Does compulsory airtightness testing result in airtight buildings or creative ways of passing the test?

DR JENNY LOVE, DR JEZ WINGFIELD, DR CLIFF ELWELL
UCL Energy Institute, University College London, WC1H 0NN
jenny.love@ucl.ac.uk

Abstract

The ATTMA airtightness testing competent person scheme collects pressure test data from the majority of new build dwellings in the UK. A dataset of around 150,000 dwellings is available for analysis and shows surprising results. Measured airtightness for the first recorded test per dwelling is disproportionately concentrated at sharp peaks related to design targets. This is contrary to the skewed normal distribution expected from a process of building, testing, remedial works to seal the primary air barrier and retesting, and indicates that short term measures are being undertaken to pass the test that may not ultimately result in airtight buildings. We reflect on the purpose of airtightness targets and suggest ways in which the regulatory environment could encourage good design and consistent quality of construction.

Keywords ATTMA, airtightness, testing, building regulations, data

1.0 Introduction

Airtightness testing of new dwellings has been compulsory for new dwellings in the UK since 2006 (1). Compulsory testing was incorporated into the Building Regulations after evidence from measurements carried out in the 2000s (2-4) indicated that dwelling air permeabilities could be much higher than design assumptions, varying widely between buildings, and that therefore the existing regulatory process of robust construction details in use prior to 2006 (5) was ineffective on its own in terms of controlling the air permeability of new build dwellings to an acceptable level (6).

The theory for compulsory testing had previously been advocated by Lowe et al (7) in 2000. The authors argued that compliance with the Regulations should depend on a measured rather than modelled value achieving or surpassing a certain target permeability, so that construction practices and processes would be forced to produce consistently airtight buildings. Setting appropriate targets and requiring all or a high percentage of buildings to adhere to them should then both narrow the distribution and shift its mean to well below the target. The anticipated change in the distribution of airtightness of new dwellings upon imposition of compulsory testing with a limit of 10 $m^{3/}h.m^2$ was illustrated by Lowe et in Figure 1, using a simple scaling rule to transform the old distribution into the new.

