggest that dwellings constructed with a wet/mechanically plastered internal finish, can default to a reasonable standard of airtightness by UK standards, without much additional attention being given to airtightness.

Keywords: airtightness, air leakage, housing, pressurisation testing.

INTRODUCTION

Airtightness is crucial to improving the energy performance of buildings. This was recognised, for the first time, in Approved Document Part L1 of the 2002 Building Regulations (DTLR, 2001), which included a maximum air leakage target of 10 $m^3/(h.m^2)$ @ 50Pa for domestic buildings. This document has since been superseded by the publication of two revised versions of Approved Document Part L1; L1A Work in New Dwellings (ODPM, 2006a) and L1B Work in Existing Buildings (ODPM, 2006b). Approved Document L1A (ADL1A) requires that the building fabric should be constructed to a reasonable quality of construction so that the air permeability is within reasonable limits (ODPM, 2006a). Guidance on a reasonable limit for the design air permeability is given as 10 $m^3/(h.m^2)$ @ 50Pa. 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. Early work undertaken by the BRE for the Office of the Deputy Prime Minister (ODPM) on a small number of dwellings built to Approved Document Part L1 2002,

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indicated that about two thirds of the dwellings failed to achieve an air permeability of 10 $m^3/(h.m^2)$ @ 50Pa (cited in Grigg, 2004).

In 2004, the BRE undertook airtightness measurements on a much larger non-random sample of 99 dwellings that had been built to Approved Document Part L1 2002 (see Grigg, 2004). The sample included a range of dwelling types, of both masonry and framed construction, which were located in various geographical locations and were from both the private and social housing sectors. The results showed that a relatively wide range of airtightness was observed within the sample (see Figure 1). The air permeability of the dwellings ranged from 3.2 to 16.9 $m^3/(h.m^2)$ @ 50Pa, with a mean of 9.2 $m^3/(h.m^2)$ @ 50Pa and a standard deviation of 2.8 $m^3/(h.m^2)$. In addition, approximately two thirds of the sample (68%) achieved an air permeability that was lower than or equal to the maximum specified level of 10 $m^3/(h.m^2)$ @ 50Pa set in the 2002 Edition of the Approved Document Part L1 (DTLR, 2001). These results contrast with the earlier much smaller BRE sample where two thirds of the sample failed to achieve an air permeability of 10 $m^3/(h.m^2)$ @ 50Pa.

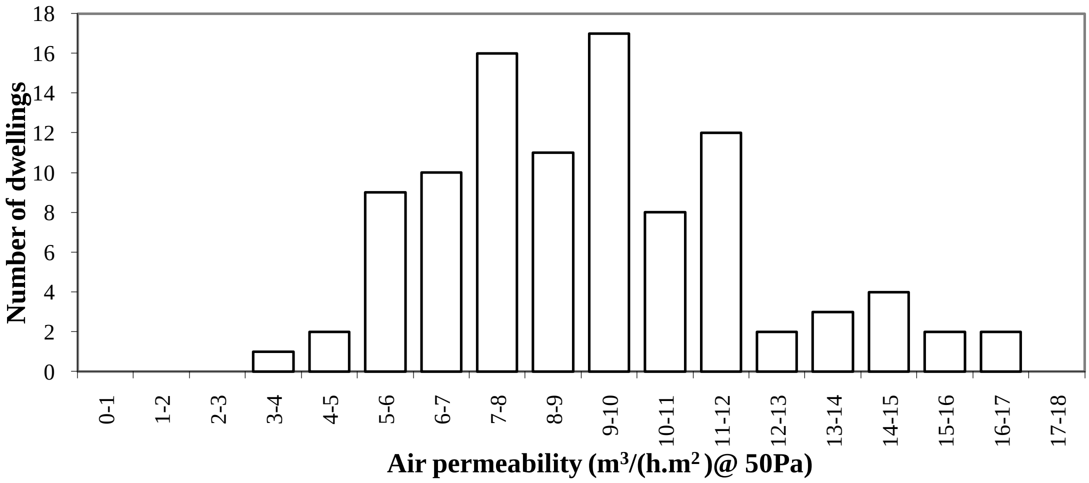

Figure 1: Mean air permeability of dwellings built to Part L1 2002. After Grigg (2004)

In addition to the work undertaken by the BRE, measurements of the airtightness of a non-random sample of 25 dwellings built to Part L1 2002 have also recently been undertaken by Leeds Metropolitan University as part of a participatory action research project (see Johnston, Miles-Shenton and Bell, 2006).

