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

AIRTIGHTNESS OF BUILDINGS — TOWARDS HIGHER PERFORMANCE

Milestone Number: D10 (Revised)

Discussion Paper 2 — Impacts of Pressure Testing

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Discussion Paper 2 — Impacts of pressure testing

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Executive Summary

1 This paper reviews the pressure testing regime incorporated within Part L1A 2006 of the Building Regulations, analyses the logistics associated with compulsory pressure testing and discusses the effect that the testing regime is likely to have on new dwellings.

2 The review highlighted a number of issues associated with the pressure testing regime incorporated within Part L1A 2006.

a) The testing regime incorporated within ADL1A 2006 involves categorising dwellings by their generic form. Such a categorisation is unlikely to capture a number of important house type issues that influence airtightness. The results obtained from this project, and supported by parallel research, suggest that the issues associated with the geometry and complexity of the construction may have a much greater influence on the eventual airtightness of a dwelling than generic form.

b) There is little guidance given within ADL1A 2006 relating to dwelling selection. Depending upon when developers are notified of the dwellings to be tested, there may be scope for additional measures to be undertaken on the selected dwellings to ensure that they meet the required airtightness target. In addition, ADL1A 2006 suggests that a significant proportion of the dwellings should be tested early on in the construction programme to enable any lessons learnt to be fed back into the construction and design process. Anecdotal evidence obtained from Phase 3 of the project suggests that this is unlikely to be the case as there was a noticeable difference in the quality of workmanship in relation to airtightness in those dwellings that were participating in the project and those that were not. Although the response of developers to Part L1A 2006 is uncertain, the experience obtained from this project would suggest a risk that the airtightness of those dwellings that are selected to be tested may not be representative of the performance of other dwellings of the same type on the same development.

c) Local authorities are authorised to accept a certificate from a person who is registered by BINDT in respect of pressure testing for the airtightness of dwellings. However, there is no clear guidance given about who else can undertake the tests and issue certificates. It will therefore be up to individual BCBs to decide who is technically competent to undertake the tests and issue certificates. This may lead to issues relating to equity and fairness if BCBs adopt different practices and developers are treated differently in different parts of the country. Also the question of the independence of testing arises if developers are allowed to test and issue certificates for their own dwellings. Guidance on this issue may be necessary.

d) The sampling frequencies outlined in ADL1A 2006 are likely to result in a small non-random number of dwellings tested on each development. The sample sizes involved are also unlikely to be statistically significant; therefore, the results obtained may not be indicative of the airtightness performance of other dwellings on the development. The results obtained from this project suggest that the proportion of dwellings requiring testing is likely to vary considerably between developments (between 1% and 14%) and will be dependent upon the number of dwelling types and the method of compliance. In addition, where apartments are being constructed, a significantly greater proportion of apartments are likely to require testing than other dwelling types. This is despite the fact that apartments tend to be intrinsically more airtight than other dwelling forms of equivalent area.

e) Experience obtained from Phase 1 and Phase 3 of this project suggests that developers appear to be unaware of how to prepare a dwelling for a pressure test and, in some instances, tests have had to be abandoned as the dwelling was not in a finished state. The incidence of unprepared and unfinished dwellings being presented for testing is likely to reduce in the medium to long term as developers become accustomed to pressurisation testing and realise that they will have to pay for aborted tests where preparation is inadequate.

f) The design air permeability target for many dwelling designs is likely to be considerably lower than the maximum recommended level of 10 $m^3/(h.m^2)$ @ 50Pa specified within ADL1A 2006, particularly where fuels with a higher carbon intensity than gas are to be used. Modelling work on statistical distributions suggests that an average air permeability of around 7, 5 and 3 $m^3/(h.m^2)$ @ 50Pa would need to be achieved by a developer to meet a design air permeability target of 10, 7 and 5 $m^3/(h.m^2)$ @ 50Pa, respectively, assuming a 10% initial failure rate. Reliably achieving an average air permeability of below 5 $m^3/(h.m^2)$ @ 50Pa will be technically

demanding, and such levels of air permeability are likely to require a fundamental rethink of airtightness design.

g) The way in which the dwelling is tested can influence the eventual levels of air permeability achieved and bias the results. The approved procedure for pressure testing a dwelling, ATTMA Technical Standard 1 (ATTMA, 2006), states that valid test results can be achieved by: pressurising the dwelling; depressurising the dwelling; or pressurising and depressurising the dwelling and averaging the results. The results obtained from Phase 1 and Phase 3 of the project indicate that the difference between pressurisation and depressurisation can be as high as 14%, and the results obtained by depressurising the dwelling only are, in most cases, lower than the corresponding pressurisation test results. Consequently, more favourable test results could be achieved by selecting only depressurisation to obtain test results.

3 The number of new dwellings requiring testing each year will be dependent upon the strategy adopted for regulatory compliance by the developer, the size of the development and the variation in dwelling types across the developments. Based on construction statistics for 2004 and 2005, it is estimated that the number of dwellings that will require testing will fall in the range 25,000 to 42,000 per year. The figure is likely to lie towards the higher end of this range due to re-tests and the trend towards constructing more multi-dwelling buildings. This will place considerable strain on testing capacity and will have a disproportionate effect on small and medium size developers, many of whom may have to test a high proportion of their production. Although the number of tests would be high the impact in quality control terms will be statistically inefficient and unbalanced since sample sizes are unlikely to be well constructed.

4 Wind speed can have a significant effect on the accuracy of pressure tests. Assuming a working day from 8am to 6pm, an analysis of the CIBSE/Met Office weather data for a semi-empirical Test Reference Year suggests that the average maximum number of hours available for testing in a year would be reduced by over 7% due to unfavourable wind conditions. The number of hours available for testing is likely to reduce further when tests are undertaken in more exposed locations, increasing the incidence of less reliable test data. Time spent travelling between sites, in order to undertake tests in different locations on the same day, will also affect the number of tests that can be performed.

5 Taking into account seasonal trends in dwelling completions and the number of hours available for testing, the average number of tests that are required to be undertaken in a single day could exceed 200 or fall below 80, depending upon the month of the year. Assuming that an average of four tests could be undertaken by a single testing team each working day, a minimum of 20 testing teams would be required in January to cover the testing requirements, rising to a minimum of 50 testing teams in June and December. These figures would double if it was only possible for the testing team to undertake an average of two tests per day.

6 The commercial charge for undertaking a single pressure test is of the order of £500 excluding VAT plus travel and subsistence. Any additional tests at the same visit are of the order of £100 per dwelling excluding VAT.

7 The strategy adopted to ensure a desired level of airtightness can influence the eventual air permeability test results that are achieved, and costs will vary accordingly. In the case of all the houses constructed by developers A, B, C and D; in Phase 3 of the project where feedback was provided but no additional effort put in to quality control and no design changes were made, negligible improvements in performance were observed over equivalent dwellings constructed in Phase 1. By improving quality control systems, through increased and better informed inspection, a 29% improvement was observed and an average mean air permeability of below 10 $m^3/(h.m^2)$ @ 50Pa was achieved. The additional costs being related to the extra staff hours accrued. The greatest reductions in air permeability observed in Phase 3 were achieved where improved construction was undertaken in the form of design-led changes with respect to the primary air barrier, combined with the plot-specific quality control. This approach saw an average improvement of over 45%, with test results averaging 6.9 $m^3/h.m^2$ @ 50Pa. This approach incurred direct costs per dwelling for labour and materials, in addition to the increased staff costs of the enhanced quality control. The apartments constructed by developer E saw an average 12% decrease in air permeability for the top-floor apartments where design changes surrounding the traditional roof construction had been introduced, but an overall increase in air leakage due in part to difference in the test procedures between the two phases, and partly due to alterations to the

detailing adopted by the developer and the apartments not being fully completed at the time the tests were undertaken.

8 Limited data are available on the costs associated with undertaking remedial work in dwellings that have failed a pressure test. Experience obtained at Derwentside on existing dwellings suggests a cost in the region of £1,200 per dwelling (see Johnston and Lowe, 2006). However, we believe that this cost is likely to exceed the costs of undertaking remedial airtightness work in newly constructed dwellings.

9 Three separate approaches have been proposed to address a number of the limitations previously identified with the pressure testing regime that is currently contained within ADL1A 2006.

a) Direct quality control — This approach involves making a number of amendments to the current edition of ADL1A 2006. These amendments concentrate on providing clearer and more detailed guidance on a range of factors such as dwelling type, dwelling selection, registered testers and dwelling preparation. In addition, it is also suggested that the current sampling frequency should be increased such that a representative sample of dwellings is tested on each development.

b) Indirect quality control — This quality control approach would be outside the regulatory loop along the lines of the Robust Details system used by many developers with respect to Part E. It involves putting in place a national airtightness quality control system as an alternative to compulsory pressure testing or a direct regulatory checking process. Within the context of the scheme a random sample of visual inspections and pressure tests of completed dwellings would then take place to ensure that the dwellings are built as designed and meet the airtightness requirements of the Approved Document. Care would need to be taken with such an approach to ensure that the sampling protocols ensure statistical validity.

c) Compulsory testing — This is the most radical of all three approaches and would involve the compulsory pressure testing of all new dwellings. Although this approach would be the most expensive, and the UK does not currently possess the necessary testing capacity to implement it, this is the only approach that would ensure that the air permeability of all new dwellings is as specified in the calculation of the Target Emission Rate.

Introduction

10 This paper constitutes milestone D10 — Impacts of Pressure Testing of Communities and Local Government Project reference CI 61/6/16 (BD2429) *Airtightness of Buildings — Towards Higher Performance* (Borland and Bell, 2003). The overall aim of this project is to investigate practical ways of achieving higher levels of airtightness performance than the current requirements of Approved Document Parts L1 and L2. This project addresses those issues relating to the domestic sector. Work is being undertaken in parallel on the airtightness of buildings in the non-domestic sector.

11 The project was undertaken in two parts:

a) Literature review — A conventional literature review was undertaken, which was supplemented by a small number of field tests of airtight dwellings, together with open-ended questionnaires with the current occupiers and those responsible for their design and construction.

b) Participatory action research — This part of the project was undertaken in three distinct phases and involved five developers (A, B, C, D and E) from the commercial and social housing sectors. Phase 1 involved a detailed assessment of the design and construction of five dwellings per developer (total of 25 dwellings) and pressure tests. 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 (five from each developer) was monitored following the feedback and enhanced understanding gained during Phase 2.

12 The purpose of this paper is to review the pressure testing regime that has been incorporated within Part L1A 2006 of the Building Regulations and discuss the effect that it is likely to have on the testing of new dwellings. It is anticipated that this discussion paper will form one of the inputs into the Forward Thinking Paper on energy conservation which is due to be updated in 2006. It is also intended that the findings of this work will be used to inform future revisions to Part L of the Building Regulations.

Pressure Testing and the Building Regulations: ADL1 2002 and ADL1A 2006

13 The 2002 edition of the Approved Document Part L1 (DTLR, 2001) came into effect in April 2002. This document (ADL1) requires that reasonable provision should be made to reduce unwanted air leakage. Compliance can be achieved by adopting the guidance given in the report on Robust Construction Details (see DEFRA, 2001), or by pressure testing the building following the method outlined in CIBSE Technical Memorandum TM23 (CIBSE, 2000). If a pressure test is to be undertaken, the air permeability of the dwelling must not exceed 10 $m^3/(h.m^2)$ @ 50Pa. Although two separate methods of compliance are identified within ADL1 2002, in the vast majority of cases Robust Construction Details have been used as the basis for regulatory approval as obligatory pressurisation testing was not required.

14 In 2005, a major review of Part L1 was undertaken following the publication of a consultation document in July 2004 (ODPM, 2004). The outcome of this review has been the publication of two revised versions of the Approved Document Part L1; L1A Work in New Dwellings and L1B Work in Existing Buildings. The brief outline in this section is based on the final version of Approved Document L1A Work in New Dwellings (ADL1A), which was published in March 2006 (ODPM, 2006a).

15 ADL1A 2006 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[1] is given as 10 $m^3/(h.m^2)$ @ 50Pa. In the majority of cases, checking compliance with the regulation will require some degree of compulsory pressure

[1] Design air permeability is defined in ADL1A 2006 as the value of air permeability that is selected by the designer for use in the calculation of the DER.

testing.[2] The exception to this concerns small developments of no more than two dwellings. On such sites an alternative approach to pressure testing can be adopted. This requires the developer to show that in the preceding 12 month period, a dwelling of the same type constructed by the same builder has been pressure tested and has achieved the required Dwelling carbon dioxide Emission Rate (DER[3]). Alternatively, the developer can avoid the need for pressure testing altogether by using a value of 15 $m^3/(h.m^2)$ @ 50Pa for the air permeability when calculating the DER. However, in order to achieve the Target carbon dioxide Emission Rate (TER) the high permeability would have to be offset against substantial improvements in energy efficiency elsewhere in the dwelling(s).

16 On developments of more than two dwellings, the degree of pressure testing varies depending upon whether the dwellings have adopted accredited construction details or not. The pressure testing regimes associated with each method of compliance are as follows:

a) Dwellings that have adopted accredited construction details – One example of each dwelling type selected by the Building Control Body (BCB) will require testing from the first completed batch of units from each dwelling type. Dwelling type is defined in ADL1A 2006 as a dwelling of the same generic form; e.g. detached, semi-detached, end-terrace, mid-terrace, ground-floor flat, mid-floor flat, top-floor flat, and where the same construction methods are used for the main elements (walls, floors, roofs, etc). Blocks of flats are to be treated as a separate development.

b) Dwellings that have not adopted accredited construction details – The number of tests required are dependent upon the number of dwellings of the same type that occur on the development. If four or less dwellings of the same type occur on the development then one test of each type is required to be undertaken. If more than four but less than 40 dwellings of the same type occur on the development then two tests of each type are required to be undertaken. If more than 40 dwellings of the same type occur on the development then at least 5% of each type are required to be tested. This number may be reduced to 2% if the first five dwellings tested all achieve their respective design air permeability. As with the adoption of Accredited Construction Details, blocks of flats are to be treated as a separate development. The dwellings to be tested may be selected by the BCB in consultation with the builder and should be selected such that about 50% of the tests for each dwelling type are undertaken during the construction of the first 25% of each dwelling type. This will enable any lessons learnt to be fed back to the builder before the majority of the dwellings are constructed.

17 For those dwellings that fail to achieve the required design air permeability, remedial works should be undertaken on the dwelling and the dwelling re-tested. The remedial works should ensure that when the dwelling is re-tested the measured air permeability is less than 10 $m^3/(h.m^2)$ @ 50Pa and the DER calculated using the measured air permeability is no less than the TER.[4] In addition to undertaking the remedial works, another additional dwelling of the same type is also required to be tested, resulting in an increase in the testing sample size. An adjustment period of up to 31 October 2007 is included to allow for dwellings failing to achieve the target design air permeability figure to be temporarily subject to less stringent re-test targets. The re-test targets allow an improvement of 75% of the difference between the initial test result and the design air permeability or if less demanding, a test result within 15% of the required design air permeability. Alternatively, the TER can be revised by substituting the measured air permeability obtained by following the above re-test procedure for the value set out in Appendix R of Sap2005, and demonstrate that the DER is not worse than the revised TER.

18 ADL1A 2006 also introduces new guidelines over who should perform the obligatory pressure testing of dwellings and the procedures to be followed. Local authorities are authorised to accept as evidence a certificate from a person who is registered by the British Institute of Non-Destructive Testing (BINDT) in respect of pressure testing for the airtightness of buildings. The tests are to be performed using the procedure approved by the Secretary of State for air pressure testing, which is set out in the Airtightness Testing and Measurement Association (ATTMA) publication Technical Standard 1: *Measuring Air Permeability of Building Envelopes* (ATTMA, 2006). This publication is

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[2] Details of the pressure testing requirements are contained within Regulation 20B of The Building Act 1984 (ODPM, 2006b).

[3] The DER is the predicted rate of carbon dioxide emissions from the dwelling.

[4] The TER is the minimum energy performance requirement for new dwellings approved by the Secretary for State. It is expressed in terms of $kgCO_2/m^2$ per annum emitted as a result of the provision of heating, hot water, ventilation and internal fixed lighting for a standardised household when assessed using approved calculation tools.

broadly based on techniques and methodologies outlined in BS EN Standard 13829:2001 (British Standards Institute, 2001).

Issues Associated with the Pressure Testing Regime in ADL1A

19 There are a number of issues associated with the pressure testing regime proposed for L1A 2006. These issues relate to the following:

a) Dwelling type.

b) Dwelling selection.

c) Registered testers.

d) Independence of the pressure testing.

e) Sampling frequency.

f) Practicalities of testing.

g) Air permeability target.

h) Test procedure.

Dwelling type

20 The current definition of dwelling type contained within ADL1A 2006 categorises dwellings into a number of generic forms. These forms comprise detached, semi-detached, end-terrace, mid-terrace, mid-floor flat, ground-floor flat and top-floor flat and assume that the dwellings are built using the same construction methods for each of the main elements. Such a categorisation significantly simplifies the issues surrounding geometric form and the complexity of construction that exists in new UK housing. For instance, such a categorisation may not enable a distinction to be made between a 2.5 and a 2-storey end-terraced dwelling[5] or between a detached dwelling that incorporates an integral garage and one that does not. Instead, they would both be treated as a generic end-terrace and detached dwelling, respectively. This has important implications for airtightness because, all other things being equal, the more complex the form and detailed design (particularly of junctions), the greater the potential for air leakage (see Johnston, Wingfield and Bell, 2004).

