Interim Report to Communities and Local Government Building Regulations Division under the Building Operational Performance Framework

AIRTIGHTNESS OF BUILDINGS — TOWARDS HIGHER PERFORMANCE

Interim Report D6 — Seminars and Developer Feedback

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Reference Number: CI 61/6/16 (BD2429)

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Interim Report D6 — Seminars and Developer Feedback

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Executive Summary

1 This report reviews progress on the feedback and guidance seminars that have been undertaken with each developer as part of Phase 2 of the project and reports on the interim results. The report also details the measures that each developer intends to undertake for Phase 3 of the project.

2 Pressurisation tests have been undertaken on all but two of the dwellings that are participating in Phase 1 of the project. Both of these dwellings are expected to be completed and tested by early May 2005. In addition, feedback and guidance seminars have been undertaken with three of the five developers involved in the project. Of the two remaining seminars, one is scheduled to take place in early May 2005, whilst the other will be arranged as soon as the remaining dwellings have been completed and pressure tested.

3 Pressurisation test results show a relatively wide range of airtightness for the dwellings tested, ranging from 4.0 to 16.5 $m^3/(h.m^2)$ @ 50Pa. The mean for all of the dwellings was 11.5 $m^3/(h.m^2)$ @ 50Pa, suggesting that the group of dwellings are broadly in line with the average for the UK stock as a whole. Despite all of the developers using Robust Details as the basis of the application for regulatory approval, only six of the tested dwellings 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 Approved Document Part L1. If the four flats tested are excluded (flats tend to be a more airtight dwelling form), only two out of 19 houses met the 2002 Part L target. This suggests that simply adopting Robust Details, at least in their current form, provides no guarantee that the current regulatory standard will be achieved with any degree of consistency.

4 Although the small sample size precludes certainty, the airtightness results do appear to show a difference in permeability between the different types of construction method used by the various developers. The tightest dwellings were those of mechanically plastered masonry cavity construction (since these were flats, their performance could also be a function of form as well as construction), whilst the leakiest dwellings were those of steel framed construction. The results also appear to show a difference in performance between the three developers that are building using dry-lined masonry cavity construction. Since no significant differences in the quality of workmanship were observed between these three developers, workmanship alone is unlikely to have caused this difference. It is more likely that the observed difference in performance is attributable to a combination of design, and site quality control as well as the workmanship of operatives.

5 A number of common air leakage paths were identified within the tested dwellings. These related to elements and junctions, fixtures and fittings, and service penetrations. The majority of these were indirect air leakage paths, which could be traced back to the observations of design and construction made during Phase 1 of the project.

6 Site observations have highlighted a number of common construction issues which are likely to have had an influence on the eventual airtightness of the tested dwellings. These issues related to the method of construction, openings and service penetrations.

7 The feedback received to date from the developers has been very positive. All of the developers indicated that what had been observed on site was typical of their construction standards nationally.

8 The concept of an air barrier was unfamiliar to all but one of the developers. Therefore, it was no surprise to find that none of the developers was aware of the construction principle that they were using to achieve an airtight envelope and none of them had explicitly identified the position of the air barrier on their drawings.

9 There is a perception from the developers that the way to improve the airtightness of their dwellings is to identify all of the individual air leakage points at internal surfaces and then adopt the ‘gap-filling’ approach. This is generally at odds with the need for a design that is clear about the location and role of an air barrier. The discussions that took place during the seminars and the responses from the developers indicated that there is a general lack of awareness and understanding of the issues surrounding airtightness. This exists at all levels, from site operatives up to senior management. Consequently, there is a need for further education, guidance, training and advice within the industry on airtightness.

Introduction

10 This report constitutes milestone D6 (Seminars and Developer Feedback) of Communities and Local Government Project reference CI 61/6/16 (BD2429) *Airtightness of Buildings — Towards Higher Performance'* (Borland and Bell, 2003). It reviews the progress that has been made on undertaking the feedback and guidance seminars to each of the individual developers as part of Phase 2 of the project and reports the interim results. The general lessons learnt from Phase 1 of the project are highlighted and details of the sites and the dwelling types that are participating in Phase 3 of the project are also illustrated (task 2.2.1).