DESCRIPTION OF THE PROJECT

The project was undertaken for the Office for the Deputy Prime Minister (ODPM) under the Building Regulations Operational Performance Framework (see Borland and Bell, 2003). The work undertaken on the domestic sector adopted an action research methodology, and involved working closely with 5 developers from the commercial and social housing sectors to investigate the practical design and construction issues that can arise when making improvements to the airtightness of speculatively built mainstream housing. The action research was undertaken in 3 distinct phases. Phase 1 involved a detailed assessment of the design and construction of 25 dwellings together with pressure tests conducted upon completion. In Phase 2, the results from Phase 1 were fed back to each of the developers in a participatory seminar and ways of improving airtightness were discussed with the developer and their design and construction teams. Phase 3 mirrored Phase 1 in which the design and construction of a further set of dwellings (28 in total) was monitored following the feedback and enhanced understanding gained during Phase 2.

This paper presents the results and the key messages that have been obtained from Phase 1 of the project. Details of the dwellings that participated in this phase are contained within Table 1. As can be seen from Table 1, the dwellings varied in terms of size, built form and construction technique.

Table 1: Size, built form, construction type, volume and exposed internal surface area of the selected dwellings

Developer	Type of construction	Dwelling	Built form	Internal floor area (m^2)	Volume (m^3)	Exposed internal surface area (m^2)
A	Dry-lined masonry cavity, partial fill.	09	Mid-terrace	83	193	209
		11	Mid-terrace	117	268	257
		12	End-terrace	117	268	257
		13	Detached	117	273	262
		14	Semi-detached	80	185	209
B	Dry-lined masonry cavity, full fill.	79	Detached	129	327	306
		80	Detached	164	420	341
		81	Detached	149	385	323
		82	Detached	149	385	323
C	Dry-lined masonry cavity, full fill.	236	Mid-terrace	72	168	204
		237	Mid-terrace	71	166	202
		238	End-terrace	61	143	184
		239	Semi-detached	69	162	189
		240	Semi-detached	68	162	189
D	Light steel frame.	39	Semi-detached	72	178	198
		42	Detached	91	225	250
		43	Detached	84	208	218
		44	Detached	91	225	250
		59	Detached	102	237	263
E	Mechanically/ manually wet plastered masonry cavity, partial fill.	CG01	Apartment	57	140	196
		CG02	Apartment	43	105	160
		C201	Apartment	58	143	198
		C202	Apartment	44	107	162
		C301	Apartment	59	217	254
		C302	Apartment	44	107	162

RESULTS FROM PHASE 1

The aim of this phase of the project was to assess in detail the design and construction of 25 dwellings built to conform to the regulatory requirements of Part L1 of the 2002 Building Regulations and to measure the airtightness of the completed dwellings. In order to assess the design and construction phase of each dwelling, a design assessment and site survey protocol was devised based upon the checklisting approaches developed by Webb and Barton (2001) and Webb, Barton and Sciyver (2001). Details of the protocols can be found within Johnston, Miles-Shenton and Bell (2004).

The design assessments were undertaken to identify the methods that were being used to construct the dwellings, identify the method used to demonstrate compliance with Part L1 2002, and to identify those aspects of the design that could have an impact on air leakage. In the main, the design assessments focussed on the position of the air barrier, the continuity of the air barrier and whether service penetrations were to be sealed or not.