21 The air permeability results observed in Phase 1 for developers C and E illustrate the effect that complexity can have on airtightness. The results illustrate that significant variations in air permeability (up to 4 $m^3/(h.m^2)$ @ 50Pa) can be observed in dwellings of similar size, construction and form that had been constructed with comparable levels of workmanship and site supervision and by the same site team. The only observed difference between the dwellings was the complexity of the detailing. Higher levels of air permeability were consistently observed in those dwellings that contained the most complex detailing. The disparities in detailing were most common where certain design features required the primary air barrier to cope with complex changes in plane, negotiate structural members and accommodate changes in material. Such details included ground floor projections, rooms adjacent to semi-exposed areas, timber bays in masonry construction and complex junctions with ventilated cold roof loft-spaces. A more detailed discussion of these results can be found in Johnston, Miles-Shenton and Bell (2006).

22 The effect that complexity can have on airtightness has also been observed in a number of field trial dwellings that have recently been constructed at Stamford Brook in Altrincham, Cheshire.[6] Pressure tests undertaken on 26 of the dwellings illustrate a noticeable difference in air permeability between the different dwellings (see Figure 1). Although the small sample size precludes certainty, the mean air permeability of the 2½-storey terraced dwellings (five of the 27 dwellings tested, 19%) were some 3 $m^3/(h.m^2)$ @ 50Pa higher than that measured for all of the other dwellings and over 2 $m^3/(h.m^2)$ @ 50Pa higher than the design air permeability for the dwellings (5 $m^3/(h.m^2)$ @ 50Pa). The higher air permeability of the 2½-storey terraced dwellings

[5] Some BCBs may interpret 2.5 and 2-storey dwellings as two separate dwelling types if the top floor is built using a different method of construction for the external walls.

[6] The maximum design air permeability target for the field trial dwellings was 5 $m^3/(h.m^2)$ @ 50Pa.

was felt to be attributable to the fact that these properties incorporate more complex detailing associated with a room-in-the-roof design.

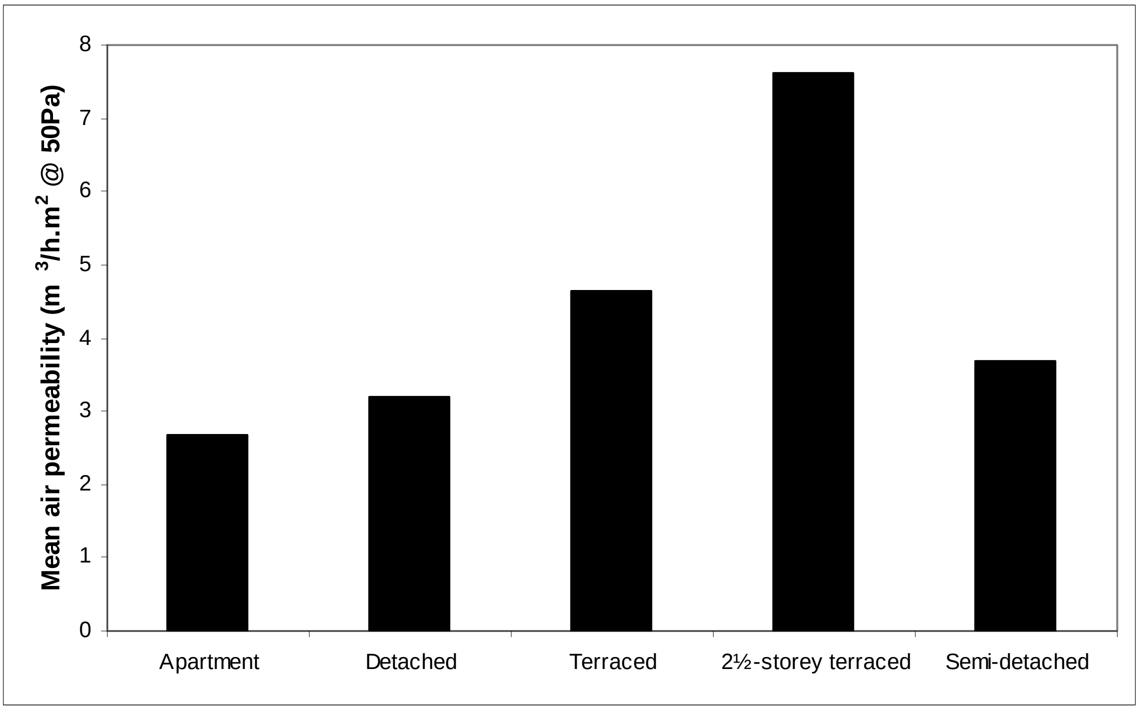

Figure 1 Mean air permeability of the field trial dwellings (adapted from: Wingfield and Bell, 2006).

23 Both results illustrate that the approach to testing set out in ADL1A 2006 is unlikely to capture the important house type issues that arise with respect to a viable testing regime. It is clear that dwellings of the same generic type will display considerable differences in geometric form and complexity of construction, characteristics which are likely to have a much greater influence on airtightness.

Dwelling selection

24 There are two issues relating to dwelling selection that are contained within ADL1A 2006. The first issue relates to the point at which the developer is notified of the dwellings that require testing and the second issue relates to the front loading of the testing requirement.

25 With respect to notification, ADL1A 2006 states that the BCB will select the dwellings to be tested and that these dwellings should come from the first completed batch of units of each dwelling type. However, no guidance is given within the document as to when the BCB should notify the developer of their selection. The point at which the developer is notified of the dwellings that are to be tested is crucial. If notification occurs either prior to the dwellings construction or early on in the construction process, then there may be an opportunity for the developer to make the dwelling more airtight than it would have otherwise been by undertaking 'additional measures' to the selected dwellings. These measures may include making changes to the dwelling's design, constructing the dwelling in a manner that would not normally be undertaken and placing a much greater emphasis on site supervision and workmanship. Consequently, the airtightness performance of the resulting dwelling may be much better than it would have normally been if it had been built as standard. However, if the developer is not notified of the selection until after the dwelling has been completed, say at the pre-handover inspection,[7] there will be no opportunity for the developer to undertake any 'additional measures' on the dwelling to improve its airtightness.

[7] Under the Council of Mortgage Lenders (CML) initiative lenders will not release the mortgage funds for new dwellings until the builder confirms that it has passed a pre-handover inspection by the NHBC or another warranty provider.

Therefore, the airtightness performance of the constructed dwelling is more likely to be representative of the performance of other dwellings of the same type on that site.

26 In terms of when the selected dwellings should be tested, ADL1A 2006 states that when accredited construction details are being used all of the dwellings tested should be taken from the first completed batch of each type. If Accredited Construction Details are not being used, about 50% of the required tests should be undertaken on the first 25% of each dwelling type constructed. The rationale for testing a significant proportion of the dwellings early on in the development is that it gives the developer sufficient time for any lessons learnt to be fed back into the design and construction process, enabling changes to be made before the majority of the dwellings are constructed. Although the rationale is sound, it is based upon a rather naïve view that once the developer demonstrates that the selected dwellings can be constructed to meet a particular airtightness target, the remaining dwellings on the development will also be constructed to the same standard of airtightness. This is unlikely to be the case as there will be little incentive for the developer to make sure that the remaining dwellings are constructed to the same level of airtightness. Consequently, those dwellings that are not required to be tested may have a higher air permeability than those that were tested.

27 Anecdotal evidence from the developments participating in Phase 3 of the project indicates that considerably greater care and attention to airtightness was being paid in those dwellings that were participating in the project. In those dwellings that did not participate in the project, there was a noticeable difference in the quality of workmanship in relation to airtightness. For instance, perpends were not fully filled, gaps were observed in the blockwork and there were gaps around built-in joists. This suggests that knowledge gained on airtightness from Phases 1 and 2 of the project may not have been disseminated to the workforce on site and are not featuring in standard quality control processes. Of course it must be acknowledged that this behaviour may be an artefact of the project since there was no requirement to achieve the same standard as the test dwellings across the development. Under the new regime the new regulatory context may make a difference but it cannot be assumed that it will.

Registered testers

28 With respect to who can undertake the pressure test, ADL1A 2006 states that local authorities are authorised to accept as evidence a certificate from a person who is registered by the British Institute of Non-Destructive Testing (BINDT) in respect of pressure testing for the airtightness of buildings. However, there is no requirement that the pressure tests must be undertaken by a BINDT registered person. The only requirement contained within ADL1A 2006 is that the results and data from the test are recorded based upon a manner approved by the Secretary of State and the results should be given to the local authority no later than seven days after the final test has been carried out. Since there is no requirement for the tests to be undertaken by a BINDT registered person, BCBs may accept test results from organisations that are not registered members of BINDT, as long as they can demonstrate that they are technically competent. Such a situation is likely to lead to issues relating to equity and fairness across the country, as some BCBs may prefer that the pressure test certificates are issued by a BINDT registered member, whilst others might not and there will be different interpretations of technically competent made by the various BCBs. It may also result in the same developer being treated differently in different regions of the country, due to variances in interpretation.

29 The requirements for becoming registered by BINDT in respect of pressure testing for the airtightness of buildings are laid down by the ODPM, as with all approved persons schemes. BINDT are currently in discussion with the ODPM over some of the requirements. The ATTMA is a special interest group within BINDT that are accredited to carrying out airtightness testing of buildings. At the time of writing, only six member organisations were listed on the ATTMA website, one of which is a national house builder. Due to issues surrounding commercial confidentiality, it is unlikely that other developers would allow this house builder to test their dwellings. In order to become a member of ATTMA the organisation must be accredited by UKAS to ISO/IEX 17025, with a scope covering airtightness testing to BS EN 13829:2001 (BSI, 2001) and CIBSE TM23 (CIBSE, 2000). At the time of writing, only nine organisations in the UK were UKAS accredited specifically to undertake building air leakage tests.

Independence of the testing

30 The 2004 consultation paper on Part L stated that any pressure tests should be carried out in an independent manner (ODPM, 2004). Interestingly, the guidance relating to the independence of pressure testing has been removed from ADL1A 2006. This implies that pressure tests could in theory be undertaken by the developer that constructed the dwellings or another organisation that has a vested interest in the outcome of the results. If this was to happen, it raises a concern relating to the quality and robustness of the tests and the procedures that would need to be in place to ensure an acceptable level of confidence in the results.

Sampling frequency

31 Under ADL1A 2006, the number of dwellings that are required to be tested are dependent upon the number of dwelling types on the particular development and the method that is being used to demonstrate compliance. In most instances, the sampling frequencies outlined in ADL1A 2006 are only likely to result in a small non-random sample of dwellings being tested on each particular development.

32 An analysis of the developments that were selected to participate in Phase 1 of the project was undertaken to determine the numbers of dwellings that are likely to be tested on a particular site if the dwellings were constructed in accordance with ADL1A 2006. Table 1 illustrates the results assuming that all of the developers adopt accredited construction details as the means of regulatory compliance. A detailed breakdown of each of the sites by dwelling type, and testing requirements if different compliance strategies are adopted, can be found in Appendix A. It should be noted that this analysis is merely illustrative and not necessarily representative of new UK developments as a whole.

Developer	Total number of units	Dwelling types	Total no of dwellings requiring testing	% of dwellings requiring testing
A	80	Mixture of apartments, terraced, detached and semi-detached properties.	11	14
B	86	Mixture of apartments, terraced, detached and semi-detached properties.	11	13
C	278	Mixture of terraced, detached and semi-detached properties.	4	1
D	143	Mixture of apartments, terraced, detached & semi-detached properties.	17	12
E	128	Apartments.	12	9

Table 1 Dwellings requiring testing assuming adoption of Accredited Construction Details.

33 The results illustrate that the proportion of dwellings requiring testing is likely to vary considerably between developments. In this particular instance there is over a ten-fold difference in the proportion of dwellings requiring testing, ranging from just over 1% for developer C to approximately 14% for developer A. The results also indicate that large developments with few dwelling types (developer C) will require a much smaller proportion of the dwellings to be tested than small developments with a large number of dwelling types (developer A). This issue is better addressed where non-accredited details are adopted, as the number of tests required on each dwelling type is dependent upon the number of instances in which that dwelling type occurs on the development.

34 The results for each developer have also been analysed further to determine the percentage of apartments and other dwelling types that are likely to require testing on each development (see Table 2). The analysis indicates that in all of the developments that incorporate apartments, a significantly greater proportion of the apartments require testing than the other dwelling types. This is despite that fact that apartments tend to be intrinsically more airtight than other dwelling forms of

equivalent area.[8] The reason for the disparity in testing between the different dwelling types relates to the fact that under ADL1A 2006, each block of apartments has to be treated as a separate development. The results also illustrate that the smaller the apartment block, the greater the percentage of apartments that will require testing. In the case of developers A and B, 50% of the apartments will require testing as opposed to just over 9% of the apartments constructed by developer E.

Developer	Total number of units	Dwelling types	Total no of dwellings requiring testing	% of dwellings requiring testing
A	80	Apartments. Other dwellings	6 5	50 7
B	86	Apartments. Other dwellings.	6 5	50 7
C	278	Apartments. Other dwellings.	0 4	- 1
D	143	Apartments. Other dwellings.	12 5	23 6
E	128	Apartments. Other dwellings.	12 0	9 -

Table 2 Apartments and other dwellings requiring testing assuming adoption of Accredited Construction Details.

35 Another important implication of the analysis is that, in most cases, the sample sizes involved and the method of selection will result in samples that are not statistically significant. Therefore it will be very difficult for BCBs to be confident in the performance of those dwellings not tested. Further tests would need to be undertaken to establish whether the results obtained are likely to be truly indicative of the airtightness performance of the dwellings on the particular development as a whole. This could be achieved by undertaking tests on a randomly selected statistically significant sample of dwellings for each development.

Preparation for testing

36 ADL1A 2006 requires pressure tests to be performed using the procedure set out in the ATTMA Technical Standard 1: *Measuring Air Permeability of Building Envelopes* (ATTMA, 2006). This standard states that the building must be prepared prior to any tests being undertaken to allow effective pressurisation, and that the external envelope should be in its final completed state to enable representative results to be obtained. Responsibility for the preparation of the building is likely to vary depending upon the situation. If more than one test is to be undertaken, responsibility normally lies with the main contractor and/or client. However, if the test is a ‘one-off’, the testing organisation is likely to be responsible for preparing the building for the test. The standard also refers to BS EN 13829:2001 Method B – Test of the Building Envelope (BSI, 2001) as a method of preparing the building. Further guidance on preparing the building is also contained within the standard. However, since TS1 (ATTMA, 2006) encompasses procedures for both domestic and non-domestic building pressurisation testing, the guidelines contained within this standard tend to be generic, some of which are not particularly applicable to a large proportion of domestic buildings. For instance, the guidelines state that lift doors should be closed and reference is made to riser cupboards.

[8] The reason for this is that apartments are more likely to have solid intermediate floors, fewer external door and window openings and fewer service penetrations.

37 Experience suggests that it is not uncommon to arrive on site and find that the dwelling is unprepared for testing. In some instances the reason why the dwelling is unprepared relates to the fact that the developer is unaware of how to prepare the building for testing. For instance, during Phases 1 and 3 of the project is was not uncommon to find that the external envelope was complete but the drainage traps were not filled with water, external windows and doors were not closed, trickle ventilators were in the open position, the loft hatch was either missing or was open and the extract fans had not been turned off or temporarily sealed. These issues can easily be rectified on site and a test undertaken; however, this will increase the time taken to conduct the pressure test and may significantly decrease the number of tests one team could perform in a day. In time, it is expected that the occurrence of unprepared dwellings will diminish as developers gain more experience of pressure testing.

38 During this project It was not uncommon to arrive on site and find that the external envelope of the dwelling was in an unfinished state and various site operatives still working within the dwelling. This occurred in a number of instances during both Phases 1 and 3 of the project. In many cases, it would not have been possible to obtain representative results for the dwellings so the tests had to be abandoned. Experience from the non-domestic market does suggest that this occurs on a far less frequent basis when the contractor has to pay for this service.

39 It is also not uncommon to find that prior to the test, the developer has temporary sealed various elements of the building fabric in an attempt to achieve improved results. Any results obtained from testing such a dwelling will be unrepresentative and the dwelling will require to be re-tested at the developer's expense. Experience indicates that more direct guidance needs to be provided to developers prior to any testing that highlights their responsibilities and details how the building should be prepared.

Air permeability target

40 Although compliance with ADL1A 2006 will require all dwellings to achieve a maximum air permeability of 10 $m^3/(h.m^2)$ @ 50Pa, the airtightness specification of many dwelling designs (particularly where fuels with a higher carbon intensity than gas are to be used) may have to be much lower than this. An air permeability of 5 $m^3/(h.m^2)$ @ 50Pa or less may become a common design requirement, particularly post 2010. If this is the case, the average air permeability of the dwellings that are being constructed by the developer will need to reduce to a figure somewhere below the design air permeability target. The average figure will be dependent upon the failure rate that is acceptable by the construction industry and the shift in the distribution of air leakage that occurs as developers seek to achieve compliance. In order to establish what the average value may be for a given design air permeability, the existing distribution of air leakage[9] measured by Grigg (2004) has been scaled using a simple model[10] developed by Lowe, Johnston and Bell (2000). The model is as follows:

$$P_{(n50)} = aP_{0(n50)}$$

Where $P_{0(n50)}$ is the distribution of air leakage rates in current new dwellings, $P_{(n50)}$ is the distribution of air leakage rates following the introduction of ADL1A 2006, and *a* is a variable scaling parameter.

41 Figure 2 illustrates the resulting air leakage distribution assuming an initial failure rate of 10% and a design air permeability target of 10 $m^3/(h.m^2)$ @ 50Pa. The resulting average air permeability rate that would need to be achieved by a developer would be around 7.0 $m^3/(h.m^2)$ @ 50Pa. The results obtained from Phase 3 of the project illustrate that an average air permeability of around 7 can be achieved within new UK dwellings (see Johnston, Miles-Shenton and Bell, 2006). However, this requires the introduction of design-led improvements to the primary air barrier.