Summary of Progress to Date

11 This project is a participatory action research project involving five developers from the commercial and social housing sectors. The project is designed to be undertaken in three distinct phases:

a) Phase 1 — Assessment of the design and construction of five house types per developer (total 25 types) and undertake pressurisation tests and leakage identification for each house type.

b) Phase 2 — Undertake a participatory seminar (oe per developer) in which the results of Phase 1 and airtightness guidance will be discussed with the developer and design and construction teams. Where possible the developer will be encouraged to set an airtightness standard (commensurate with existing ventilation strategies) for the design and construction of a further set of dwellings that would be assessed and tested in Phase 3.

c) Phase 3 — This phase mirrors Phase 1 in which the design and construction of a further set of dwellings (five from each developer) will be monitored following the feedback and enhanced understanding gained during Phase 2. Upon completion and testing, a feedback seminar will be held to review the design and construction experience from the developer's point of view.

12 Site surveys for Phase 1 of the project have been completed for 23 of the 25 selected dwellings (five from developers A, C and four from developers B and E). The site surveys for the remaining two dwellings are expected to be completed by the end of April 2005.

13 Of the 25 dwellings selected as part of Phase 1, 23 have been pressure tested. It was not possible to test one dwelling from developer B prior to occupation due to the very quick completion date requested by the buyer. In order to maintain the number of selected dwellings, an addition dwelling was selected from developer E (dwelling EC201). Site surveys on this dwelling have been completed and the dwelling has also been pressure tested. With respect to the two remaining apartments that are being constructed by developer E, pressurisation tests have not been undertaken due to delays in construction. These delays have been caused by inclement weather. It is anticipated that the two remaining apartments will be completed and pressure tested by the end of April 2005.

14 Feedback and guidance seminars have been undertaken with three of the five developers (developers A, B and D). The feedback seminar for developer C is arranged for the second week in May 2005. The seminar for developer E will be arranged as soon as possible after all of the apartments have been completed and pressure tested.

15 Five dwellings have been selected from developers A and D to participate in Phase 3 of the project, and we are in the process of selecting five dwellings from developer B. Due to staff changes within developer A, the five dwellings originally selected are currently under review.

16 Site visits have commenced for Phase 3 of the project. To date, three site visits have been undertaken to developer D.

Update on the Pressurisation Test Results

17 This section updates the pressurisation test results and leakage identification work that was previously reported in milestone D4 — Airtightness Results from Phase 1 (Johnston, Miles-Shenton and Bell, 2004).

18 The results of all the individual air permeability tests undertaken to date are shown in Table 1 and Figure 1. The mean air permeability for those dwellings tested to date for each developer and construction type are given in Figure 2 and Tables 2 and 3.

Dwelling	Pressurisation test		Depressurisation test		Mean permeability ($m^3/(h.m^2)$)
	Permeability ($m^3/(h.m^2)$)	r^2 coefficient of determination	Permeability ($m^3/(h.m^2)$)	r^2 coefficient of determination	
A9	13.95	0.999	13.86	0.999	13.91
A11	15.46	0.996	14.66	0.997	15.06
A12	12.12	0.990	12.49	0.999	12.31
A13	14.51	0.999	14.16	0.999	14.33
A14	15.33	0.993	15.71	0.994	15.52
B79	8.96	1.000	9.02	0.983	8.99
B80	11.76	0.992	11.20	0.990	11.48
B81	10.11	0.999	9.66	0.993	9.89
B82	12.04	0.996	11.53	0.999	11.79
C236	16.81	1.000	16.26	1.000	16.53
C237	14.08	1.000	13.98	1.000	14.03
C238	11.17	0.998	11.02	1.000	11.09
C239	12.46	0.997	11.90	0.986	12.18
C240	12.11	0.971	11.40	0.981	11.76
D39	12.82	0.992	12.61	0.984	12.72
D42	15.55	1.000	16.37	0.999	15.96
D43	12.10	0.997	11.44	0.999	11.77
D44	14.58	1.000	14.94	1.000	14.76
D59	12.50	0.990	11.76	0.984	12.13
ECG01	5.13	0.999	4.90	0.996	5.01
ECG02	4.37	0.998	4.32	0.997	4.35
EC201	4.79	1.000	4.43	0.997	4.61
EC202	3.94	0.999	3.96	1.000	3.95

Table 1 Mean air permeability of the tested dwellings.