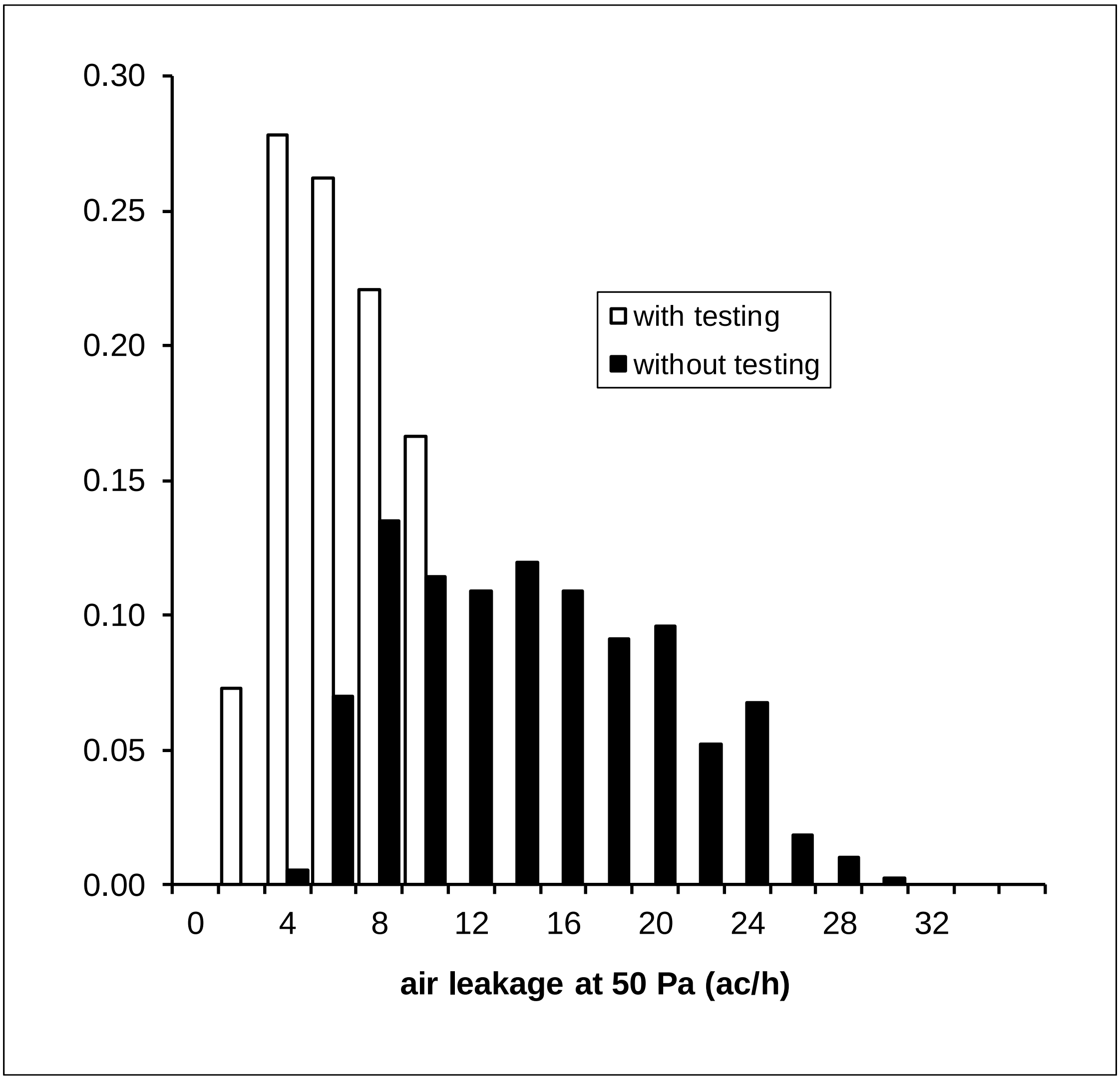

Figure 1. Intended effect of compulsory airtightness testing. Reproduced from (7) with permission.

Two routes to achieving the design target were considered by Lowe et al in their argument: ensuring construction methods lead to sufficient airtightness when a dwelling is built, or not doing this and missing the target upon first test but undertaking remedial works to seal the building retrospectively until it passes a retest. These two methods were, and still are, both permitted in the Regulations. Lowe et al reasoned that proper remedial works addressing the primary air barrier would be prohibitively expensive for housing developers, and would therefore incentivise the development of processes that were more likely to achieve airtight construction first time without the need for remedial measures. Thus, the aim of compulsory testing in the Building Regulations was to improve airtightness and consistency through better construction (4).

The blower door pressure test is the mandated airtightness test method for the measurement of air permeability in the UK. A protocol developed by the Air Tightness Testing and Measurement Association (ATTMA) is used to standardise the test procedure (8). This describes how the building should be prepared, how the test should be conducted and what data should be recorded.

Four years after the introduction of compulsory testing, statistical analysis on several hundred test results presented a positive picture of airtightness progress (9).

However, small scale evaluation studies cast the quality of some of the data used in large scale analyses into doubt. Researchers replicating airtightness tests to check the values reported in regulatory tests have found their own tests to yield significantly higher air permeabilities than the compliance tests. For example, Johnston et al reported results 14-43% higher a month after the compliance test (10), UCL reported results 58-75% higher a week afterwards (11), and Littlewood et al report a result 83% higher four years after the regulatory test (12).