42 Figures 3 and 4 illustrate the resulting air permeability distribution if the design air permeability target is reduced to 7 and 5 $m^3/(h.m^2)$ @ 50Pa with resulting average air permeabilities of 4.7 and 3.2 $m^3/(h.m^2)$ @ 50Pa, respectively. Recent results obtained from some field trial dwellings at Stamford Brook (see Wingfield and Bell, 2006) suggest that an average air permeability of around

[9] It is impossible to know what the distribution of air leakage would be following the adoption of a particular design air permeability.

[10] This model reduces the mean air leakage rate and the standard deviation of leakage rates in the same proportion. It is important to realise that this may not occur in practice and the adoption of a particular design air permeability rate may result in a very different distribution of air permeability.

4.7 $m^3/(h.m^2)$ @ 50Pa can be achieved in practice by concentrating efforts on site supervision and workmanship and by maintaining continuity of the air barrier in the external walls by the application of a thin parging coat (3-4 mm) to all of the external walls prior to the application of the plasterboard dry-lining.

43 Achieving an average air permeability of around 3 $m^3/(h.m^2)$ @ 50Pa is much more demanding as this level of air permeability is very tight by UK standards. Although an air permeability of less than 3 $m^3/(h.m^2)$ @ 50Pa has been achieved in a number of dwellings constructed in the UK, for instance Stenness in Orkney (Scivyer, Perera and Webb, 1994), these dwellings tend to be one-off 'specials'. It is difficult to see how this level of air permeability could be consistently achieved in mass housing without there being a fundamental rethink of airtightness design in new UK dwellings.

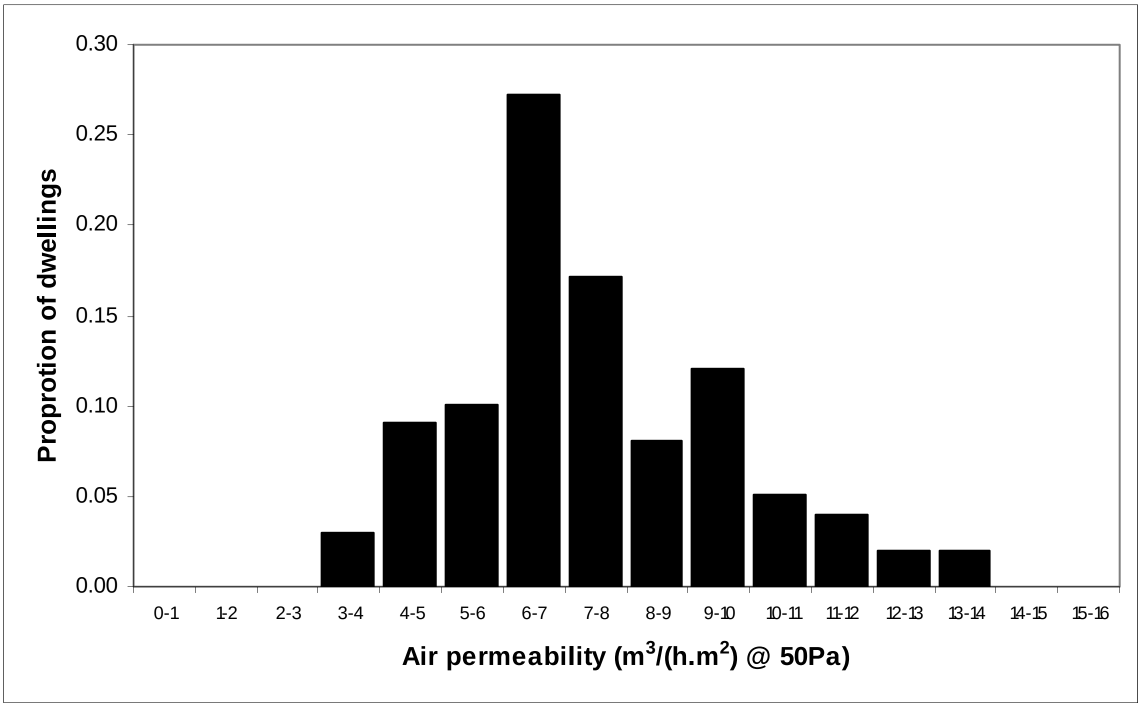

Figure 2 Distribution of air leakage rates assuming a design air permeability target of 10 $m^3/(h.m^2)$ @ 50Pa and an initial failure rate of 10%.

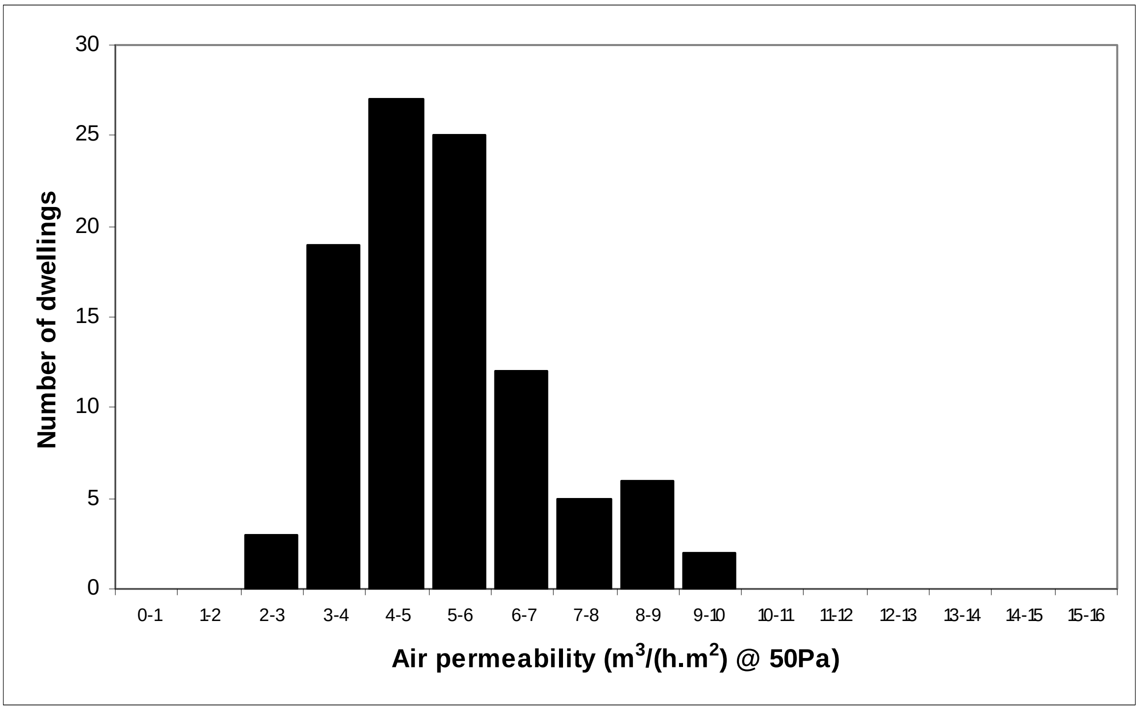

Figure 3 Distribution of air leakage rates assuming a design air permeability target of 7 $m^3/(h.m^2)$ @ 50Pa and an initial failure rate of 10%.

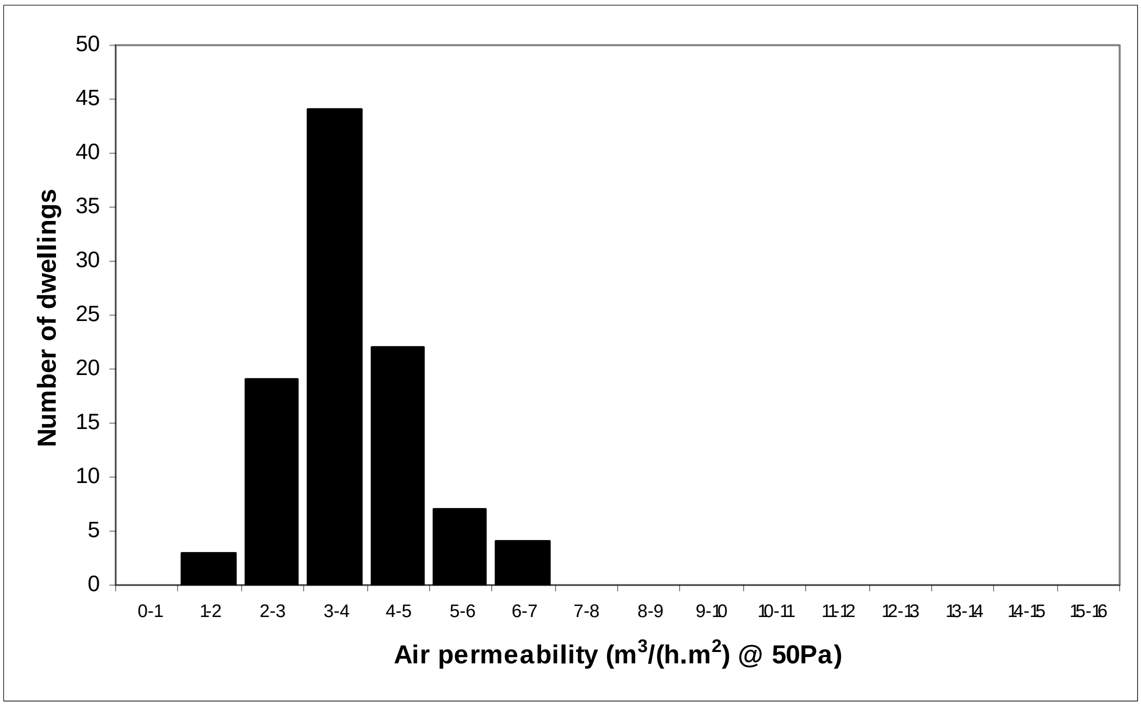

Figure 4 Distribution of air leakage rates assuming a design air permeability target of 5 $m^3/(h.m^2)$ @ 50Pa and an initial failure rate of 10%.

44 Anecdotal evidence obtained from site, coupled with recent pressure test data from the field trial dwellings at Stamford Brook suggests that even when a demanding design air permeability target has been set (in this case 5 $m^3/(h.m^2)$ @ 50Pa), there can be a deterioration in site workmanship

and quality over time (Wingfield, Bell, Lowe and Bell, 2006). One of the first dwellings to be constructed on site was built to a high standard of workmanship and achieved an air permeability of 1.8 $m^3/(h.m^2)$ @ 50Pa. This compares with the latest results obtained from site on a similar dwelling type where an air permeability of 3.6 $m^3/(h.m^2)$ @ 50Pa was recorded. An analysis of the main air leakage points identified within both dwellings concluded that although air was leaking through the same points in both dwellings, it was leaking at a much greater rate in the leakier dwelling.

45 Another important point that is worthy of note is that airtightness tends to deteriorate over time (see Johnston, Wingfield and Bell, 2004). This effect has recently been observed in one of the dwellings participating in the field trail at Stamford Brook (see Figure 5). The dwelling was initially tested in February 2005 and achieved a mean air permeability of 3.3 $m^3/(h.m^2)$ @ 50Pa. The dwelling was further tested in December 2005 and March 2006 and achieved a mean air permeability of 4.2 and 4.9 $m^3/(h.m^2)$ @ 50Pa, respectively. This represents a deterioration in airtightness of almost 50% over the period of a year. The dwelling has been utilised as a show home and remained unoccupied over this time period; the increased leakage is presumed to be due to general shrinkage and other movement as the building envelope adjusts over time.

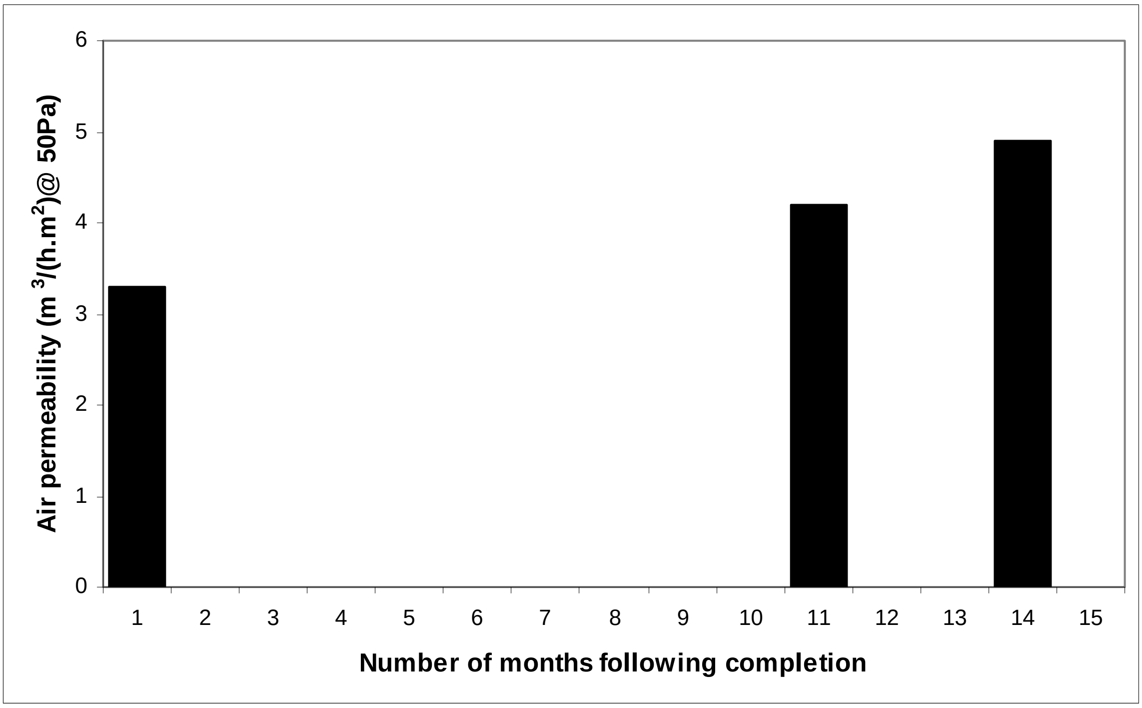

Figure 5 Effect of time on air permeability.

Test procedure

46 ADL1A 2006 states that the approved procedure for pressure testing a dwelling is given in ATTMA Technical Standard 1 — *Measuring Air Permeability of Building Envelopes* (ATTMA, 2006). This standard states that valid test results can be obtained by either pressurising or depressurising the building. Alternatively, the building can be pressurised and depressurised and the results averaged. This procedure is consistent with the advice given in CIBSE TM 23 (CIBSE, 2000). BS EN 13829:2001 (British Standard Institute, 2001), on the other hand, states that although compliance with the standard can be achieved by making only one set of measurements, it is recommended that two sets of measurements are made, one for pressurisation and one for depressurisation.

47 BS EN 13829: 2001 is not the only procedure to recommend that two sets of measurements are undertaken. The American Society for Testing and Materials (ASTM) standard E779-03 (ASTM, 2003) and the testing protocol devised by the BRE (see Stephen, 1998) both recommend that pressurisation and depressurisation tests are performed, and the results averaged.

48 There are valid reasons why two sets of measurements should be undertaken when pressure testing. All of the air leakage paths occurring within a dwelling will have particular aerodynamic characteristics that are dependent upon the direction in which the air is flowing. In addition, various elements of the building fabric, such as windows and doors, can either be pushed tight against their seals or pushed off, depending upon whether the dwelling is being pressurised or depressurised. Therefore, it is likely that more favourable results could be achieved by depressurising rather than pressurising the dwelling. By undertaking both sets of measurements and averaging the results, any aerodynamic effects cancel one another out and no preference is given to one set of results as opposed to the other.

49 Significant differences in the two sets of air permeability measurements can occur. For dwellings, CIBSE claim that it is common for the difference between the pressurisation and the depressurisation results to be more than 10% (CIBSE, 2000). Stephen (1998), on the other hand, suggests that the results can differ by as much as 20%. These sorts of differences in air permeability could make the difference between a dwelling complying with the requirements of ADL1A 2006 or not. Two examples in Phase 3 demonstrate this. In a pre-completion pressure test for Plot D76 constructed by developer D, the dwelling achieving an air permeability of 9.7 $m^3/(h.m^2)$ @ 50Pa on depressurisation, whilst delivering an air permeability of 10.5 $m^3/(h.m^2)$ @ 50Pa for pressurisation and a mean air permeability of 10.1 $m^3/(h.m^2)$ @ 50Pa. A pressure test on Plot C21 built by developer C gave results of 9.6 $m^3/(h.m^2)$ @ 50Pa on depressurisation, 10.4 $m^3/(h.m^2)$ @ 50Pa on pressurisation and a mean of 10.0 $m^3/(h.m^2)$ @ 50Pa. In both cases the choice of depressurisation only, pressurisation only or mean permeability will determine whether a limit of 10 $m^3/(h.m^2)$ @ 50Pa has been achieved or not.

50 An analysis of the results obtained for Phases 1 and 3 of the project was undertaken to determine the differences in air permeability that were measured when the dwellings were pressurised and depressurised. Tables 3 and 4 summarise the results. Details of the individual pressurisation and depressurisation results for each of these dwellings are contained in Appendix B.

Developer	Dwelling	Difference between pressurisation and depressurisation results (%)
A	9	0.6
	11	5.5
	12	3.1
	13	2.5
	14	2.5
B	79	0.7
	80 (pre-completion)	2.5
	80 (completed)	5.0
	81	4.7
	82	4.4
C	236	3.4
	237	0.7
	238	1.4
	239	4.7
	240	6.2
D	39	1.7
	42	5.3
	43	5.8
	44	2.5

	59	6.3
E	CG01	4.7
	CG02	1.2
	C201	8.1
	C202	0.5
	C301	11.3
	C302	1.1

Table 3 Difference in air permeability between pressurisation and depressurisation in Phase 1 dwellings.