The completed design assessments were then used as a starting point for the site surveys. The site surveys were designed to capture the dwellings at a number of important stages throughout the build programme where inspections could be made of various elements that were likely to influence the eventual airtightness performance of the dwellings. In total, three separate stages were identified. These were as follows:

- **Stage 1: During intermediate floor construction.** This enabled inspection of the method of supporting the intermediate floors and enabled any potential leakage problems to be identified.
- **Stage 2: During dry-lining/wet plaster phase.** This enabled inspection of the internal leaf of the external walls, the application of the dry-lining/wet plaster, inspection of window/wall junctions and inspection of service penetrations.
- **Stage 3: Completion**. This enabled identification of any potential leakage areas that had not been picked up during the ‘snagging’ process.

The site surveys were also designed to be purely observational in nature. Therefore, no attempt was made to influence dwelling construction either during or following the site surveys.

The key issues that emerged from the design assessments and the site surveys were as follows:

- There was considerable difference in the way in which information on air leakage was presented to those on site and the level of detail that it contained. The information varied from general arrangement drawings containing general textual material, to sets of detailed 1:10 scaled drawings that indicated explicitly where sealing work had to be undertaken. In some cases, the sealing work would be very difficult to achieve. For instance, applying sealing around the perimeter of plasterboard linings to external walls and openings with continuous ribbons of plaster.
- None of the drawings submitted identified the location of the air barrier or indicated that it should be continuous around the envelope.
- All of the developers were using Robust Construction Details – Part L1 2002 (see DEFRA, 2001) as the basis of the application for regulatory approval.
- There was considerable variation in the work that had been undertaken on site to achieve a particular specification. Site observations illustrated that a mixture

of approaches had been undertaken to achieve the same specification. For instance, around built-in joists there was considerable variation in the way in which the mastic sealant had been applied around the bottom flange and the web of the timber I-beams, and in a number of cases, the mastic sealant appeared to have only been applied where the mortar had been missed out. This suggests that the operatives undertaking the work do not always fully understand the importance of the particular detail.

- The site observations also identified areas where there appeared to have been a lack of foresight in the detailed design stage. This resulted in specifications that were practically very difficult to achieve and forms of construction that sought to "work-round" any practical problems. Such "work-rounds" were made up on site based on the experience and trade knowledge of operatives and site managers.

Airtightness results

Figure 2 illustrates the air permeability of the 25 tested dwellings compared to the UK mean and the recommended maximum level set in the 2002 Edition of the Building Regulations Approved Document Part L1 of 10 $m^3/(h.m^2)$ @ 50Pa (ODPM, 2001). The data show that a relatively wide range of airtightness was measured for the tested dwellings. The air permeability of the dwellings ranged from 4.0 to 16.5 $m^3/(h.m^2)$ @ 50Pa, with a mean of 11.1 $m^3/(h.m^2)$ and standard deviation of 3.9 $m^3/(h.m^2)$. Although the range of air permeability measured within these dwellings was consistent with the recent measurements undertaken by the BRE (see Grigg, 2004), the mean for these dwellings was higher (11.1 as opposed to the BRE's 9.2 $m^3/(h.m^2)$ @ 50Pa). This is probably a result of the larger proportion of apartments (36%) included in the BRE sample compared to this sample (24%). The data also indicate that only 10 of the 25 dwellings (40%) had an air permeability that was lower than or equal to the UK mean of 11.5 $m^3/(h.m^2)$ @ 50Pa. The mean of all 25 results (11.1 $m^3/(h.m^2)$ @ 50Pa) suggests that these dwellings are broadly in line with existing UK stock as a whole and that, at least in these cases, the impact of the 2002 edition of Part L1 has been minimal. Given the qualitative nature of the project it is not possible to extrapolate to the post 2002 new build stock with any confidence, but the recent BRE data (see Grigg, 2004) would suggest that these results are not atypical.

The results obtained from Figure 2 also suggest that despite all of the developers using Robust Construction Details – Part L1 2002 (DEFRA, 2001) as the basis of the application for regulatory approval, only 8 of the tested dwellings (6 flats and 2 houses – 32%) had air leakage values that were lower than the maximum specified level of 10 $m^3/(h.m^2)$ @ 50Pa set in the 2002 Edition of the Approved Document Part L1 (ODPM¸2001). If the 6 flats tested are excluded (flats tend to be a more airtight dwelling form), only 2 out of 19 houses achieved a level below the value given in ADL1 2002. In addition, only one of the developers (developer E – flats) managed to satisfy the air leakage criterion with all of their tested dwellings. The other four developers were unable to achieve the airtightness target in the majority of cases.