Developer	Mean permeability of all dwellings tested to date ($m^3/(h.m^2)$ @ 50Pa)
A	14.2
B	10.5
C	13.1
D	13.5
E	4.5

Table 2 Mean air permeability by developer.

Construction type	Mean permeability of all dwellings tested to date ($m^3/(h.m^2)$ @ 50Pa)
Mechanically plastered masonry cavity (Developer E)	4.5
Dry-lined masonry cavity (Developers A, B and C)	12.6
Light steel-frame (Developer D)	13.5

Table 3 Mean air permeability by construction type.

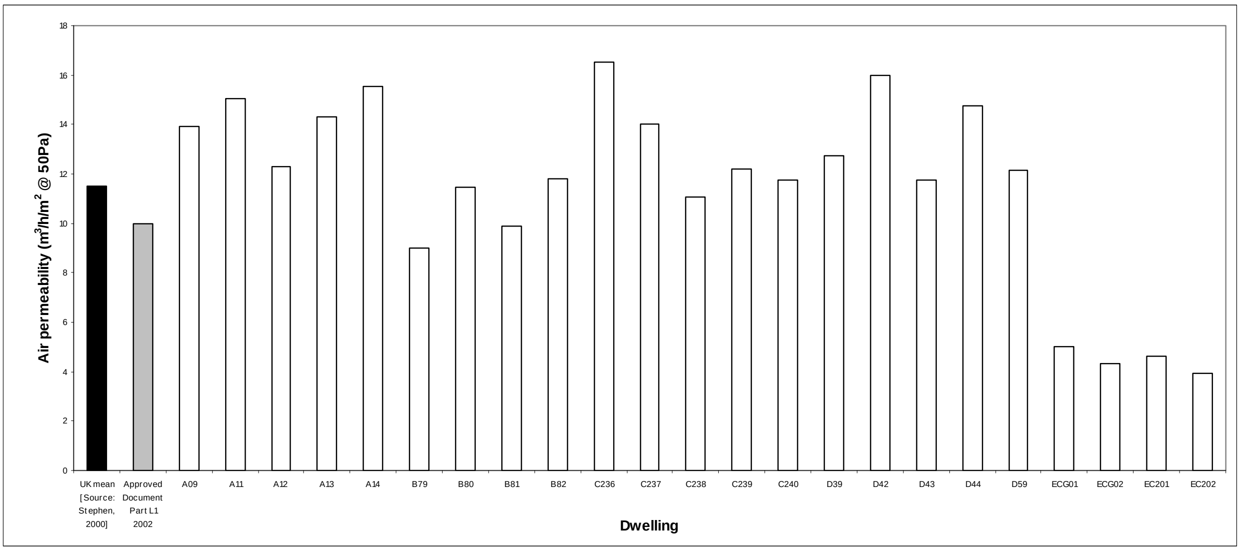

Figure 1 Mean air permeability of the tested dwellings.