Developer	Dwelling	Difference between pressurisation and depressurisation results (%)
A	64	4.8
	65	10.0
	66	0.6
	79	2.2
	80	2.0
B	14	14.5
	16	3.5
	17	1.2
	21	0.3
	22	0.8
C	193	3.9
	194	13.4
	17 (1st fix)	1.2
	17 (2nd fix)	3.7
	17 (completed)	3.7
	18	6.1
	19 (1st fix)	0.3
	19 (2nd fix)	1.7
	19 (completed)	0.4
	20	6.4
	21	8.3
D	73	1.3
	74	1.4
	75	7.3
	76 (pre-completion)	8.0
	76 (completed)	7.8
	96	7.0
E	AG01	0.2
	AG02	5.1

	A201	3.2
	A202	2.1
	A301	3.1
	A302	0.8

Table 4 Difference in air permeability between pressurisation and depressurisation in Phase 3 dwellings.

51 The results indicate that the difference between the two measurements can vary significantly. In the Phase 1 and Phase 3 dwellings this difference ranged from less than 1% to more than 14%, with an average of 4.1%. This difference is comparable to the figures stated by CIBSE (2000). In addition, in most instances, the depressurisation results obtained were lower than the corresponding pressurisation results.

Logistics of Compulsory Pressure Testing

52 In order to discuss the logistics for pressure testing a number of questions need to be addressed. These questions are as follows:

a) How many new dwellings are likely to be tested per year?

b) How many hours per year would you be able to test?

c) How many blower doors are likely to be needed to meet testing demand?

d) What are the costs involved in undertaking a pressurisation test?

e) What are the likely remedial costs associated with failing a test?

f) What are the likely costs in making new dwellings airtight?

Number of dwellings requiring testing

53 The number of new dwellings that will require testing each year will depend on the strategy adopted for regulatory compliance, the size of the development and the variation in dwelling types across each development. NHBC new house-building statistics (NHBC, 2006) show that in 2005, 16% of all NHBC registered new dwelling starts in Great Britain were by builders building less than 30 units per year (smaller developers), 24% by builders building between 31 and 499 units (medium size developers) and 60% by builders building over 500 units (large developers). The full breakdown is provided in figure 6. If these proportions are applied to the total number of UK dwelling completions for the year ending April 2005[11] it is estimated that some 124,000 dwellings were constructed by large developers, 49,000 by medium size developers and 33,000 by smaller developers.

[11] Figures for the proportion of output by size of builder were available for NHBC dwelling starts only (NHBC, 2006). In an ideal world a similar breakdown would be available for completions. However, given the relationships between starts and completions it is unlikely that the proportions would differ significantly and in calculating the likely number of tests the proportions have been applied to completions. Similarly, since NHBC statistics on completions represent about 84% of the UK total, the proportions have been applied to the national totals in deriving the estimates of test numbers. The ODPM Live Table 201 (Housebuilding: permanent dwellings started and completed — ODPM, 2006c) has been used for dwellings completed in 2004/5 (205,991).

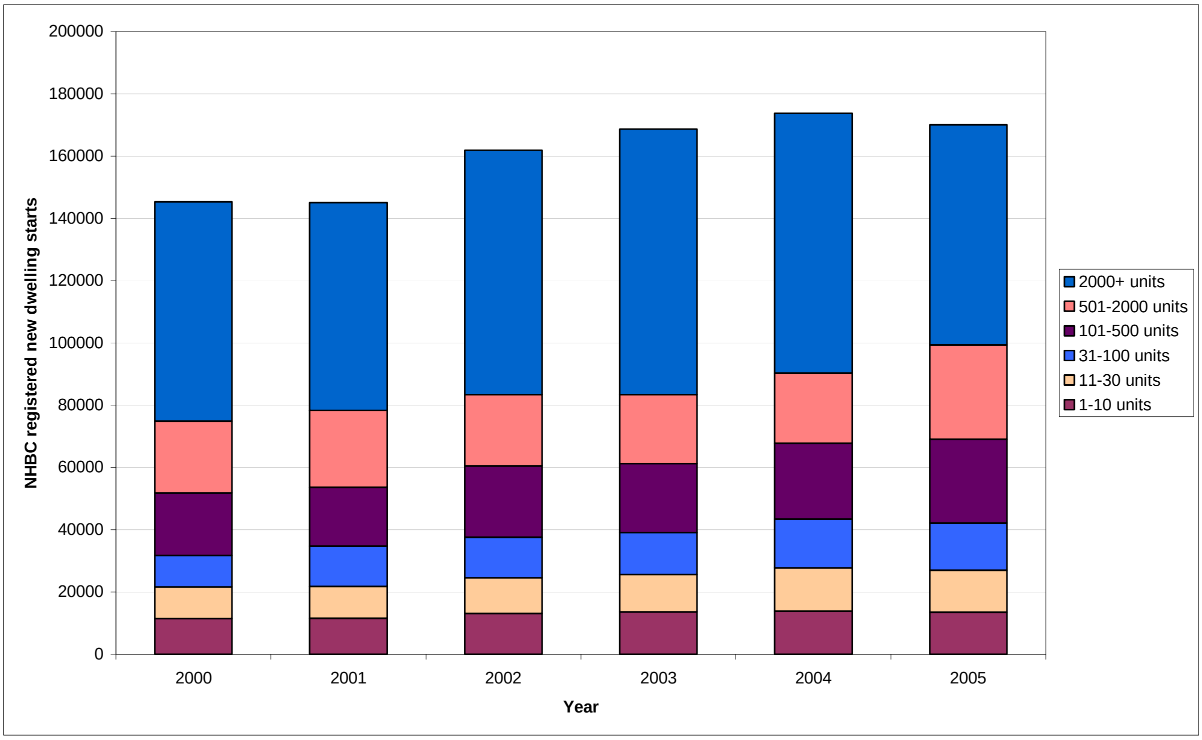

Figure 6 Number of NHBC registered dwelling starts by size of builder (Source: NHBC, 2006).

54 It is expected that the proportion of smaller developers relying on testing for Part L compliance will be high since they often operate from GA drawings and, at least in the short term, may not be in a position to develop a suitable set of details that follow generic accredited details. This is likely to contrast with large developers, who will be capable of supporting the technical infrastructure necessary to adapt designs and recalculate emission rates as required, in order to achieve compliance through an Accredited Construction Details route. In the case of large developers it is assumed that the testing requirement will be around 10%. This is broadly in line with the analysis of the schemes studied as part of this project and set out in Table 1. For small developers, less inclined to use the Accredited Construction Details route, proportions of 25% and 50% have been adopted, based on an assessment of likely development size. The figures for medium sized developers are assumed to be somewhere between 10% and 25%. Using 2004/5 construction completions (ODPM, 2006c) as the base figure, and applying the different proportions, it is estimated that some 12,000 units will be tested for large developers, 5,000 to 12,000 for medium sized developers and 8,000 to 16,000 for small developers.

55 Using the above set of assumptions it can estimated that the number of new dwellings that will require pressure testing, under the schedule specified in Section 2 of ADL1A, will initially fall within the range of 25,000 to 42,000 per year. Given that any dwellings that fail a pressure test will require a re-test and, where appropriate, another dwelling of the same dwelling type will be selected for testing; the actual number of pressure tests to be performed per year may fall towards the higher end of this range or even extend beyond it. Of course the numbers quoted are, to a large extent, speculative and are designed more to capture a likely range rather than be definitive. However the principal message is that a relatively large number of tests will be required and at least in the early phase of operation there will be considerable uncertainty

56 A general trend towards the construction of multi-dwelling buildings may also increase the number of dwellings that require testing. As indicated in Tables 1 and 2, developments containing a greater variety of dwelling types can result in a higher proportion of dwellings that require testing. With more new-build sites including small apartment blocks, to achieve desired population density levels, and each block being regarded as a separate development, the number of tests required under ADL1A 2006 may increase further. The current ODPM live tables, a selection from which is illustrated graphically in Appendix C, show the increasing number of apartments being constructed. In 2004/5 apartments constituted 41% of new dwellings in the United Kingdom, with fractions

highest in the South East (47%) and London (83%). Recently published NHBC new house-building statistics (NHBC, 2006) further illustrate this trend. Figure 7 reveals that in the final quarter of 2005, 49% of all new dwelling starts in England were classified as 'flats and maisonettes'. How much of the increase in flat construction is due to the increasing trend for small blocks of flats included in larger developments is unclear; but with current market and political pressures to build more affordable housing and attain specific requirements for population density on many new developments, it is a trend that looks likely to continue in the near future,[12] with an increase in the number of dwellings to be tested.

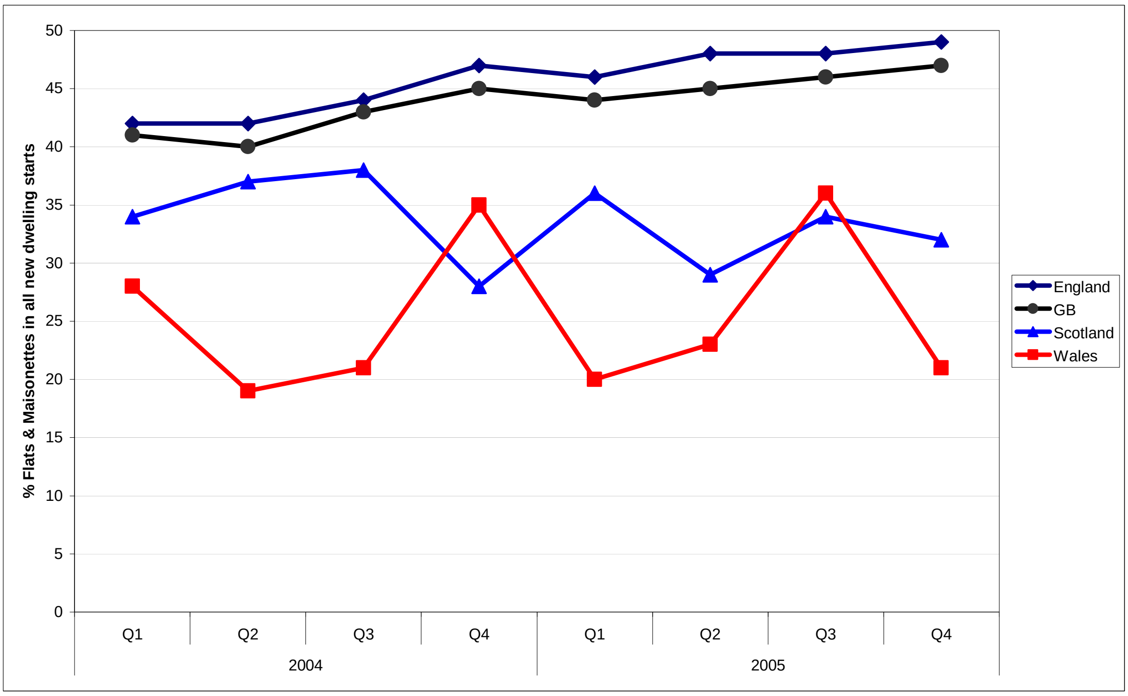

Figure 7 Proportion of flats and maisonettes, as a percentage of all NHBC registered dwelling starts, by quarter, for 2004 and 2005 (Source: NHBC 2006).

Number of hours available for testing

57 The approved procedure for pressure testing stated in ADL1A is ATTMA's Technical Standard 1 *Measuring Air Permeability of Building Envelopes* (ATTMA, 2006), which allows for a standard testing procedure to be carried out only when the following criteria have been met:

a) Wind speeds are below 6 ms^{-1}

b) Variations to the baseline pressure difference are below ±5Pa (average over a 30 s period)

c) The indoor/outdoor temperature difference multiplied by building height must not exceed 500 mK (for the purpose of dwellings, this only affects large apartment blocks)

d) The r^2 correlation coefficient remains above 0.98

58 A testing regime is suggested for atmospheric conditions outside of these, by using increased pressure differentials and taking a greater number of readings. Appendix B *Test Equipment Requirements* of TS1 (ATTMA, 2006) is based primarily around BS EN 13829:2001 *Thermal Performance of Buildings — Determination of Air Permeability of Buildings — Fan Pressurisation Method* which notes:

> *"In calm conditions the overall uncertainty will be less than 15 % in most cases. In windy conditions the overall uncertainty can reach 40 %"* (BSI, 2001 p15).

[12] It must be acknowledged that the extent to which the current trend is set to continue is very difficult to predict in the medium term. The rate of increase is likely to slow but changes in household structure and other pressures may well continue to apply upward pressure or at least maintain the proportion at current levels.

Our experience suggests that the air permeability measurements obtained using ADL1A's approved extended test procedure for more extreme meteorological conditions, contained in *Measuring Air Permeability of Building Envelopes* (ATTMA, 2006), will give the same mean air permeability (within experimental error) to that supplied by the standard test procedure under suitable conditions. However, the air permeability values calculated under pressurisation only or depressurisation only can vary considerably using the extended procedure (in excess of the values offered in Tables 3 and 4), as higher pressure differentials affect air movement, particularly around certain components such as doors, windows and loft hatches where the additional positive or negative pressure will force such components open or shut. There is also a higher likelihood under the extended test methodology that the r^2 correlation coefficient will display a greater level of inconsistency and fall below the 0.98 minimum, rendering the test results invalid. This is particularly the case when the wind is variable in both strength and direction. In such cases differential pressure and flow measurements can display large variations over very short periods of time and provide inconsistent results, hence wind conditions have a major effect on the number of hours when reliable pressure testing results are achievable.

59 In order to estimate the number of hours in which reliable pressure tests could be undertaken, an analysis of weather data obtained from CIBSE/Met Office for a semi-empirical Test Reference Year[13] (CIBSE, 2005) was carried out. This weather data was corrected to a height of 2 m above ground level (the height at which wind speed measurements are taken on site) using the methodology outlined within CIBSE Guide J: *Weather, Solar and Illuminance Data* (CIBSE, 2002) and Terrain Category III (suburban or industrial areas). Assuming a working day from 8am to 6pm, for the 11 cities in England and Wales incorporated within the CIBSE/Met Office data set, meteorological conditions would be unsuitable for the standard tests to be carried out at five of the sites (Birmingham, Nottingham, Newcastle, London and Southampton) for less than 5% of the time, for another five (Cardiff, Leeds, Manchester, Norwich and Swindon) this could be expected to be 5~10% of the time, and over 10% of the time for one of the sites (Plymouth). In addition to this regional variation, there are also monthly and hourly trends which affect the time available for testing (see Appendix D). Conveniently, the most common occurrences of high wind speeds are in the first quarter of the year when the number of dwelling completions is traditionally at its lowest, with the least common occurrences in the third and fourth quarters. Daily, the general trend is for wind speeds to increase steadily throughout the morning, peaking in the early afternoon, with maximum wind speeds usually reached between 1pm and 4pm.

60 Using the above methodology, and assuming testing is not carried out at weekends and bank holidays, the average maximum number of hours available for testing per month is illustrated in Figure 8 for the 11 locations contained in the CIBSE/Met Office data set, based on wind speed alone. It must be stressed that the values represented in Figure 8 are an absolute maximum based on data from the test reference year, and may include individual hours within days when only a few hours had atmospheric conditions suitable for pressure testing. In addition, the use of quarterly figures smooth the monthly trends to some extent, with the monthly figures ranging between 120 and 222 hours per month for Plymouth in January and Southampton in July, respectively. The wind speed does not always need to exceed 6 ms^{-1} to prevent an accurate test result being obtained. Although high wind speeds will produce significant pressure differences on various parts of the dwelling; variable gusting and changeable wind directions will also affect baseline pressure difference and may render any test results invalid, even if the extended procedure suggested in ATTMA TS1 is followed.

[13] The CIBSE/Met Office Test Reference Year is comprised from hourly weather data for 12 typical months, selected from data sets recorded between 1983 and 2004, adapted to provide a continuous 12 months sequence of data. This is a purpose built data set to enable modelling and simulation under typical weather conditions.

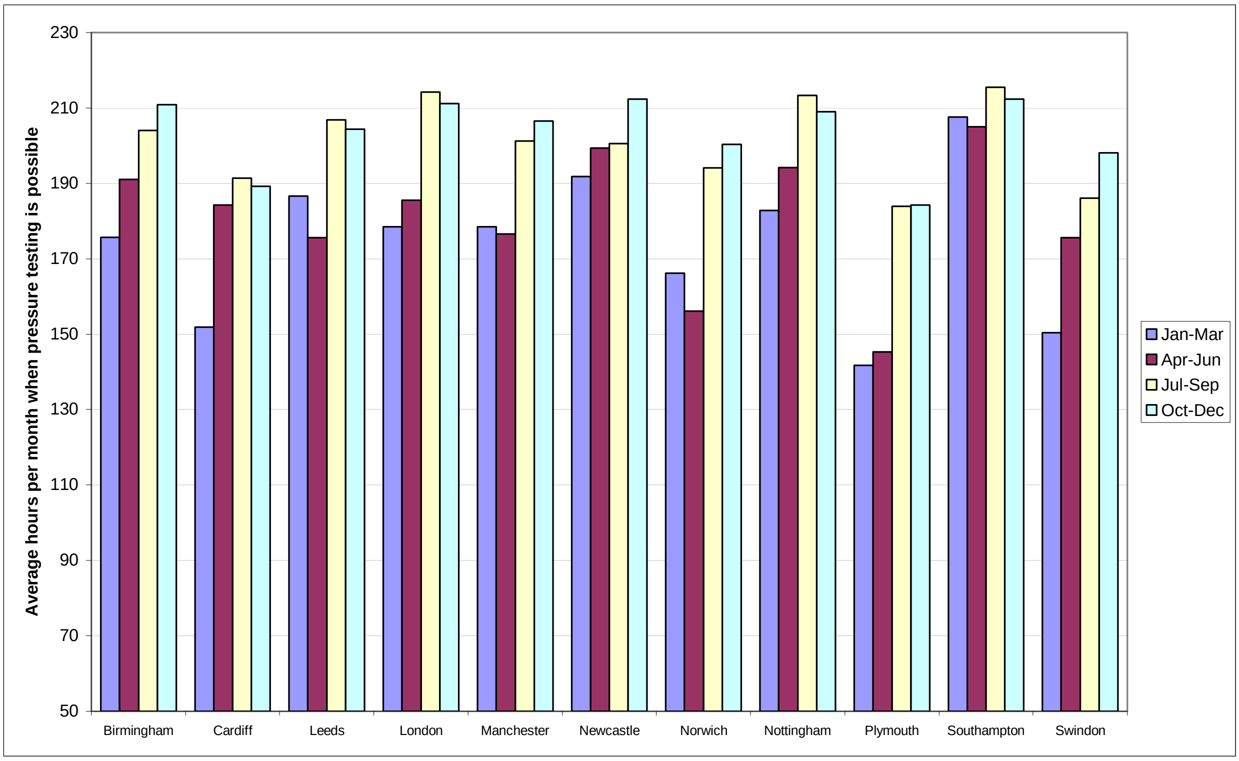

Figure 8 Average hours per month when pressure testing is possible, based on wind speed <6 ms^{-1} at 2 m above ground level, terrain category III, between 8am and 6pm, working days only.