The causes of discrepancy between regulatory test result and researcher replication vary. Evidence is given in one case of ‘potential falsified design documentation’ (12). In other cases the discrepancy is thought be a result of two categories of post-construction sealing measures undertaken during the test. The first category will here be termed *secondary sealing* (11), referring to where sealant is quickly applied to the secondary air barrier (for example by sealing around the edges of skirting board). The circumstances of such secondary sealing implies that seals are likely applied with haste and a lack of proper preparation, and could potentially result in premature failure of some of the seals, leading to an increase in air permeability over time. The second category of post-construction sealing will here be termed *temporary sealing*, referring to where excessive amounts of adhesive films and tapes are used to progressively seal leakage pathways solely for the purposes of passing the compliance test and subsequently removed (7,10). Both secondary and temporary sealing could potentially be applied during the test itself: this will be termed *in-test sealing*. The ATTMA protocol specifies which types of temporary sealing are permitted and requires testers to state any deviations made from this for the purposes of the test.

As a result of the above, questions have been raised regarding the competence of testers, quality of test results (13) and longevity of airtightness (11). However, steps have been taken to improve test quality. ATTMA introduced a competent person scheme which now covers around 76% of registered testers operating in the UK (14). Furthermore, in 2015 mandatory lodgement was introduced for all testers in the scheme. As such, a large dataset of test results has recently become available for analysis: this dataset is the focus of the analysis presented below.

2.0 Data

2.1 Method of cleaning data

The ATTMA dataset provided to the authors contains 192,731 records collected from August 2015 to December 2016. Records comprise of a test result with accompanying metadata including the inputs to the air permeability calculation (8): flow coefficient, flow exponent and dwelling envelope area. The dataset of test results was filtered to remove duplicate lodgements and calculation inputs either physically implausible or falling outside of the range permitted in the ATTMA test protocol. In addition, a check was carried out for each site to ensure that the reported air permeability test result at 50 Pa could be recreated from the lodged values for envelope area, air leakage coefficient and exponent using the standard power law equation (8). Reported tests with input information missing or those in which the recreated result and reported result differed beyond rounding error were dropped.

The latter filter only eliminated 5% of tests, showing that the majority of test results are consistent with their recorded inputs.

158,418 tests remained after the cleaning process. Further processing was carried out on the cleaned dataset to map between test IDs and dwelling IDs, since a single dwelling can be associated with multiple tests where lodged re-tests or pre-completion check tests (known as pre-tests) have been carried out. Dwellings in the dataset do not have a unique address or ID, therefore the combination of plot number and postcode was used as a proxy for dwelling ID. Test date is also not present in the dataset, so to infer the sequence of tests for a dwelling the test results were ranked from highest to lowest and the highest taken to be the first test and the lowest the last. It was found that 92% of dwellings have only one recorded test.

The two further processing steps set out above – assigning each dwelling a unique ID and estimating the order of tests – introduce a small amount of error into the analysis. ATTMA are currently implementing changes to the lodgement process, firstly to provide more certainty on which dwellings have multiple tests and the temporal sequence of results for those which do, and secondly to detect implausible inputs or results at the time of lodgement.

2.2 Two important pieces of metadata

A notable piece of metadata in the ATTMA dataset is the design air permeability target for each test. The distribution of air permeability targets is shown in Figure 2. The distribution is dominated by a peak at 5 m^3/h.m^2, which could reflect that 5 is the default air permeability value used in the notional building recipe to set the carbon emission target under current new dwelling energy legislation in England (15). Other countries in the UK may use different notional building recipes to set their regulatory carbon emission target, although the ATTMA dataset is dominated by results from England. For example, the air permeability value used in the current notional building recipe for new dwellings in Scotland is 7 m^3/h.m^2 (16).