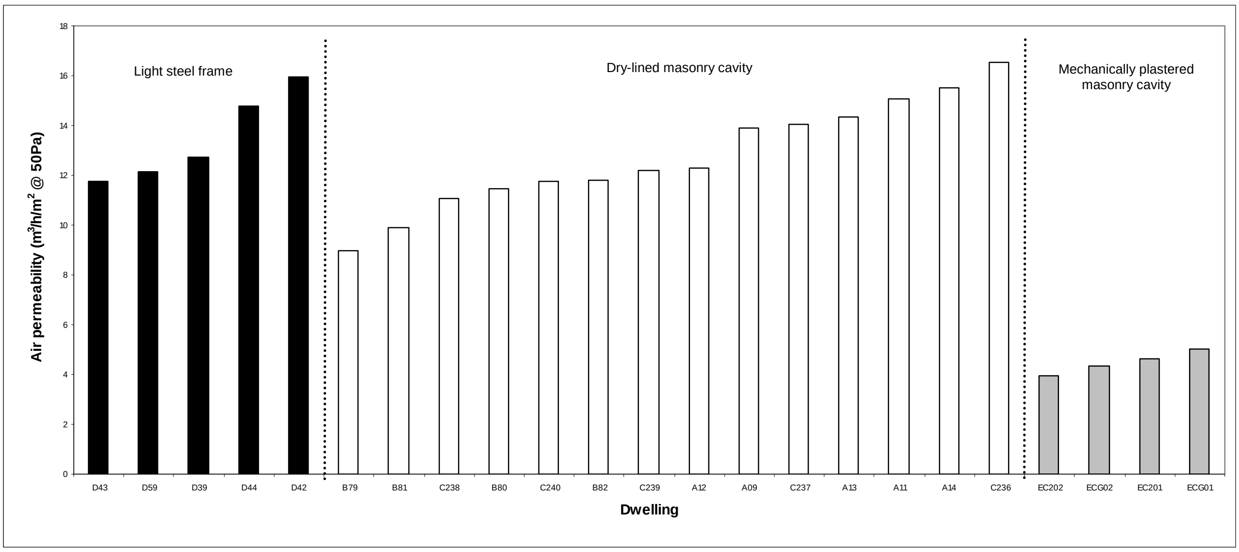

Figure 2 Mean air permeability of the tested dwellings by construction type.

19 Figure 1 illustrates the air permeability of the 23 tested dwellings compared to the UK mean[1] 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 23 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 that was measured within the tested dwellings is consistent with some recent measurements undertaken by Grigg (2004),[2] the mean for the dwellings tested in this project is higher (11.1 as opposed to Grigg's 9.2 $m^3/(h.m^2)$ @ 50Pa). This is probably a result of the larger proportion of apartments[3] (36%) that were included in the sample tested by Grigg (2004) compared with our sample (24%).

20 Only eight of the 23 dwellings (35%) had an air permeability that was lower than or equal to the UK mean of 11.5 $m^3/(h.m^2)$. The mean of all 23 results (11.5 $m^3/(h.m^2)$ @ 50Pa) suggests that these dwellings are as airtight as the average for the UK stock as a whole (11.5 $m^3/(h.m^2)$ @ 50Pa).

21 One of the most important results to be obtained from Figure 1 is that only six of the tested dwellings (four flats and two houses) (26%) 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). Of the 19 houses tested only two achieved a level below the value given in ADL1, However, given the small sample size and the range of values measured, no claims of statistical significance can be made. All five developers were using Robust Details (see DEFRA, 2001) as the basis of the application for regulatory approval. Given this, only one of the developers (developer E) has managed to satisfy the air leakage criterion with all of their dwellings that have been tested. The other four developers were unable to achieve the airtightness target in the majority of cases. The reasons for this could be due to a lack of on site quality control relating to the construction of Robust Details, poor communication, poor inherent construction design relating to airtightness, a lack understanding of how Robust Details work or possibly even that the Robust Details themselves may be difficult to achieve in practice, impractical or insufficiently tolerant of site variability - so called 'buildability'. We understand that the impact of Robust Details on whole dwelling air leakage was not subjected to empirical testing when the current catalogue was compiled. This report suggests that empirical testing would be needed as part of a process of developing a catalogue of details capable of reliably delivering an air leakage target.

22 The small sample size of this survey precludes absolute certainty when comparing data either by developer or by construction type. However, ignoring the issue of sample size, the data do show a difference in the air permeability between the different types of construction method covered in this survey (see Figure 2 and Table 3). The tightest dwellings were those of mechanically plastered masonry cavity construction (developer E). These dwellings are on average a factor 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, wet plastered masonry dwellings tend to be intrinsically more airtight than comparable dry-lined masonry or steel frame construction (Olivier, 1999). Secondly, as previously mentioned, apartments tend to be more airtight than comparable dwellings of different built form. The least airtight dwellings were those constructed using light steel frame (developer D). These dwellings were only marginally leakier than the dry-lined masonry cavity dwellings (mean air permeability of 13.5 as opposed to 12.6 $m^3/(h.m^2)$ @ 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. Assuming that the air barrier within these dwellings is formed by the plasterboard dry-lining, such gaps between components would enable free passage of air to the outside. This suggests that the poor air leakage of these dwellings may therefore be attributable to factors such as poor tolerances of

[1] The UK mean has been derived from the Building Research Establishment's (BRE's) air leakage database, which is the largest and most comprehensive source of information on the airtightness of UK dwellings (see Stephen, 1998 and 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.

[2] The measurements undertaken by Grigg (2004) are based upon a non-random sample of 99 dwellings that were constructed to the provisions contained within the 2002 edition of the Building Regulations Approved Document Part L1.