61 The number of available testing hours is likely to be reduced further by other factors. The above figures are adjusted to a terrain category III which simulates a suburban location. In more exposed areas the wind speed at 2 m above ground level will be greater, with fewer obstacles and a reduced surface roughness. The winter months present a potential problem with extreme differences in temperature inside and outside the dwelling resulting in less reliable test readings, particularly in larger apartment blocks, increasing the possibility of the correlation coefficient falling below the minimum acceptable level. Performing tests in a number of locations on the same day may also require substantial time spent travelling between sites, further limiting the time available for testing.

Meeting the demand for testing

62 House-building statistics for 2004 and 2005 (NHBC, 2006) show that the monthly number of dwelling completions, and hence the probable number of pressure tests required under ADL1A (ODPM, 2006a), can vary by over 100% as shown in Figure 9 and Table 5. With ADL1A recommending that 50% of initial tests for each dwelling type are carried out during construction of the first 25% of the development, the link between completions and pressure testing may not be straightforward. However, with any test failures requiring re-tests plus the selection of an additional dwelling for testing, and many construction phases of individual developments invariably grouping together certain dwelling types (as observed in sites B and D of this project[14]); it is expected that the testing regime on many sites will not be completely front-loaded. On smaller sites where a higher sampling proportion is required, particularly where Part L compliance is not sought through the adoption of accredited details, the link between the number of completions per month and the number of pressure tests per month is likely to be strongest. With such a high variation in the anticipated requirement for testing throughout the year, the number of active teams necessary to carry out these pressurisation tests will also vary on a monthly basis. This is envisaged to reach peaks each June and December, when a high number of completions will require pressure testing.

[14]Site B was built in two phases: Phase 1 consisted of only detached and semi-detached dwellings, Phase 2 contained all dwelling types. Site D was built in three phases: Phase 1 was comprised of apartments, detached and semi-detached dwellings, Phase 2 only detached and semi-detached dwellings, Phase 3 included apartments, detached, and end and mid-terraced dwellings.

In December this is further compounded as the number of testing days available is reduced by annual holidays.

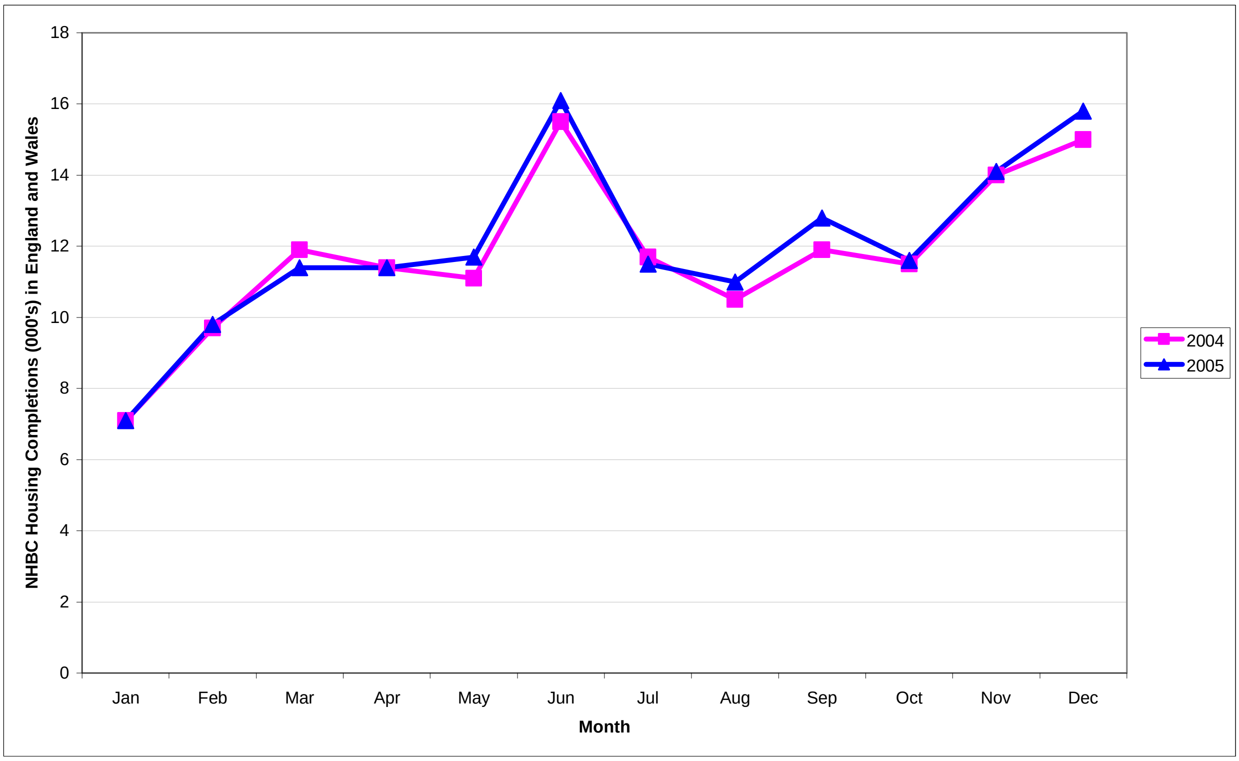

Figure 9 Number of NHBC registered dwelling completions, by month, for 2004 and 2005 (Source: NHBC, 2006).

	January		June		December	
	000's	% of annual total	000's	% of annual total	000's	% of annual total
2004	7.1	5.0	15.5	11.0	15.0	10.6
2005	7.1	4.9	16.1	11.2	15.8	10.9

Table 5 Number, and proportion of annual total, of NHBC registered dwelling completions for selected months in England and Wales (Adapted from: NHBC, 2006).

63 Given the data on numbers of hours for which testing is possible and the seasonal trends in dwelling completions, it is conceivable that the average number of tests to be carried out each working day, in England and Wales, could exceed 200 or fall below 80 depending purely on the month of the year. This vast range can be further compounded by considering additional regional variations, atmospheric conditions and levels of exposure.

64 The number of tests that could be undertaken in a day by a single team is not only dependent upon the weather conditions, location of the development compared with tester and proximity of sites (if more than one site is to be tested in one day), but also upon dwelling availability. Our experience suggests that currently it is unusual on low-rise developments to have more than two or three dwellings available on each development at any one time. Staggered build programmes are favoured by many developers as they allow a smaller number of subcontractors of a single trade to move from plot to plot, rather than a larger number all hired at once, giving greater flexibility. The introduction of compulsory pressure testing may encourage developers to revise build programmes once testing costs and availability begin to gain more consideration. This is not such an issue for larger apartment blocks where whole blocks, or a number of apartments in a particular section, are completed for handover at the same time, allowing a number of dwellings to be tested in a single visit.

65 Estimates that eight to 10 pressure tests can be undertaken in a day by a single test team have been suggested.[15] Our experience indicates that this figure is unrealistic, and that a maximum of three or four tests per day is more likely. This figure is based upon a brief time and motion study (Appendix F) on how long it takes to undertake a test, and the fact that there are rarely more than two or three dwellings at a suitable stage of completion for testing at any one time on any one site before being handed over to the purchaser. It also does not take into account the number of times when a testing team turns up on site to perform a pre-arranged pressure test and the test cannot be conducted for other unforeseen reasons such as water leaks, damage caused through theft and vandalism, and dwellings not being ready on time. However, it is anticipated that commercial imperatives are likely to reduce this problem in the medium to long term.

66 Assuming that a single testing team can perform pressure tests on an average of three or four dwellings per working day, the above figures would require a minimum of 20 to 25 testing teams available in January to cover the testing requirements in England and Wales under ADL1A 2006. In June and December the minimum number of teams required would rise to between 50 and 65. If, given all the factors, the average testing rate falls to two dwellings per day per team, the number of teams required to meet the testing demand would increase to over 40 in January and more than 100 in June and December.

Costs involved in undertaking pressure tests

67 The commercial charge for undertaking a pressurisation test on a single dwelling on a single site is currently of the order of £500 excluding VAT plus travel/subsistence costs, although quotations far in excess of this are not uncommon. The introduction of compulsory airtightness testing for dwellings may result in increased competition and economies of scale which will reduce this figure in the medium and long term. However, the dominating factor in estimating the cost per test is how many tests can be performed in a single visit and, as noted above it is currently uncommon for more than two or three dwellings to be ready for testing on any given day. Experience suggests that instances where greater numbers of dwellings are available for testing normally only occur with multi-dwelling buildings such as apartment blocks. The costs associated with undertaking any additional tests once on site are marginal, and are of the order of £100 per dwelling excluding VAT.

68 The number of tests possible in a single visit can vary considerably depending on whether the dwellings have been fully prepared prior to the tests. With a fully prepared dwelling the time taken to perform an individual pressure test (dwelling inspection, equipment assembly and disassembly, recording of atmospheric data, taking test readings) can be as little as 30 minutes, however, this is rarely the case. Most dwellings will require additional preparation prior to the test being performed if accurate results are to be achieved. If the tester has to perform temporary sealing, additional costs are incurred in terms of both labour and consumables. The processes of signing in and out of site, undergoing a site induction, obtaining access to the dwellings, unloading and loading equipment from the vehicle and waiting for operatives to vacate the dwelling can all add significant amounts of time, and therefore cost, to the test procedure (see Appendix F). Travelling time between sites may also become a key cost factor, particularly in more rural areas with smaller sites and a greater geographical distribution.

69 In consideration of current commercial charges for performing domestic pressure tests, rates are weighted towards staffing costs. With direct costs for travel and subsistence overshadowing those for consumables. Capital costs and overheads will vary greatly depending upon the size of the testing organisation, and the infrastructure that the organisation presently has in place. ATTMA members and other UKAS accredited testing stations will benefit from in house facilities to calibrate test equipment and train staff.

70 Appendix E lists the necessary equipment for a blower door kit and suggests a current approximate net cost of around £3,200. This figure does not include delivery, calibration or training, and assumes that the purchaser will already own certain essential items including a computer suitable for running the necessary software. The cost of such a blower door kit should not prove prohibitive for most house builders should they want to perform pre-completion testing themselves to ensure that their dwellings will achieve the desired level of airtightness in a subsequent authorised test. However, it remains to be seen whether developers adopt this approach as the testing regime matures.

[15] BSRIA seminar 11-Oct-2005

Remedial costs

71 The costs associated with failing to gain the pressure test result required to achieve the TER may not initially be fully appreciated by the developers until they have experienced it. As well as incurring costs associated with improving the airtightness performance of the failed dwelling to the re-test target level, the developer will also have to pay to re-test the dwelling and test another additional dwelling of the same type on the development. In addition, it is also likely that leakage detection will also be performed on the failed dwelling so that any remedial action can be better focused. This detection work will also increase the costs associated with failing the initial pressure test.

72 Little is known about the costs associated with undertaking remedial work in dwellings that have exceeded an air permeability target. However, experience suggests that the costs could vary significantly and will be dependent upon the scale of the reductions in air permeability that will be required, the location of the main air leakage points and the amount and nature of the remedial work that is required to be undertaken. For instance, it may be possible to reduce the air permeability of the dwelling by undertaking some simple secondary sealing measures such as sealing service penetrations through walls, whilst in other instances much more intrusive work may need to be undertaken such as replacing plasterboard dry-lining, removing carpets, replacing floors and redecoration.

73 An indication of the costs associated with undertaking remedial airtightness work on dwellings has been obtained from work on a small number of existing dwellings (12 in total) that were refurbished at Derwentside, County Durham (see Johnston and Lowe, 2006). The dwellings were built in the early 1970s using dry-lined load-bearing cavity masonry construction and, prior to the refurbishment, the dwellings were in a poor state of repair with an air permeability of between 24 and 26 $m^3/(h.m^2)$ @ 50Pa. A programme of general and targeted airtightness work was carried out by Leeds Metropolitan University in conjunction with a partial refurbishment undertaken by Derwentside District Council. Following these works, the air permeability of the dwellings was reduced by almost 55%, to a mean of just over 11 $m^3/(h.m^2)$ @ 50Pa. The costs of undertaking the remedial airtightness work were in the region of four man days per dwelling, plus approximately £200 in total material costs (majority of which was expanding polyurethane foam). Assuming a labour cost of approximately £250 per day, the total costs at current rates would be in the region of £1,200 per dwelling. Of course the lack of published data on this issue means that any figures quoted at this stage are highly speculative.

Cost of making dwellings airtight

74 Little is also known about the additional costs associated with achieving the airtightness standards in ADL1A. Costs are likely to be dependent upon the method of construction used, the approach taken to make the dwellings airtight and the target air permeability rate. However, the results obtained from Phase 3 of the project provide some evidence. In the case of eightr dwellings from Phase 3 significant reductions in air permeability were achieved (reductions averaging 47% and up to 60% were observed based upon the Phase 1 mean) by introducing design-led changes that focus attention on the primary air barrier, its identification and its continuity (see Table 6). The direct costs of achieving this ranged from a relatively modest one man day per dwelling plus minimal material costs, suggesting figures around £300 to £400 (dwellings B16 and B17), to an estimated amount possibly in excess of £1,000 (dwellings A79 and A80). Although the changes adopted and the scale of the reductions achieved varied between the developers, all of the dwellings achieved an air permeability of less than 10 $m^3/(h.m^2)$ @ 50Pa.

Dwelling	Action taken	Construction type	Phase 1 equivalent ($m^3/(h.m^2)$ @ 50Pa)	Phase 3 test result ($m^3/(h.m^2)$ @ 50Pa)
A79	Additional sealing (with mortar, tape, mastic and expanding polyurethane foam) of blockwork, loft boundary and service penetrations prior to dry-lining.	Dry-lined load bearing cavity masonry	14.3	6.5
A80	Additional sealing (with mortar, tape, mastic and expanding polyurethane foam) of blockwork, loft boundary and service penetrations prior to dry-lining.	Dry-lined load bearing cavity masonry	11.8	5.6
B16	All internal blockwork and junctions inspected at pre-plaster stage and additional pointing work undertaken to remedy any defects.	Dry-lined load bearing cavity masonry	10.5	5.6
B17	Application of a 3-6mm full parging layer to the blockwork prior to dry-lining.	Dry-lined load bearing cavity masonry	10.5	5.7
D76	Additional sealing (with tape, mastic and expanding polyurethane foam) and a minor design change at the intermediate floor level.	Light steel frame	13.5	8.9
C17	Application of a full parging layer to the blockwork prior to dry-lining.	Dry-lined load bearing cavity masonry	11.7	6.1
C19	Amended semi-exposed wall detail and application of a full parging layer to the blockwork prior to dry-lining.	Dry-lined load bearing cavity masonry	15.2	7.3
C193	Amended semi-exposed wall detail and additional detailed inspection of blockwork, openings and service penetrations prior to dry-lining.	Dry-lined load bearing cavity masonry	15.0	9.6

Table 6 Reductions in air permeability that were achieved by introducing design-led changes.

75 Data obtained from the Stamford Brook project (Lowe and Bell, 2002) suggests that very high levels of airtightness, by UK Standards, can also be achieved for moderate costs. Besides additional staff training in airtightness awareness, the two main material measures adopted within the dwellings was the application of a thin plaster-based parging coat to the internal blockwork face of all of the external and party walls and high performance windows and doors with improved U values, sealing and trickle vents (see Figure 10). The costs associated with incorporating the parging layer into the dwellings have been estimated at ranging from £277 to £693 depending on the size of the dwelling. Although the specification of high performance windows and doors contributed to improved airtightness the additional cost (£1,535 to £1,673, Roberts, Anderson, Lowe, Bell and Wingfield, 2005) is not primarily related to airtightness, since much of the cost lies in achieving a U-value of 1.3 W/m^2K and the specification of timber instead of PVCu. In principle there is no reason why well sealed windows should add any additional cost since, with the possible exception of the trickle vents, most standard frame units are as airtight as those used at Stamford Brook. The cost of higher performance trickle vents is almost certainly marginal. The resulting mean air permeability of the dwellings tested to date on this site is 4.9 $m^3/(h.m^2)$ @ 50Pa, with the test sample consisting of 31 dwellings in total including 28 houses and three apartments.