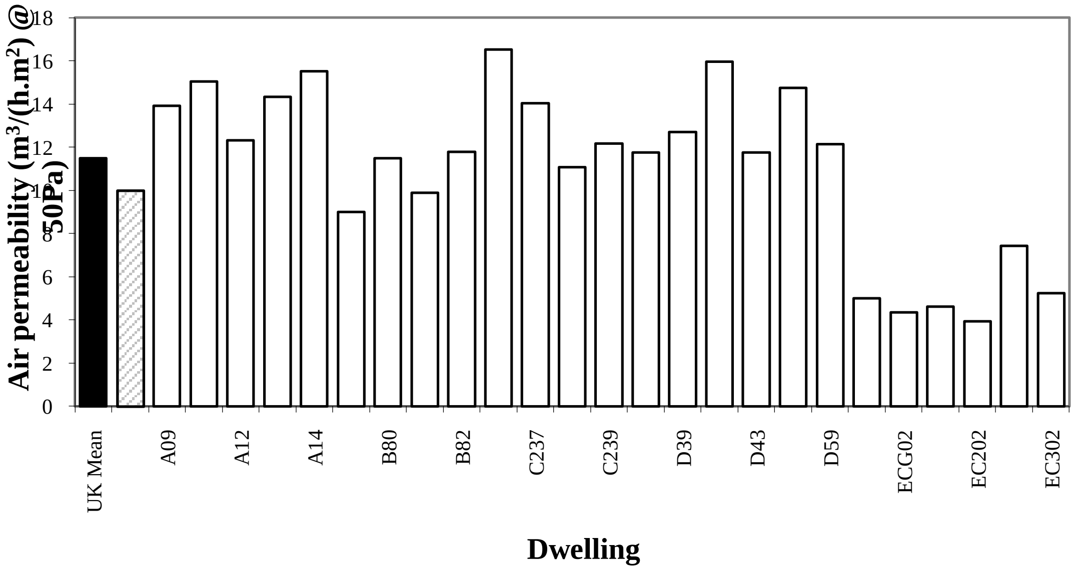

Figure 2: Mean air permeability of the tested dwellings

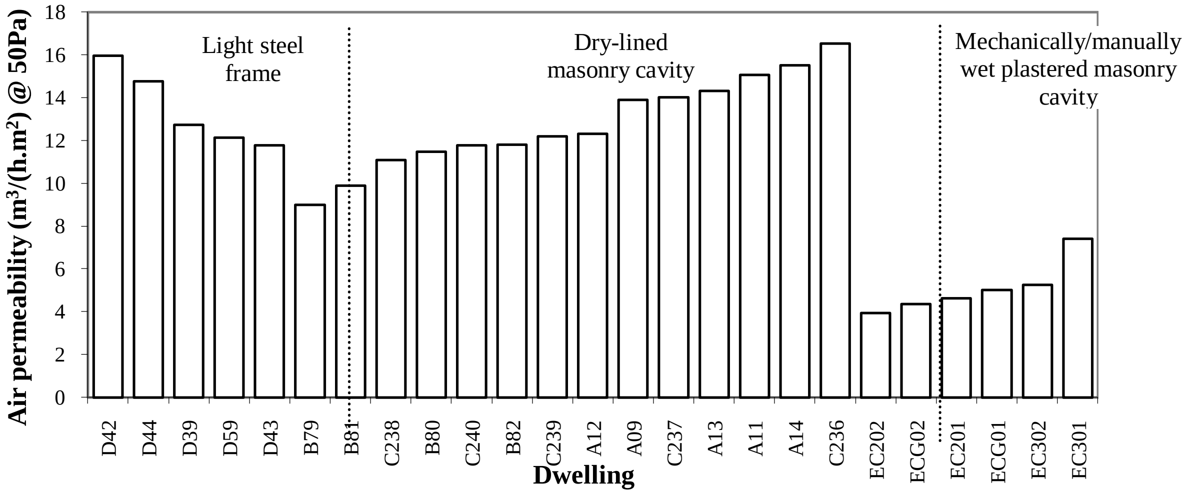

Figure 3: Mean air permeability of the tested dwellings by construction type

The small sample size of this survey precludes absolute certainty when comparing data either by developer or by construction type. However, accepting the qualification relating to sample size, the data suggest a difference in the air permeability between the different types of construction method used by the developers (see Figure 3 and Table 2). The tightest dwellings were those of mechanically/manually wet plastered masonry cavity construction. These dwellings were on average a factor of 3 more airtight than those that were built using dry-lined masonry cavity construction. The reasons for this are likely to be two-fold. First of all, as previously mentioned, apartments tend to be more airtight than comparable dwellings of different built form. Secondly, wet plastered masonry dwellings tend to be intrinsically more airtight than comparable dry-lined masonry or steel frame construction (Olivier, 1999). The least airtight dwellings were those constructed using light steel frame construction (developer D). These dwellings were only marginally leakier than the dry-lined masonry cavity dwellings (mean air permeability of 13.5 $m^3/(h.m^2)$ @ 50Pa as opposed to 12.8 $m^3/(h.m^2)$ @ 50Pa) constructed by developers A, B and C. It is not certain whether the poor performance of the light steel framed dwellings is attributable to an intrinsic problem with the airtightness of steel framed construction, the quality of workmanship, or a combination of the two. However, large gaps were observed between a number of the components in dwellings D42 and D44, such as flooring panels and floor-wall junctions all of which, in the absence of a clearly defined and well constructed air barrier, would enable free passage of air to outside.

Table 2: Mean air permeability by construction type.

Construction type	Mean Permeability ($m^3/(h.m^2)$ @ 50Pa)
Mechanically/manually wet plastered masonry cavity (Developer E)	5.1
Dry-lined masonry cavity (Developers A, B and C)	12.6
Light steel frame (Developer D)	13.5