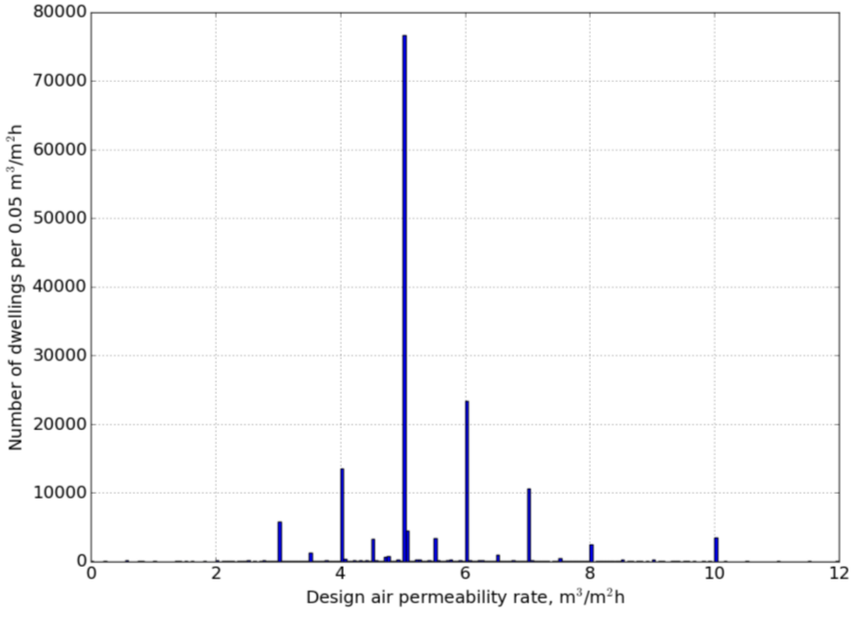

Figure 2. Design air permeability targets for the ATTMA dataset.

Another important piece of metadata provided for each dwelling is the intended ventilation strategy. The stated ventilation systems and their proportions in the ATTMA sample are given in Table 1. The frequency of the most common air permeability design targets from Figure 2 (3,4,5,6 and 7 $m^3/h.m^2$) are grouped by ventilation type in Figure 3.

Ventilation type (Acronym)	Ventilation type (Full)	Proportion of sample with this ventilation strategy
Natural	Natural Ventilation	62%
PSV	Passive Stack Ventilation	< 1%
MEV	Mechanical Extract Ventilation	11%
MVHR	Mechanical Ventilation with Heat Recovery	26%
Other	Other Ventilation System covered by a European Technical Approval. May include for example Positive Input Ventilation (PIV) or hybrid systems	< 1%

Table 1. Ventilation types and prevalence in the ATTMA dataset.