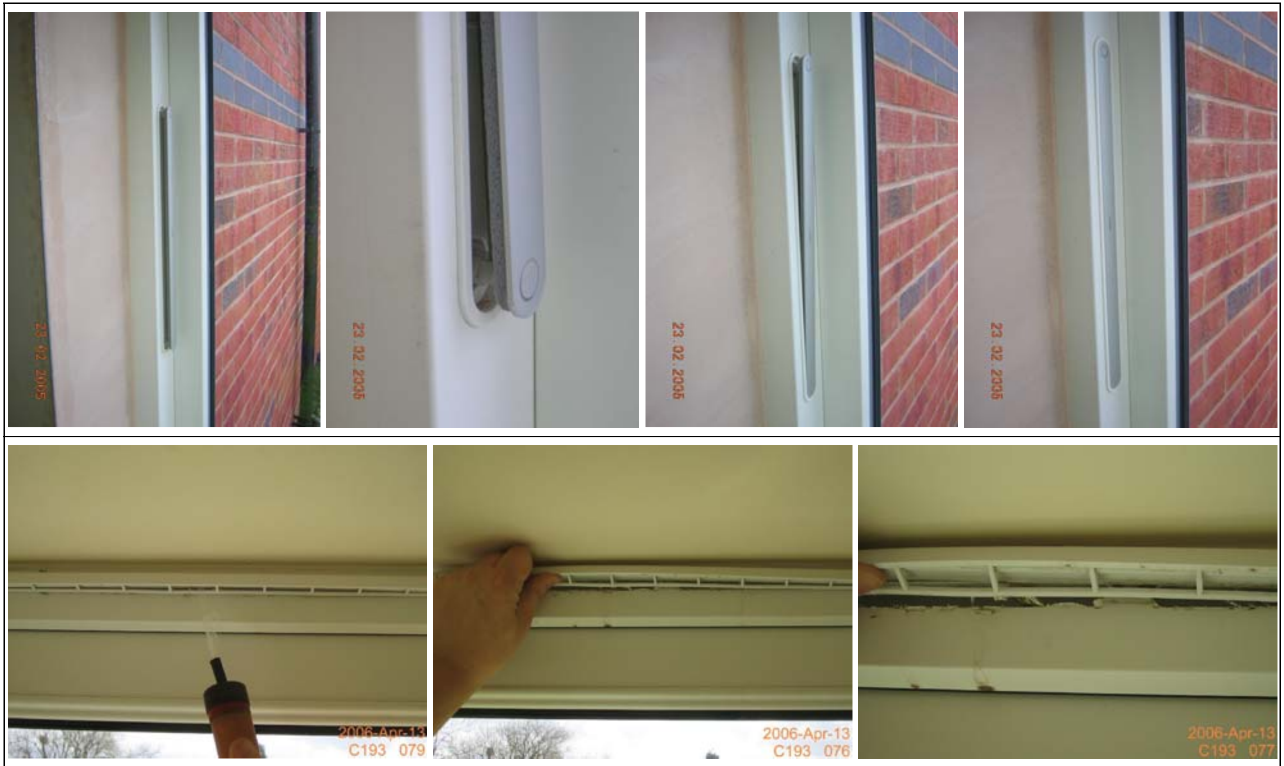

Figure 10 High performance trickle vents with compressible seals fitted at Stamford Brook (top) compared with a typical, significantly less airtight example observed during this project (below).

Proposals for Pressure Testing

76 It is clear from the previous discussions that there are a number of limitations associated with the pressure testing regime that is currently incorporated within ADL1A 2006. In order to address a number of these limitations, we have proposed three possible approaches to improving the testing regime contained within ADL1A 2006: These approaches are intended to represent three distinct methodological approaches to incorporating a pressure testing regime into ADL1A 2006. The approaches proposed are as follows:

a) Direct quality control.

b) Indirect quality control.

c) Compulsory pressure testing of all new dwellings.

Direct quality control

77 This option would follow the approach established in ADL1A 2006 but with considerable revision. These revisions would concentrate on improving the nature of the sampling regime and the guidance given on pressurisation testing. The amendments would be as follows:

a) The current definition of dwelling type that is contained within ADL1A 2006 would be revised so that it is capable of capturing the considerable differences in geometric form and complexity of construction that can exist within dwellings of the same generic form. This would not be a straightforward process since it would require some complex definitions of house type and could be prone to misinterpretation.

b) Clear guidance incorporated within ADL1A 2006 stating how dwellings will be selected for testing. Dwellings would be selected independently at the pre-handover inspection stage to prevent developers undertaking 'additional measures' on only those dwellings that are to be tested. Dwellings would also be selected from various different stages of the construction programme. This is intended to ensure that all of the dwellings on a particular development are constructed to a comparable standard of airtightness.

c) A clear definition within the Approved Document of who can undertake pressure tests and issue certificates. This would prevent any issues regarding variances in interpretation and prevent the same developer being treated differently in different regions of the country. In addition, there should be a requirement within the Approved Document that pressure tests are to be undertaken in an independent manner by a suitably qualified third party. This would prevent developers testing their own dwellings or employing a testing organisation that has a vested interest in the outcome of the test results.

d) As a minimum, the sampling frequency would be altered such that a representative sample of dwellings was tested on every site. This sample would reflect the size of the development, the variety of dwelling types on the development and the method of compliance. The sampling frequency would be increased if non-accredited construction details are adopted as the method of regulatory compliance.

e) Clearer guidance incorporated within ATTMA Technical Standard 1 (2006) on how dwellings should be prepared for testing. For instance, this guidance should state that all external windows and doors are closed, all trickle ventilators are closed, all water traps in sinks, baths, shower trays and WCs are filled with water or temporarily sealed, extract fans are switched off and the extract grilles are temporarily sealed. This is likely to result in separate guidance being developed for domestic and non-domestic buildings. The Technical Standard would also incorporate a statement making it clear that the responsibility for the preparation of the building must be agreed between the contractor/client and the testing organisation prior to any testing work being undertaken.

f) The testing procedure contained within ATTMA Technical Standard 1 is revised, requiring two sets of measurements to be undertaken, one for pressurisation and one for depressurisation. This will prevent developers submitting only the most favourable of the sets of results.

Indirect quality control

78 This option would concentrate efforts on ensuring that a robust and rigorous airtightness quality control system is put in place which is operated alongside but not part of the direct building control process. This would operate as an alternative to compulsory BCB pressure testing requirements. The quality control system would be run and administered by a not-for-profit organisation and developers would be required to pay a plot registration fee for every dwelling built using the system. This would be akin to the system that is currently being run by Robust Details Ltd for compliance with Part E of the Building Regulations. The system would require developers to specify the location of the primary air barrier, identify any potential discontinuities in that air barrier, and provide information on what measures need to be adopted on site to ensure continuity of the air barrier during construction. The details used would be part of a Robust Detail system that ensured good detailing practice.

79 For this approach to be successful it is important that developers put in place a third party quality control system for their design process for new dwellings and for any subsequent design changes. Visual inspections of work in progress and field tests of completed dwellings would then be undertaken using a rigorous quality control sample approach. This would ensure that design standards are being followed, that details have been built as designed and that the dwellings meet the airtightness requirements.

80 It is suggested that, within this framework, there would be scope for larger developers to consider the appointment of a senior quality manager at either regional or national level. The remit of such a role would be to develop robust quality systems to monitor and control the performance of new dwellings not just in terms of airtightness, but also other important measurable performance indicators such as continuity of insulation and acoustics. It is envisaged that the developers would want to develop their own testing expertise and to monitor a set of key performance indicators using a statistically based process control system (SPC). The quality system would ideally link with the product development, design and group purchasing functions.

81 Adopting such an approach may result in fewer pressurisation tests being undertaken than would currently be the case under Part L1A 2006. Under steady state conditions sampling under the Part E Robust Details model is expected to deliver around about 1,000 visual inspections and 2,000 acoustic tests per year. In the first 18 months of operation of the Part E scheme some 1,500

inspections and 1,000 tests have been carried out with testing success rates over 95%.[16] Although any sampling and inspection regime for airtightness may require a different sample size the number of inspections and tests are likely to be of the same order of magnitude. This would represent a significant reduction in the testing requirement but with robust quality control sampling, it could result in a much more robust overall system and one which is much more efficient in the application of testing resources. Such a system would enable the systematic building of a robust database that could be used to improve the system overall and provide evidence that could be applied to future reviews of performance standards.

Compulsory testing of all new dwellings

82 This is the most radical, and expensive of the three approaches proposed and is the only approach that will ensure that the air permeability is within reasonable limits in all new dwellings. This proposal would involve pressure testing all new dwellings after the pre-completion handover inspection by the warranty provider. However, such an approach will require a significant increase in the number of pressure testing teams to meet the required demand.

Conclusions

83 This paper reviews the pressure testing regime incorporated within Part L1A 2006 of the Building Regulations, analyses the logistics associated with compulsory pressure testing and discusses the effect that the testing regime is likely to have on new dwellings.

84 The review highlighted a number of issues associated with the pressure testing regime incorporated within Part L1A 2006. These issues relate to the following:

a) **Dwelling type** — The testing regime incorporated within ADL1A 2006 involves categorising dwellings by their generic form. Such a categorisation is unlikely to capture a number of important house type issues that influence airtightness. For instance, dwellings of the same generic form can display considerable differences in geometry and complexity of construction. The results obtained from Phase 1 of the project and Stamford Brook suggest that differences in geometry and complexity of construction can result in variations in air permeability of up to 4 $m^3/(h.m^2)$ @ 50Pa, with higher levels of air permeability being consistently observed in those dwellings containing the most complex detailing. The results also suggest that the issues associated with geometry and the complexity of the construction may have a much greater influence on the eventual airtightness of a dwelling than those issues associated with generic form alone.

b) **Dwelling selection** — There is little guidance given within ADL1A 2006 relating to dwelling selection. For instance, no advice is given relating to dwelling notification. Depending upon when developers are notified of the dwellings to be tested, there may be scope for additional measures to be undertaken on the selected dwellings to ensure that they meet the required airtightness target. In addition, ADL1A 2006 suggests that a significant proportion of the dwellings should be tested early on in the construction programme to enable any lessons learnt to be fed back into the construction and design process. However, this approach is based upon the premise that once a developer has demonstrated that the selected dwellings meet a particular air permeability target, the remaining dwellings will also be constructed to the same standard of airtightness. Anecdotal evidence obtained from Phase 3 of the project suggests that this is unlikely to be the case as there was a noticeable difference in the quality of workmanship in relation to airtightness in those dwellings that were participating in the project and those that were not. Consequently, the airtightness performance of those dwellings that are selected to be tested is unlikely to be representative of the performance of other dwellings of the same type on the same development.

c) **Registered testers** — Local authorities are authorised to accept a certificate from a person who is registered by BINDT in respect of pressure testing for the airtightness of dwellings. However, there is no clear guidance given about who else can undertake the tests and issue

[16] It is inevitable that testing rates will take time to build up since there is a significant time lag between plot registration and completion. The RSD Ltd business model indicates that steady state conditions will be reached in around two years. The data for the first 18 months (Robust Details Ltd, 2006) would indicate that good progress is being made towards their inspection and testing targets.

certificates. It will therefore be up to individual BCBs to decide who is technically competent to undertake the tests and issue certificates. This may lead to issues relating to equity and fairness if BCBs adopt different practices and developers are treated differently in different parts of the country.

d) **Independence of the pressure testing** — Currently, there is no specific requirement for pressure tests to be carried out by an independent testing organisation. Consequently, a series of issues may arise if developers are allowed to test and issue certificates for their own dwellings.

e) **Sampling frequency** — Sampling frequencies outlined in ADL1A 2006 are likely to result in a small non-random number of dwellings tested on each development. The sample sizes involved are also unlikely to be statistically significant; therefore, the results obtained may not be indicative of the airtightness performance of other dwellings on the development. The results obtained from this project suggest that the proportion of dwellings requiring testing is likely to vary considerably between developments, in this case between 1% and 14%, and will depend upon the number of dwelling types on the development and the method of compliance. In addition, where apartments are being constructed, a significantly greater proportion of apartments are likely to require testing than other dwelling types. This is despite the fact that apartments tend to be intrinsically more airtight than other dwelling forms of equivalent area.

f) **Preparation for testing** — Experience obtained from Phase 1 and Phase 3 of this project suggests that developers appear to be unaware of how to prepare a dwelling for a pressure test and, in some instances, tests have had to be abandoned as the dwelling was not in a finished state. The incidence of unprepared and unfinished dwellings being presented for testing is likely to reduce in the medium to long term as developers become accustomed to pressurisation testing and realise that they will have to pay for the service irrespective of whether the dwelling is tested or not.

g) **Air permeability target** — The design air permeability target for many dwelling designs is likely to be considerably lower than the maximum level of 10 $m^3/(h.m^2)$ @ 50Pa specified within ADL1A 2006, particularly where fuels with a higher carbon intensity than gas are to be used. Modelling work suggest that an average air permeability of around 7, 5 and 3 $m^3/(h.m^2)$ @ 50Pa would need to be achieved by a developer to meet a design air permeability target of 10, 7 and 5 $m^3/(h.m^2)$ @ 50Pa, respectively, assuming a 10% initial failure rate. Although an average air permeability of 5 $m^3/(h.m^2)$ @ 50Pa has been measured in new UK dwellings (measured at Stamford Brook), achieving an average air permeability of around 3 $m^3/(h.m^2)$ @ 50Pa will be technically demanding. Such levels of air permeability are likely to require a fundamental rethink of airtightness design in new dwellings if they are to be consistently achieved in mass UK housing. Results from Stamford Brook also suggest that even when a demanding design air permeability target has been set, the air permeability of the dwellings constructed on site may increase over time due to a deterioration in site workmanship and quality.

h) **Testing procedure** — The way in which the dwelling is tested can influence the eventual levels of air permeability achieved and bias the results. The approved procedure for pressure testing a dwelling, ATTMA Technical Standard 1 (ATTMA, 2006), states that valid test results can be achieved by: pressurising the dwelling; depressurising the dwelling; or pressurising and depressurising the dwelling and averaging the results. The results obtained from Phase 1 and Phase 3 of the project indicate that the results obtained by depressurising the dwelling only are, in most cases, lower than the corresponding pressurisation test results. This suggests that more favourable test results could be achieved by adopting this method of testing. In addition, the difference between the pressurisation and the depressurisation results can be as much as 14%. This is consistent with the figures quoted by CIBSE (2000) and Stephen (1998).

85 The number of new dwellings requiring testing each year will be dependent upon the strategy adopted for regulatory compliance by the developer, the size of the development and the variation in dwelling types across the developments. Based on construction statistics for 2004 and 2005, it is estimated that the number of dwellings that will require testing will fall in the range 25,000 to 42,000 dwellings per year. The figure is likely to lie towards the higher end of this range due to re-tests and the trend towards constructing more multi-dwelling buildings.

86 Wind speed can have a significant effect on the accuracy of pressure tests. ATTMA's Technical Standard 1 (ATTMA, 2006) standard test procedure allows tests to be carried out only when wind speeds are below 6 ms^{-1}. An approved extended test procedure is also available for wind speeds

greater than 6 ms^{-1}. Hence wind conditions can have a major effect on the number of hours when a reliable pressure test result is achievable. Assuming a working day from 8am to 6pm, an analysis of the CIBSE/Met Office weather data for a semi-empirical Test Reference Year (corrected to a height of 2 m above ground level) suggests that the average maximum number of hours available for testing in a year over the 11 sites incorporated within the Test Reference Year would be reduced by just over 7%. This analysis assumes a Terrain Category III, which simulates a suburban location. The number of hours available for testing are likely to reduce further as tests are undertaken in more exposed locations, the temperature differences experienced in winter increase the incidence of less reliable test data and time is spent travelling between sites in order to undertake tests in different locations on the same day.

87 Taking into account seasonal trends in dwelling completions and the number of hours available for testing, the average number of tests that are required to be undertaken in a single day could exceed 200 or fall below 80, depending upon the month of the year. Assuming that an average of three to four tests could be undertaken by a single testing team in a day, a minimum of 20–25 testing teams would be required in January to cover the testing requirements, rising to a minimum of 50–65 testing teams in December. These figures would double if it was only possible for the testing team to undertake two tests per day.

88 The commercial charge for undertaking a single pressure is test is of the order of £500 excluding VAT plus travel and subsistence. Additional tests performed on the same visit are of the order of £100 per test excluding VAT.

89 Limited data are available on the costs associated with undertaking remedial work in dwellings that have failed a pressure test. Experience obtained at Derwentside suggests a cost in the region of £1,200 per dwelling. However, there are no reliable data available that would enable a firm estimate to be provided.

90 Three separate approaches have been identified to address a number of the limitations previously identified with the pressure testing regime that is currently contained within ADL1A 2006. These are as follows:

a) **Direct quality control** — This approach involves making a number of amendments to the current edition of ADL1A 2006. These amendments concentrate on providing clearer and more detailed guidance on a range of factors such as dwelling type, dwelling selection, registered testers and dwelling preparation. In addition, it is also suggested that the current sampling frequency should be increased such that a representative sample of dwellings are tested on each development.

b) **Indirect quality control** — This approach involves putting in place an airtightness quality control system as an alternative to compulsory pressure testing. A random sample of visual inspections and pressure tests of completed dwellings would then take place to ensure that the dwellings are built as designed and meet the airtightness requirements of the Approved Document. Care would need to be taken with such an approach to ensure that the sample sizes chosen are representative of the dwellings being constructed using this approach and a greater proportion of dwellings are tested than would otherwise be the case under the current edition of Part L1A 2006.

c) **Compulsory testing** — This is the most radical of all three approaches and would involve the compulsory pressure testing of all new dwellings. This is the only approach that would ensure that the air permeability of all new dwellings is within reasonable limits.

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Appendix A

Approved Document L1A Criterion 4 — Number of Pressure Tests to be Performed

Number of dwelling pressurisation tests required under ADL1A.