The data also show that there appears to be a difference in performance between the 3 developers that are building using dry-lined masonry cavity construction (developers A, B and C (see Table 3)). The tightest dwellings were those constructed by developer B (mean air permeability of 10.5 $m^3/(h.m^2)$ @ 50Pa), whilst the leakiest dwellings were those constructed by developer A (mean air permeability of 14.2 $m^3/(h.m^2)$ @ 50Pa). Despite these results, no significant differences in the quality of the workmanship were observed between the dwellings constructed by developers A, B and C. Given the small sub-samples involved, the differences are more likely to be attributable to natural variations in construction rather than any intrinsic differences in approach by each developer.

Table 3: Mean air permeability by developer

Developer	Mean Permeability ($m^3/(h.m^2)$ @ 50Pa)
A	14.2
B	10.5
C	13.1
D	13.5
E	5.1

Leakage identification

In addition to the pressurisation tests, the main air leakage path entry points within all of the 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 the main air leakage path entry points within each dwelling, it was not possible to quantify the contribution that these leakage points made to the dwellings overall air leakage rate. The results of the leakage identification work are summarised in Tables 4 and 5.

Table 4: Main air leakage entry points associated with developers A, B, C and D (all houses)

Elements and junctions	Fixtures and fittings	Service penetrations
Between skirting board and ground floor. Around the stairs. Between skirting board and intermediate floor. Between flooring panels on the intermediate floor.	Around kitchen units. Around trickle vents. Around French door and patio doors. Around loft hatch. Around the bath panel and the shower tray. Through sliding mechanism of patio doors.	Service penetrations in the kitchen and utility room. Service penetrations in the toilets, bathroom and en-suite. Pipework penetrations behind the radiators. Service penetrations in the bathrooms and en-suite. Around electrical fuse box. Around extract fans.

Table 5: Main air leakage path entry points associated with developer E (apartments)

Elements and junctions	Fixtures and fittings	Service penetrations
Ceiling/wall junction in airing cupboard.	Around patio/balcony doors. Around bath panel.	Service penetrations in the kitchen and bathroom. Around purpose provided ventilation openings. Around electrical fuse box. Through spot lights.