[3] Apartments tend to be more airtight than other dwelling forms of equivalent area as they are more likely to have solid intermediate floors, fewer door and window openings and fewer service penetrations.

components, quality of workmanship, site supervision and training, or unfamiliarity with the construction technique.

23 The data also show that there appears to be a difference in performance between the three developers that are building using dry-lined masonry cavity construction (developers A, B and C). 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. Therefore, we believe that workmanship alone is unlikely to have caused the difference in performance that has been observed between these three developers. It is more likely that the difference in performance is due to a combination of design, and site quality control processes as well as workmanship.

24 It is important to note that given the small size, the non-random nature of the sample of dwellings that have been tested, and the high probability of confounding variables, it not possible to establish whether there is a difference between the developers and if so, whether this difference is attributable to such factors as differences in construction type, dwelling form or site supervision and workmanship. Therefore, further work (both field tests on whole dwellings and laboratory tests on construction samples) is needed to establish whether such differences are real, or whether they have occurred purely by chance.

Leakage identification

25 In addition to the pressurisation tests, the main air leakage paths within each of the dwellings were identified by pressurising the building, and locating the main areas of air leakage using hand held smoke generators. It was not possible to quantify the contribution that each leakage path made to each of the dwellings overall air leakage, but the smoke tests that were carried out enabled the main leakage paths within each of the dwellings tested to be identified. The results of the leakage identification work are summarised in Tables 4 and 5.

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 4 Main air leakage paths associated with developers A, B, C and D (all houses).

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

Table 5 Main air leakage paths associated with developer E (flats).

26 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 paths, which could be categorised under the following three headings: elements and junctions, fixtures and fittings and service penetrations. The tables illustrate that there are fewer air leakage paths within the mechanically 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 paths relating to all of the tested dwellings. These principally relate to service penetrations within the kitchens and the bathrooms.

27 The majority of the air leakage paths identified within Tables 4 and 5 are indirect air leakage paths, rather than direct air leakage paths. Indirect air leakage paths not only enable the air to freely communicate with other gaps and voids within the building, but they also add to the complexity of the air flows that exist within and through the building envelope. The result is that air leakage can be very difficult to trace and seal effectively.

28 The majority of the leakage paths identified within Tables 4 and 5 can also be traced back to various construction issues that were observed on site.

29 In addition to a number of common air leakage paths, leakage paths were also identified that were particular to specific dwellings. Details of these are contained within the individual developer pressurisation test reports, which are available in the project archive.

Feedback Seminars

30 Feedback from Phase 1 of the project consisted of a feedback and guidance seminar for each of the developers, making five seminars in total. Three of these seminars have been undertaken to date, each of which has lasted around half a day. To ensure confidentiality, the seminars were undertaken at the developer's offices. Where possible, the participants included regional directors, the technical director for design and development, someone from the design team, the site manager or assistant site manager and a number of trade supervisors and site operatives. Each seminar made use of all of the material that had been gathered during Phase 1 of the project, such as photographs and video recordings, to provide tailored feedback and advice to each of the developers. In addition, a two-way dialogue was facilitated to allow feedback from the developers to the research team.

31 Prior to each seminar, the developer's team were presented with a copy of the design assessments and the pressurisation test report for the dwellings that were selected on their site. This information was provided to the developers to enable them to gather their thoughts and investigate any of the issues raised in the reports prior to their attendance at the seminar.

32 Although the seminars were tailored towards each particular developer, where possible, a common approach was used. This approach was as follows:

a) The seminar began with a PowerPoint presentation from the research team which included the following information:

- Introduction to airtightness, the importance of airtightness with regard to the energy performance of dwellings, the airtightness requirements of the current Building Regulations and expected changes to the Building Regulations with respect to airtightness.
- Details of the pressurisation tests, how they are undertaken, why they are undertaken and methods of leakage detection.
- Airtightness results for the developer in question. The results will be compared against those for the rest of the tested cohort, the UK mean and the current Building Regulation requirements.
- Details of the construction issues observed on site.
- Precise details of the leakage paths observed on site.
- General advice and guidance given on airtightness.

b) The results from the site observations and the pressurisation tests were then discussed. The developer's team were also asked whether they agreed with the findings and whether what was observed on-site was typical practice for the developer in question. They were also asked to identify what changes could be put in place to address the issues raised during the seminar, such as dwelling design, availability/completeness of drawings, Robust Details, planning/sequencing, quality of components, quality control, workmanship, site management and training.

c) Finally, the developers were asked to agree to a plan of action that seeks to improve the airtightness performance of their dwellings. They were also asked to agree to an informal airtightness target for the dwellings that will be tested during Phase 3 of the project.