Site and Dwelling Type		No. of Dwellings	Non-accredited details No. to test (ADL1A)	Non-accredited details % to test (ADL1A)	Accredited details No. to test (ADL1A)	Accredited details % to test (ADL1A)
Site A						
Mid-terrace		24	2	8.3	1	4.2
End-terrace		21	2	9.5	1	4.8
Semi-detached		14	2	14.3	1	7.1
Detached		8	2	25.0	1	12.5
Apartments 2 Blocks	Top floor	4	2	50.0	2	50.0
	Mid floor	4	2	50.0	2	50.0
	Ground floor	4	2	50.0	2	50.0
Combination dwelling type		1	1	100.0	1	100.0
Total		80	15	18.8	11	13.8
Site B						
Mid-terrace		8	2	25.0	1	12.5
End-terrace		14	2	14.3	1	7.1
Semi-detached		22	2	9.1	1	4.5
Detached		28	2	7.1	1	3.6
Apartments 2 Blocks	Top floor	4	2	50.0	2	50.0
	Mid floor	4	2	50.0	2	50.0
	Ground floor	4	2	50.0	2	50.0
Combination dwelling type		2	1	50.0	1	50.0
Total		86	15	17.4	11	12.8
Site C						
Mid-terrace		75	4	5.3	1	1.3
End-terrace		74	4	5.4	1	1.4
Semi-detached		48	3	6.3	1	2.1
Detached		81	5	6.2	1	1.2
Total		278	16	5.8	4	1.4
Site D						
Mid-terrace		4	2	50.0	1	25.0
End-terrace		6	2	33.3	1	16.7
Semi-detached		34	2	5.9	1	2.9
Detached		46	3	6.5	1	2.2
Apartments 4 Blocks	Top floor	18	6	33.3	4	22.2
	Mid floor	16	4	25.0	4	25.0
	Ground floor	18	6	33.3	4	22.2
Combination dwelling type		1	1	100.0	1	100.0
Total		143	26	18.2	17	11.9
Site E						
Apartments 4 Blocks	Top floor	32	8	25.0	4	12.5
	Mid floor	64	8	12.5	4	6.3
	Ground floor	32	8	25.0	4	12.5
Total		128	24	18.8	12	9.4
Overall		715	96	13.4	55	7.7

Appendix B

Phase 1 and Phase 3 Pressurisation Test Results

Phase 1 Pressurisation Test Results

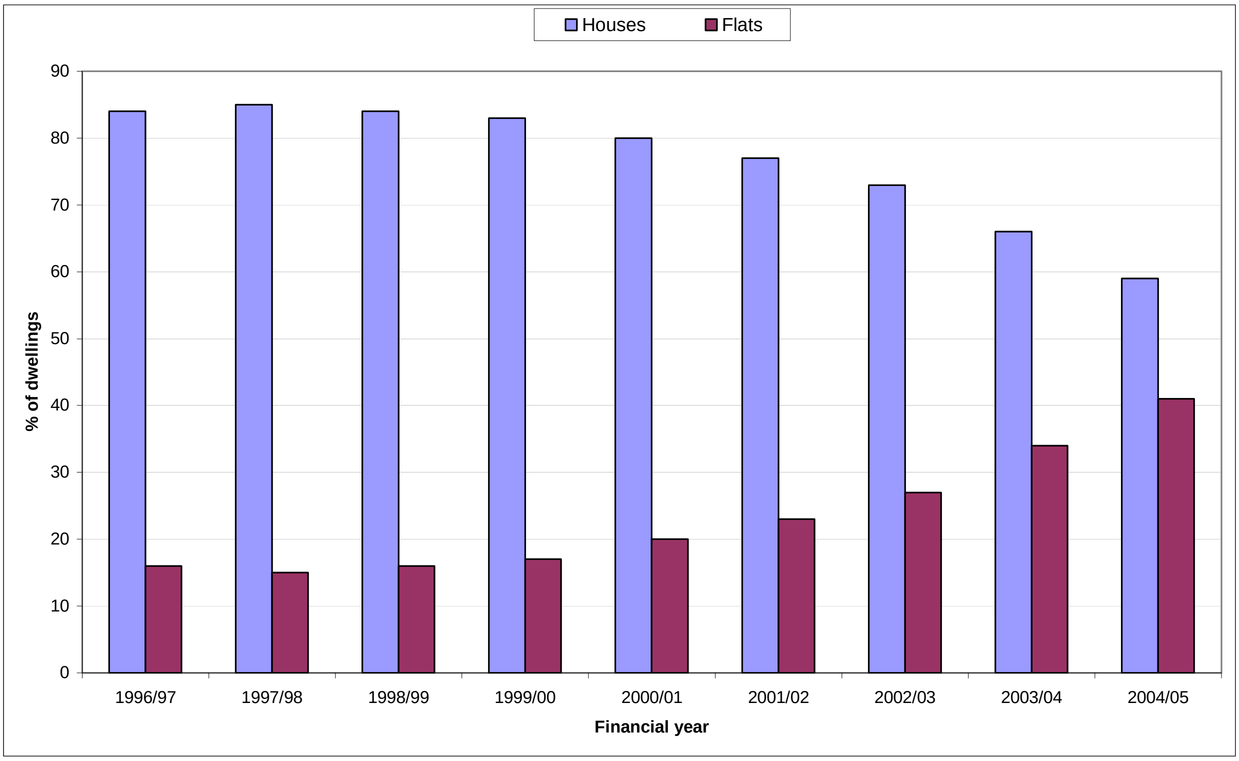
Developer	Dwelling	Pressurisation test ($m^3/(h.m^2)$ @ 50Pa)	Depressurisation test ($m^3/(h.m^2)$ @ 50Pa)	Mean permeability ($m^3/(h.m^2)$ @ 50Pa)
A	9	13.95	13.86	13.91
	11	15.46	14.66	15.06
	12	12.12	12.49	12.31
	13	14.51	14.16	14.33
	14	15.33	15.71	15.52
B	79	8.96	9.02	8.99
	80 (pre-completion)	15.70	15.32	15.51
	80 (completed)	11.76	11.20	11.48
	81	10.11	9.66	9.89
	82	12.04	11.53	11.79
C	236	16.81	16.26	16.53
	237	14.08	13.98	14.03
	238	11.17	11.02	11.09
	239	12.46	11.90	12.18
	240	12.11	11.40	11.76
D	39	12.82	12.61	12.72
	42	15.55	16.37	15.96
	43	12.10	11.44	11.77
	44	14.58	14.94	14.76
	59	12.50	11.76	12.13
E	CG01	5.13	4.90	5.01
	CG02	4.37	4.32	4.35
	C201	4.79	4.43	4.61
	C202	3.94	3.96	3.95
	C301	7.46	7.38	7.42
	C302	5.53	4.97	5.25

Phase 3 Pressurisation Test Results

Developer	Dwelling	Pressurisation test ($m^3/(h.m^2)$ @ 50Pa)	Depressurisation test ($m^3/(h.m^2)$ @ 50Pa)	Mean permeability ($m^3/(h.m^2)$ @ 50Pa)
A	64	10.68	10.19	10.44
	65	8.44	7.67	8.06
	66	8.01	7.96	7.98
	79	6.45	6.59	6.52
	80	5.54	5.65	5.59
B	14	9.33	8.15	8.74
	16	5.50	5.69	5.60
	17	5.61	5.76	5.69
	21	7.31	7.27	7.29
	22	7.44	7.31	7.37
C	193	9.82	9.45	9.64
	194	15.90	14.02	14.96
	17 (1st fix)	16.57	16.37	16.47
	17 (2nd fix)	7.64	7.37	7.51
	17 (completed)	6.17	5.95	6.06
	18	9.13	9.69	9.41
	19 (1st fix)	15.71	15.76	15.74
	19 (2nd fix)	11.39	11.58	11.48
	19 (completed)	7.32	7.29	7.30
	20	10.77	10.12	10.45
	21	10.40	9.80	10.00
D	73	13.39	13.22	13.31
	74	12.62	12.80	12.71
	75	10.97	10.22	10.60
	76 (pre-completion)	10.48	9.70	10.09
	76 (completed)	9.23	8.56	8.89
	96	11.52	10.77	11.14
E	AG01	6.56	6.57	6.56
	AG02	4.98	4.74	4.86
	A201	7.11	6.89	7.00
	A202	5.47	5.36	5.41
	A301	6.24	6.05	6.15
	A302	4.92	4.96	4.95

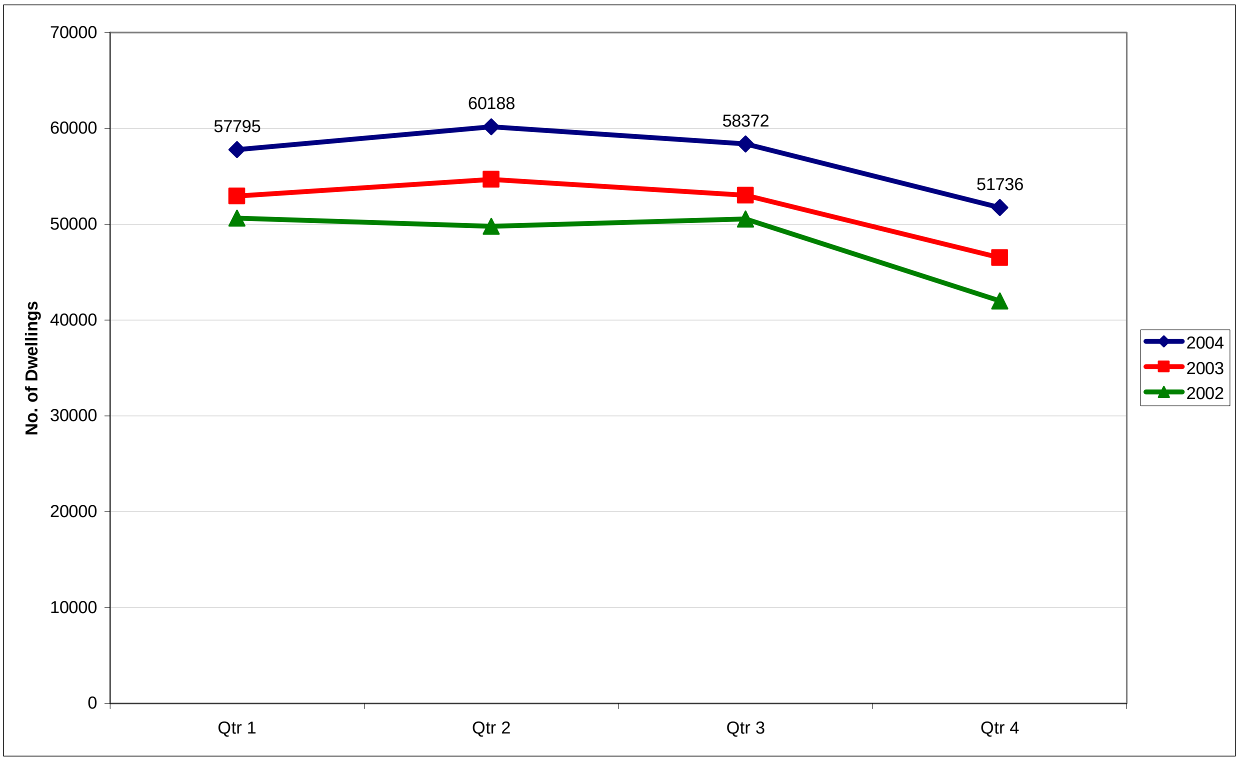
Appendix C

Housebuilding Data from ODPM Live Tables

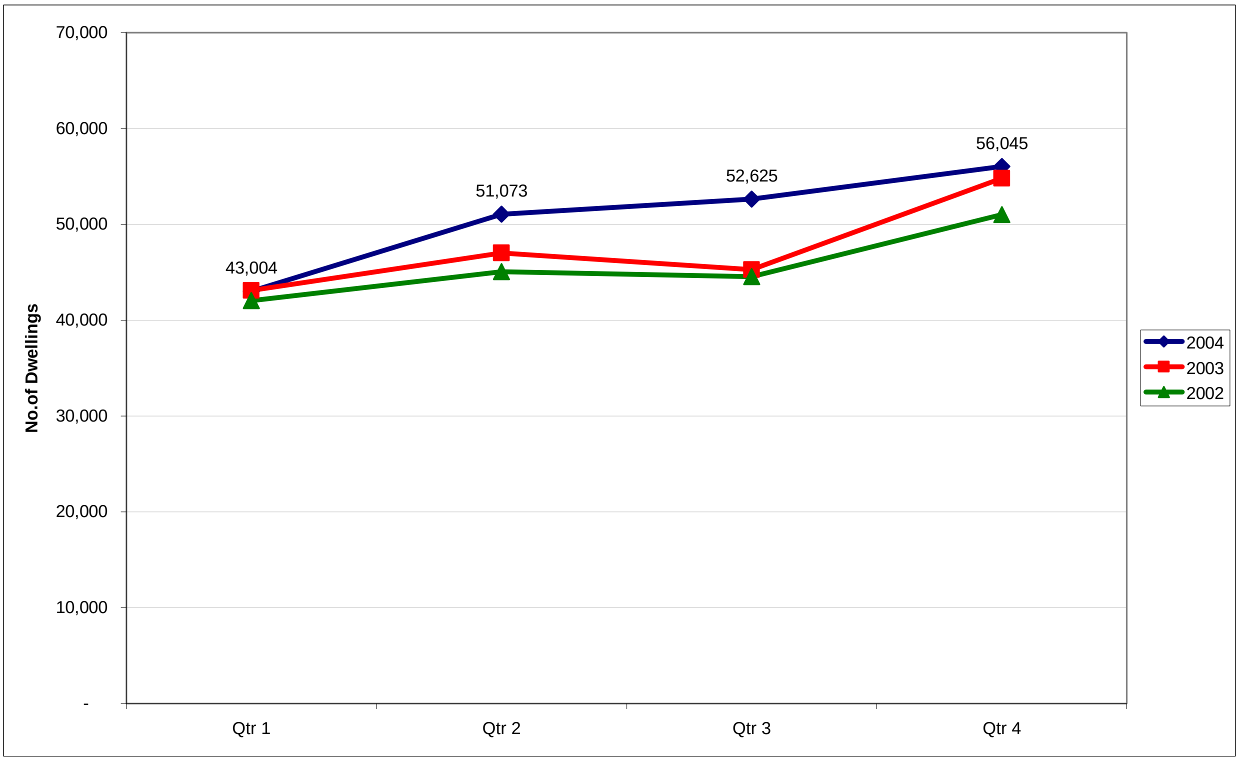


Source: ODPM Live Table 251 – Comparison of annual UK dwelling completions by type.

Source: ODPM Live Table 232 – 2004/5 dwelling completions by type and region.



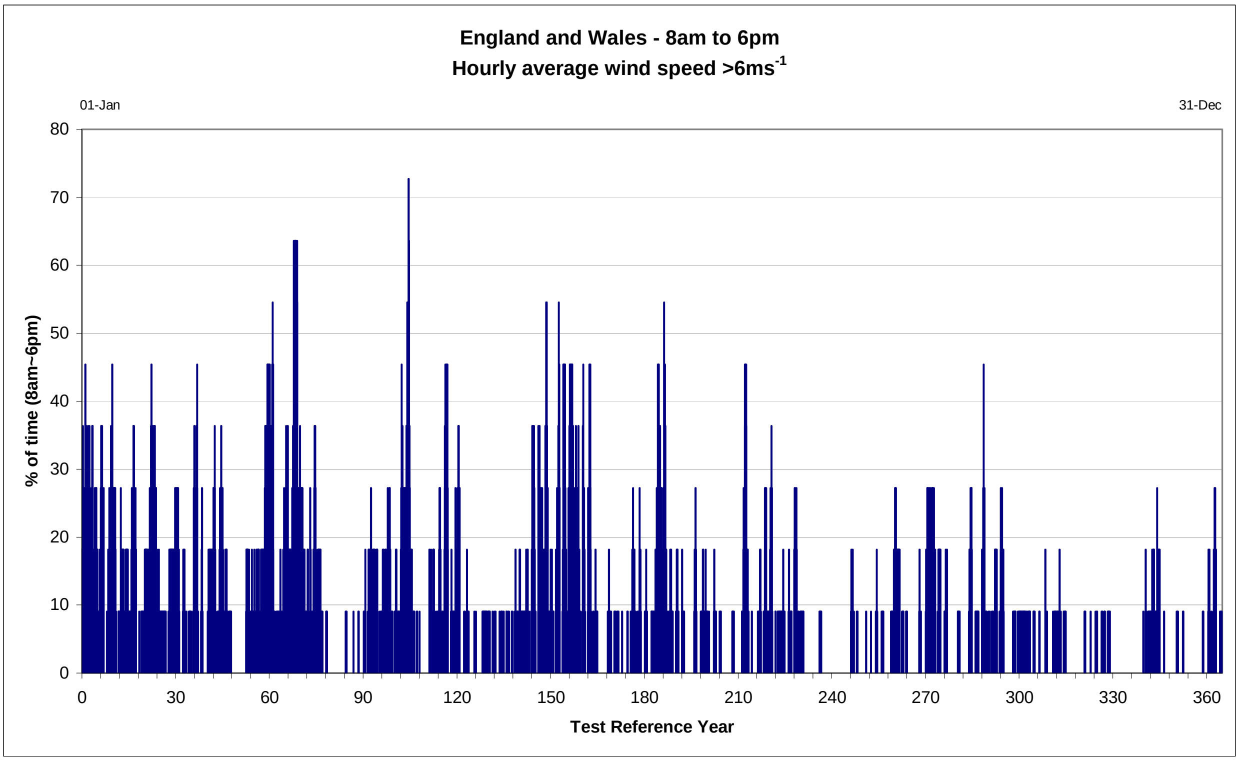
Source: ODPM Live Table 211 – UK dwelling starts per quarter.