As can be seen from Tables 4 and 5, the majority of the dwellings tested were found to have a number of common air leakage path entry points, which could be traced back to the construction issues that had been observed during construction. These related to elements and junctions, fixtures and fittings and service penetrations. The Tables illustrate that there are fewer air leakage path entry points within the mechanically/manually wet plastered masonry cavity apartments being constructed by developer E, than in the dry-lined masonry cavity and light steel-framed dwellings being constructed by developers A, B, C and D. Therefore, it is no surprise that the apartments being constructed by developer E are more airtight than the dwellings being constructed by all of the other developers. Tables 4 and 5 also illustrate that there are a number of common air leakage path entry points relating to all of the tested dwellings. These principally relate to service penetrations within the kitchens and the bathrooms.

One of the most important points to be inferred from Tables 4 and 5 is that the majority of the air leakage points identified within the tested dwellings relate to indirect air leakage points, where the smoke is leaking into secondary spaces within the dwelling through various gaps such as the floor/wall junction at skirtings and service entries into internal service ducts. Practically, it is almost impossible to seal all of these gaps. In addition, the difficulties associated with sealing these gaps are compounded by the fact that many of the secondary spaces within the construction communicate with each other, resulting in a very complex pattern of air flows both within and through the building envelope. The result is that air leakage can be very difficult to trace and seal effectively once a dwelling has been completed.

CONCLUSIONS

This paper discusses the results and key messages that have been obtained from a detailed assessment of the design, construction and air permeability of 25 dwellings that were constructed to conform to the requirements of Approved Document Part L1 2002.

An analysis of the design assessments and site surveys indicates that there is considerable difference in the way in which the developers present information on air leakage to those on site and the level of detail that this information contains. The presented information varies from the use of general arrangement drawings that contain general textual material, to sets of detailed 1:10 scaled drawings that indicate explicitly where sealing work has to be undertaken. There is also considerable variation in the work that has been undertaken on site to achieve a particular specification. Site observations illustrate that a mixture of approaches have been undertaken to achieve the same specification. This suggests that the operatives undertaking this work do not fully understand the importance of the detail. The site observations have also identified areas where there appears to have been a lack of foresight in the detailed design stage. This has resulted in specifications that are practically very difficult to achieve.

Although the size, structure and non-random nature of the sample preclude certainty, the air permeability results suggest that the impact of Part L1 2002 on air tightness has been minimal. The failure of the majority of the dwellings tested to achieve the Part L1 2002 air tightness target of 10 $m^3/(h.m^2)$ @ 50Pa suggests that the adoption of Robust Construction Details, at least in their then current form, provides no guarantee that the current regulatory standard will be achieved with any degree of consistency. The mean of all 25 results (11.1 $m^3/(h.m^2)$ @ 50Pa) also suggests that dwellings built to the requirements of Part L1 2002 are no more airtight than the mean of the existing UK housing stock as a whole.

The results also indicate that wet/mechanically plastered masonry cavity construction can default to a reasonable standard of airtightness by UK standards (<~5 $m^3/(h.m^2)$ @ 50Pa), without much additional attention being given to airtightness. Other construction types, such as dry-lined masonry cavity and light steel framed construction appear to require much greater attention to detail if they are to reliably achieve an air permeability below 10 $m^3/(h.m^2)$ @ 50Pa. The poor air leakage performance of the majority of the dry-lined masonry cavity and light steel frame dwellings could be attributable to a range of factors such as poor inherent design for airtightness, a lack of adequate training on the issues surrounding airtightness, lack of necessary details on drawings, incomplete understanding of Robust Construction Details, poor quality control of Robust Construction Details on site, poor communication of the importance of Robust Construction Details or difficulties in achieving current Robust Construction Details in practice.

A number of common air leakage points were also observed within the dwellings tested. The majority of these were indirect air leakage points relating to gaps around elements and junctions, fixtures and fittings and service penetrations. In practical terms, it is almost impossible to seal all of these gaps as these gaps tend to communicate with each other via secondary spaces within the construction, resulting in a very complex pattern of airflows both within and through the building envelope. Consequently, air leakage can be very difficult to trace and seal effectively once the dwelling is completed.

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