33 Copies of the individual PowerPoint presentations for each of the developers are available in the project archive.

34 The main issues that were fed back to the developers during the feedback sessions are set out in the following subsections.

Construction observations

35 Observations from site highlighted a number of construction issues that could potentially affect the eventual airtightness performance of the selected dwellings. A number of these issues were common to the majority of the developers. These issues related to the following:

a) Method of construction

- Dry-lining. The inadequacy of dry-lining as an effective air barrier was highlighted within the dry-lined masonry cavity dwellings. Technically it is very difficult to seal the dry-lining using continuous ribbons of plasterboard adhesive at the perimeter of external walls, openings, and services on external walls. The result is that air can move freely into the gap between the plasterboard and the masonry wall. This air gap then acts as a plenum, effectively connecting all of the leakage paths within the dwelling.
- Light steel frame construction. These dwellings used a warm frame construction, with the external face of the insulation boards acting as the air barrier. The joints between the insulation boards were not always sealed, particularly around window and door openings, around service penetrations and at the intermediate and ground floor junction, resulting in a number of potential air leakage paths at these points.
- Built-in joists. Where built-in joists were used, difficulties were experienced sealing the joists to the external/party walls. This was a particular problem where the joists had been offset from the external wall to enable services to run from one floor to the other. The result was a number of hidden air leakage paths from the intermediate floor void to the cavity.
- Blockwork. In the masonry cavity dwellings, cracks and gaps were visible on the internal leaf of the external/party walls, perpends were not always fully sealed and the buttering of joists resulted in a number of potential air leakage paths through these walls.
- Wall, floor and roof junctions. There was no evidence of continuity of the air barrier at these junctions. Gaps were observed around the edges of intermediate floors and at the junction between the skirting boards and the ground/intermediate floors. Internal partitions had also been erected before the ceiling, resulting in hidden air leakage paths at the partition/ceiling junction.
- Ground and intermediate floors. Ground floor slabs were incomplete, particularly around the patio door area, resulting in holes in the ground floor slab. Holes were also observed in the intermediate flooring, as wells as gaps between the intermediate flooring panels.
- Rooms-in-the-roof. There was no evidence of continuity of the air barrier in dwellings that incorporated rooms-in-the-roof. Gaps were also observed around rooflights and dormer windows, allowing air movement from behind the dry-lining to the roof and rafter voids.

b) Openings

- Windows and doors. Trickle vents were either of a poor fit or would not close properly allowing the passage of air either through the vent itself (when in the closed position), or through a gap between the vent and window. In several cases, the patio doors did not fit correctly such that the seals were uncompressed. In the worst cases, there were observable gaps between the external door and the surrounding door frame.
- Loft hatch. Hatches had not been adequately sealed to the ceiling, resulting in air leakage between the loft hatch frame and ceiling. In addition, a number of the hatches did not compress the draught seals fully when they were closed. With one of the developers this was due to the method of installation.

c) Service penetrations

- Through walls, floors and ceilings. Little attempt had been made to seal the majority of service penetrations through walls, floors and ceilings. Where attempts had been made, the penetrations are generally inadequately sealed and/or inappropriate sealants have been used. In a number of cases, larger holes than necessary had also been made for services to allow for positioning. These large holes are then much more difficult to seal.
- In kitchens, utility rooms, bathrooms, toilets and en-suites. Penetrations in these areas were often left unsealed as they would subsequently be hidden behind boxing, panels or units.

36 Photographs of all of the construction issues associated with each developer can be found within the respective PowerPoint presentations, which are retained in the project archive.

Air permeability results and leakage identification

37 All of the air permeability results that have been undertaken to date were presented and compared against the UK mean and the current Building Regulations requirements. These results indicated the following:

a) A relatively wide range of airtightness was encountered.

b) Only a small number of the dwellings tested had an air permeability that was lower than or equal to the UK mean of 11.5 $m^3/(h.m^2)$ @ 50Pa.

c) The majority of the dwellings tested failed to satisfy the air leakage criterion set out in Approved Document Part L1.

d) No obvious difference in construction quality was observed between the various developers.

e) In our opinion, the air permeability target of 10 $m^3/(h.m^2)$ @ 50Pa could be achieved by all of the developers. However, work needs to be done if all of the dwellings are to achieve this level of airtightness.