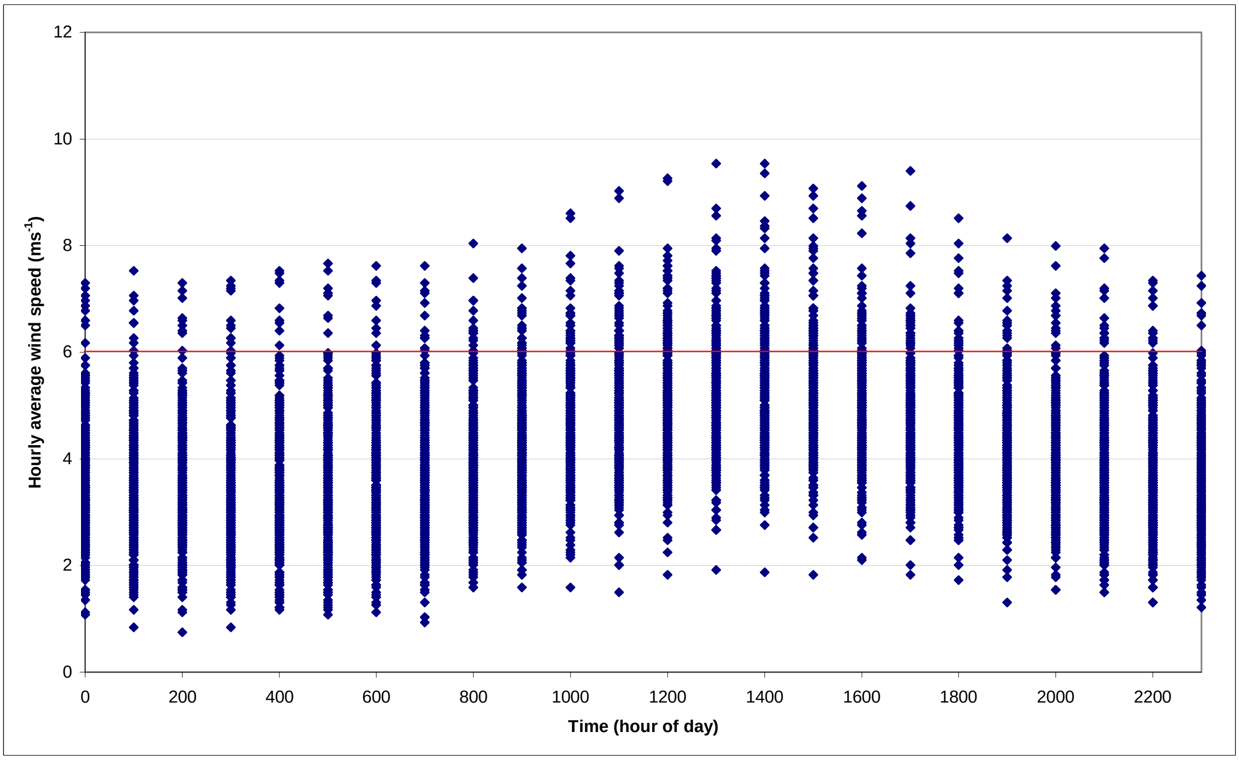
Source: ODPM Live Table 211 – UK dwelling completions per quarter.

Appendix D

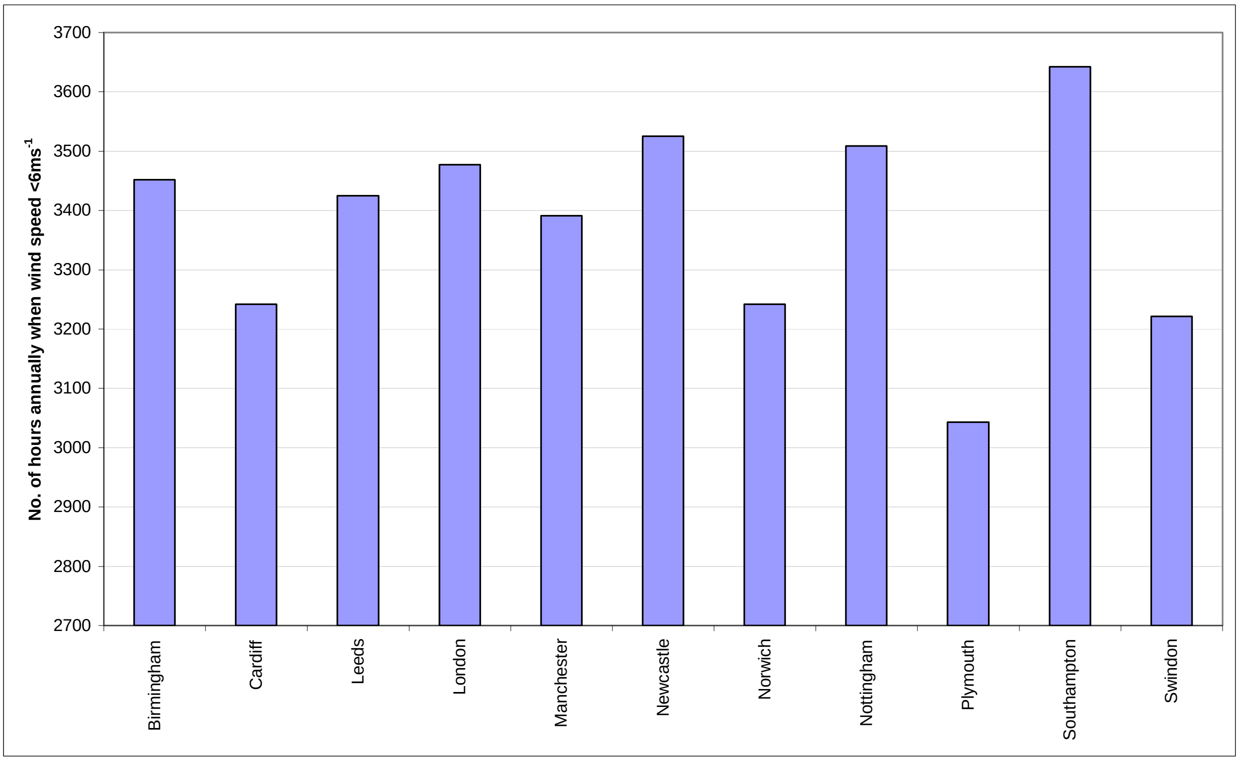
CIBSE/Met Office Hourly Weather Data



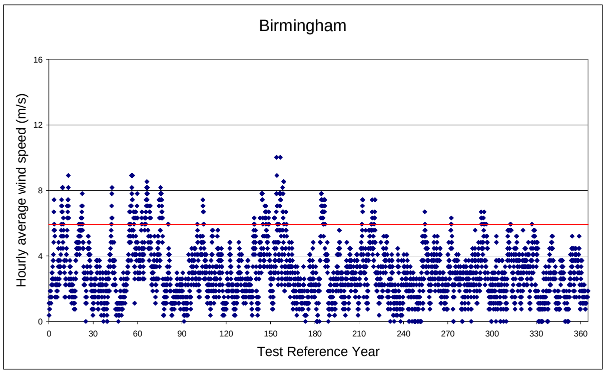
Source: CIBSE/Met Office Hourly Weather Data – 11 vertical lines for each day, one for each weather station, all normalised to 2 m above ground and Terrain Category III.

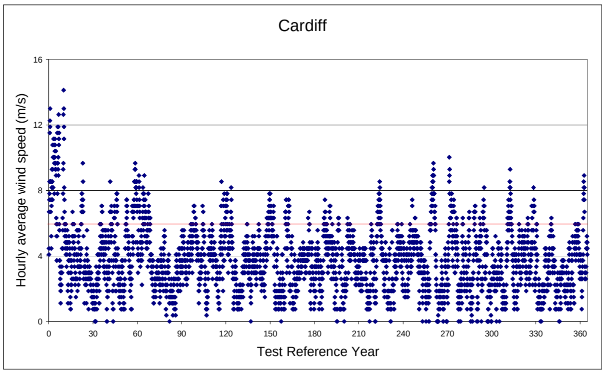


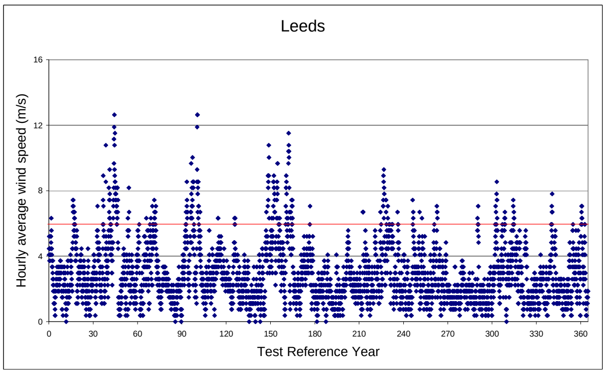
Source: CIBSE/Met Office Hourly Weather Data – England and Wales, hourly average wind speed.

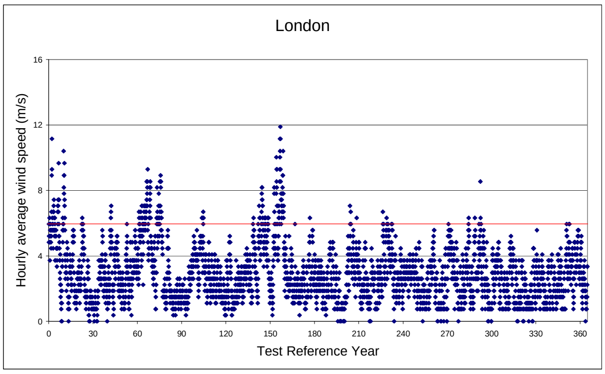


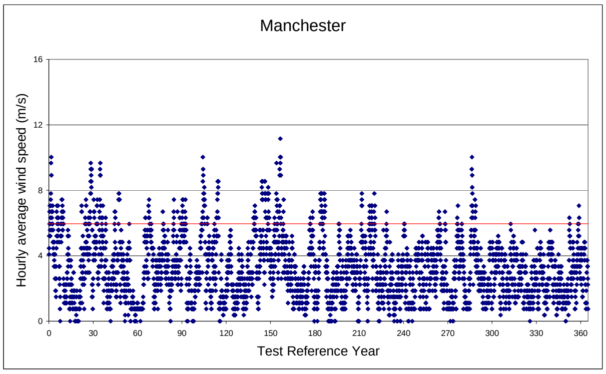
Source: CIBSE/Met Office Hourly Weather Data – Annual number of hours between 8am and 6pm when wind speed <6 ms^{-1}, all normalised to 2 m above ground and Terrain Category III.

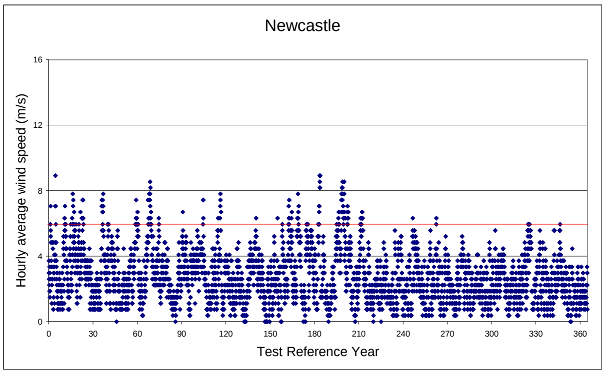

Birmingham
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year

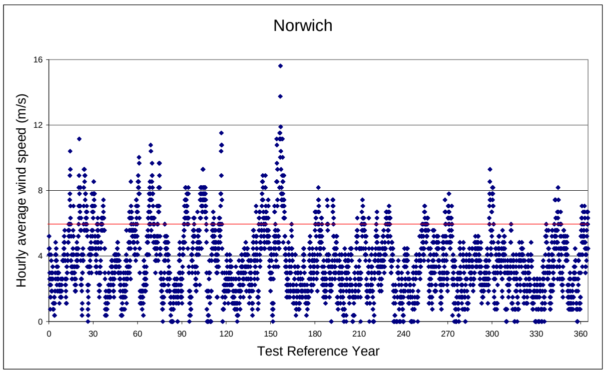

Cardiff
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year

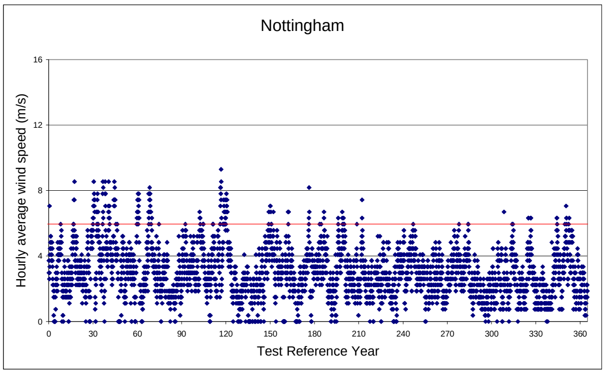

Leeds
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year

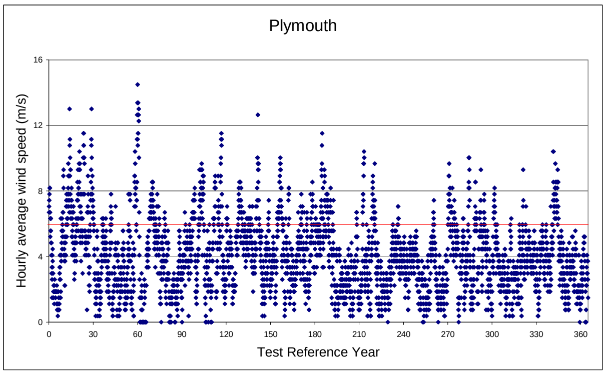

London
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year

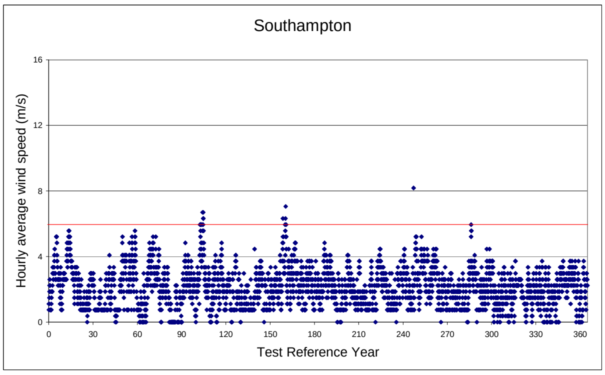

Manchester
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year

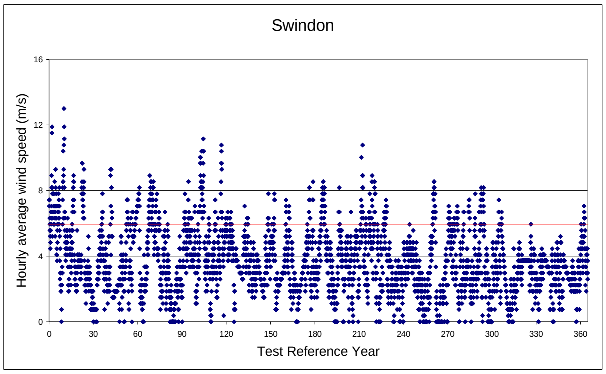

Newcastle
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year


Norwich
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year


Nottingham
Hourly average wind speed (m/s)
0
4
8
12
16
0 30 60 90 120 150 180 210 240 270 300 330 360
Test Reference Year







Source: CIBSE/Met Office Hourly Weather Data — Hourly average wind speed between 8am and 6pm, normalised to 2 m above ground and Terrain Category III.

Appendix E

Pressure Test Equipment

Domestic pressure test equipment

Item	Approximate cost (plus VAT & carriage) £
Blower door system (including frame, controller and gauge)	2,500
Additional low-flow ring	50
Fan case	100
Airtightness test and analysis software	150
Atmospheric data meters (anemometer, thermometer, RH meter, barometric pressure gauge)	200
Sealing film/tape	30
Smoke puffer/pencil	40
Access equipment (ladder/steps)	100
Extension cable + RCB	30
Total	**£3,200**
Plus: (additional equipment) Laptop computer, camera, transformer, PPE kit.	

Appendix F

Time and Motion Study

	Task	Time Taken (man.minutes)		
		Min.	Max.	Av.
1	On arrival at site			
	Sign In	4	8	6
	Site Induction	0	40	4
	Gain access to dwelling(s)	1	2	2
	Wait for cleaners/decorators/etc. to vacate premises	0	14	2
	Total	5	50	14
2	Pre-test requirements			
	Initial inspection of dwelling readiness for testing	6	19	9
	Unload car	4	6	5
	External temperature/RH/wind-speed measurements	2	8	5
	Assemble test equipment	10	16	14
	Extraordinary items: a, b	0	22	2
	Total	22	37	35
3	Pre-test inspection			
	Check/Close all external, wedge open internal doors	1	5	4
	Check/Close windows and trickle vents	1	4	3
	Check/Fill drainage traps	1	4	3
	Check extracts (inc. vents & cooker hood) and seal if required	3	10	7
	Check combustion appliances shut down	1	1	1
	Total	8	24	18
4	Perform test			
	Initial internal temperature and RH measurements	1	4	2
	Calculate baseline figure	1	3	2
	Depressurisation test (extended if windy)	9	29	17
	Pressurisation test (extended if windy)	8	23	15
	Final internal temperature and RH measurements	1	1	1
	Extraordinary item: c	0	12	1
	Total	22	67	38
5	Additional tasks and measurements			
	Perform minor alterations and re-test (if necessary)	0	21	2
	Perform minor alterations and take spot readings (if necessary)	0	15	2
	Leakage detection (if required)	29	35	32
	Total	29	56	36
6	Post-test			
	Remove all temporary sealing	3	7	5
	Dismantle test equipment	6	16	11
	Final check of dwelling	1	1	1
	Load car	6	12	7
	Total	16	30	24
7	On departure from site			
	Return keys	0	4	2
	Inform site management of results and findings	16	34	25
	Sign out	1	1	1
	Total	17	39	28
8	Total Permeability-Test Time	119	302	191
Comments:				
	Max. time taken totals are measurements for an actual test, not a sum of timings for all tasks in that section. Calculation of envelope was performed prior to arrival on site in all cases.			
Extraordinary items:				
a	Clean around threshold to get good seal around blower door			
b	Acquire electricity & water supply			
c	Tape up loft hatch as it was blowing open under pressurisation			

Timings are based on nine pressure tests performed by teams of Leeds Met research staff between January and March 2006, covering a range of house types and locations, with either two or three team members performing each test.