38 The individual results associated with each developer were then discussed in detail.

39 The main air leakage paths within each of the tested dwellings were also identified. The dwellings were found to have a number of common air leakage paths. These leakage paths related to elements and junctions, fixtures and fittings and service penetrations.

40 Details of the individual developer air permeability results and air leakage paths are contained within the respective PowerPoint presentations.

Advice and guidance

41 General advice and guidance on airtightness was given to each of the developers during the feedback presentation. This was as follows:

Prior to construction

a) Identify the construction principle that will be used to achieve an airtight building envelope.

b) Identify the position of the air barrier on the drawings — make it explicit!

c) Undertake a *'pen on section'* test to ensure continuity of air barrier — continuity is crucial!

d) Ensure air barrier can be easily installed, is durable and accessible for maintenance.

e) Avoid or minimise penetrations through the air barrier.

f) Avoid complex detailing.

g) Where possible, ensure that the air barrier is in the same plane throughout the structure.

h) Identify those areas where attention to detail is required to ensure airtightness.

i) Provide explicit details and guidance at any potential air leakage point.

During construction

j) Ensure that site supervision and workmanship are good.

k) Ensure all construction staff are aware of airtightness issues.

After construction

l) Some relatively simple measures could be adopted that may improve the airtightness of the dwellings once they have been constructed:

- Seal all visible and hidden service penetrations using an appropriate sealant.
- Seal all junctions between the walls, floors and ceilings.

m) However, it is important to realise that these measures do not address the hidden air leakage paths!

Response from the Developers on the Feedback

42 The response to the three feedback seminars that have been undertaken to date has been very positive. All three developers fully participated in the seminars, resulting in a number of interesting discussions and debates. The main responses from the developers are summarised as follows:

a) The majority of the developers lacked a general understanding of airtightness, the importance that airtightness has with regard to the energy performance of buildings, how airtightness is measured, the factors that are known to influence airtightness, the location of the main air leakage paths within UK dwellings, the difference between direct and indirect air leakage paths and how air leakage paths can be detected.

b) All of the developers agreed with the findings of the site observations, the pressurisation tests and the leakage identification work. They also agreed that what had been observed on site was typical of their construction practice nationally. In fact, at least one developer commented that what had been observed was actually good practice.

c) Two of the three developers (developers B and D) were under the perception that all they needed to do to improve the airtightness of their dwellings was to identify all of the individual air leakage points at internal surfaces and then simply go around and fill in all of the gaps. For instance, they felt that effort should be put into sealing the junction between floor boarding and intermediate floors, skirtings at floor/wall junctions and sealing of service entries to into internal service ducts. This is problematic and unlikely to be successful since it creates a very complex and disjointed air barrier that is not robust. Experience form North America and Scandinavia where low levels of air leakage have been part of national standards for a long time lays stress on the identification of a single and continuous primary air barrier, rather than filling gaps at internal surfaces.

d) Only one of the developers (developer A) had any real understanding of the concept of an air barrier, although it was apparent that this understanding, mainly at senior management level, was not widely disseminated to the sites studied.

e) None of the developers was aware of the construction principle that they were using to achieve an airtight envelope and none had explicitly identified the position of the air barrier on their drawings.

f) Although none of the dwellings tested had an explicit air barrier, all of the developers were adopting the internal airtight barrier approach by default (mainly dry-lining). The fact that only two of the dry-lined masonry cavity and steel framed dwellings achieved air leakage values less than 10 $m^3/(h.m^2)$ @ 50Pa was more by chance, rather than the developers making any conscious effort to build airtight dwellings.

g) All of the developers agreed that the quality of workmanship and site supervision were issues that were influencing the level of airtightness obtained on-site and both of these issues could be and should be improved on site.

43 The developers that participated in the feedback seminars were also asked to identify what measures they would undertake during Phase 3 of the project to improve the airtightness of their dwellings and to agree to an informal air leakage target. The measures identified and the targets agreed by each developer are illustrated within Table 6.

Developer	**Measures identified**	**Air leakage target ($m^3/(h.m^2)$ @ 50Pa)**
A	Workshops to be held with key trades who need to improve the quality of their workmanship. Key trades identified include: bricklayers, window and door installers, carpentry, heating and plumbing, electrician and dry-liner. Site Toolbox training talks aimed at management, and sub-contractors supervisors. Pre-Test Inspection Checklist to include all builders' work completed to air seal the envelope, including doors, windows, hatches, sills and services. A gallery of unacceptable work will be displayed in the canteen and regular inspections of the work will be conducted with the subcontractor's supervisors. Expansion of specific Air Leakage Robust Details to be added to national construction details sets. Assessment of practical sealant measures and product development (windows, fans, plumbing and electrical punctuations, etc.) and comparison with alternative 'all over parging' air barrier – subject of re-testing regime at selected plots. Sequencing issues will be highlighted and addressed by production and site management in conjunction with trades.	To be confirmed.
B	To be confirmed.	To be confirmed.
D	Implementation of new dwelling designs which have amendments to ground floor slabs. This should improve the airtightness of the slab and wall junction. Re-evaluate intermediate floor construction. Apply chipboard flooring to the floor cassette after the frame has been erected rather than using cassettes with attached flooring. Establish an air barrier at ceiling level. This could be done by having a continuous plasterboard ceiling with portioning installed afterwards, rather than having the frame assemblers installing the top floor partitions prior to dry-lining. Services might then be held in trays in the loft space, reducing the need for excessive individual service penetrations.	7.0

Table 6 Measures identified and agreed air leakage targets for each developer.

Conclusions

44 The results of the pressurisation tests undertaken to date suggest that mechanically plastered masonry cavity construction can default to a reasonable level of airtightness by UK standards (< ~ 5 $m^3/(h.m^2)$ @ 50Pa), without much attention being given to airtightness. However, the failure of the majority of the dry-lined masonry cavity and steel-framed dwellings to achieve the required airtightness target contained within Approved Document Part L1 of 10 $m^3/(h.m^2)$ @ 50Pa, raises serious questions about using Robust Standard Details as a method of achieving compliance with airtightness standards. The poor air leakage performance of the majority of the 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 Details, poor quality control of Robust Details on site, poor communication of the importance of Robust Details or difficulties in achieving current Robust Details in practice.

45 Although the size, structure and non-random nature of the sample precludes certainty, the results also suggest that dwellings built to the requirements of Approved Document Part L1 2002 are no more airtight than the mean of the current existing UK housing stock. If this result is true, then it could have serious implications for the industry and its preparedness for the proposed changes to Part L. Some of the issues that need to be addressed would include areas such as training, quality control and building design. The next stages of this project will give more focus on these issues.

46 A number of common air leakage paths were observed within the dwellings tested. The majority of these were indirect air leakage paths relating to elements and junctions, fixtures and fittings and service penetrations. Although a number of relatively simple measures could be adopted by the developers to reduce these leakage paths once the dwellings had been completed, such as sealing all visible and hidden service penetrations using a suitable sealant, these measures do not address the issues associated with indirect air leakage paths.

47 The current approach to providing advice on airtightness via Robust Details does not address process or conceptual issues.

48 The developers responses at the feedback sessions indicated that the observations from site were typical of their current construction standards nationally. As all but two of the dwellings tested from developers A, B, C and D failed to meet the maximum specified level of 10 $m^3/(h.m^2)$ @ 50Pa set in Part L1 2002, and all of the sites were using Robust Details as the basis of regulatory approval, this study suggests that simply adopting Robust Details, at least in their current form, provides no guarantee that the current regulatory standard will be achieved with any degree of consistency.

49 The responses from developers and discussion at the seminar supported the view that there is a general lack of awareness and understanding of airtightness issues at all levels, from site operatives and site supervisors through to site and senior management. Consequently, there is a perception from the developers that the way to improve airtightness is to adopt the ‘gap-filling’ approach, rather than concentrating on the design of the air barrier. Therefore, there is a need for clear design guidance on airtightness which focuses on the design of the air barrier, its location, ways of maintaining continuity and ensuring that it remains effective. This guidance needs to be followed-up with further education within the industry, greater and more specific levels of training and advice and higher levels of site supervision and workmanship.

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