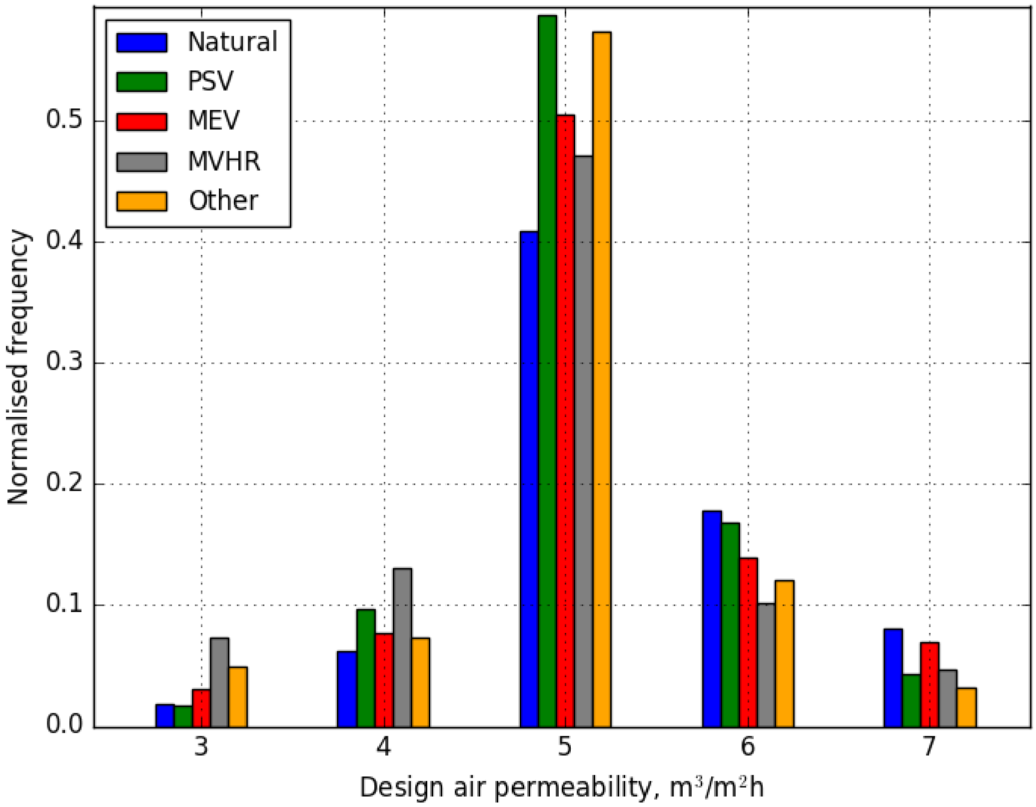

Figure 3. Design air permeability grouped by design ventilation strategy.

Figure 3 indicates that the design air permeability is not significantly influenced by the choice of ventilation strategy.

2.2 Presentation of airtightness data

The outcome of the data cleaning and preparation described in Section 2.1 enables first tests and last tests to be identified. These distributions are shown in Figure 4A and B respectively.

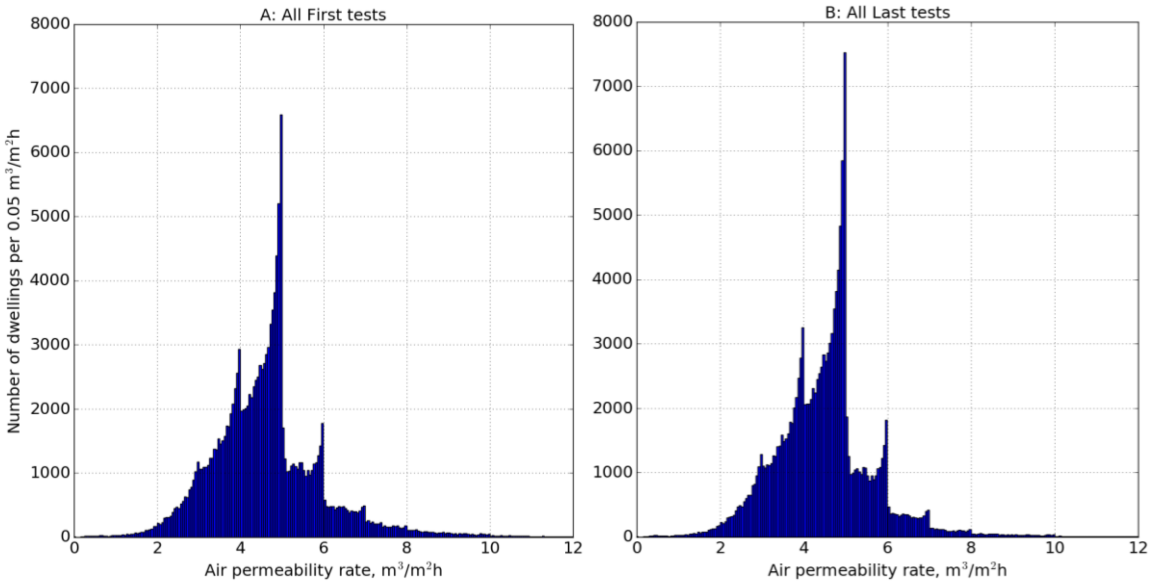

Figure 4. First tests (A) and last tests (B).

Figure 4A and 4B both strongly reflect the distribution of design targets in Figure 2, with sharp peaks being observed at the main design targets, and with steep falls just above the design targets. The distributions of first and last tests are almost identical, reflecting the fact that 92% of dwellings have only one recorded test. The use of bin width 0.05 m^3/m^2h reveals a maximum in both plots of 4.95-5 m^3/m^2h, with local peaks at 3.95-4 m^3/m^2h, 5.95-6 m^3/m^2h, and likewise at less common design targets. Figure 5 presents the data split by design target, highlighting the sharp cut off present at each target.

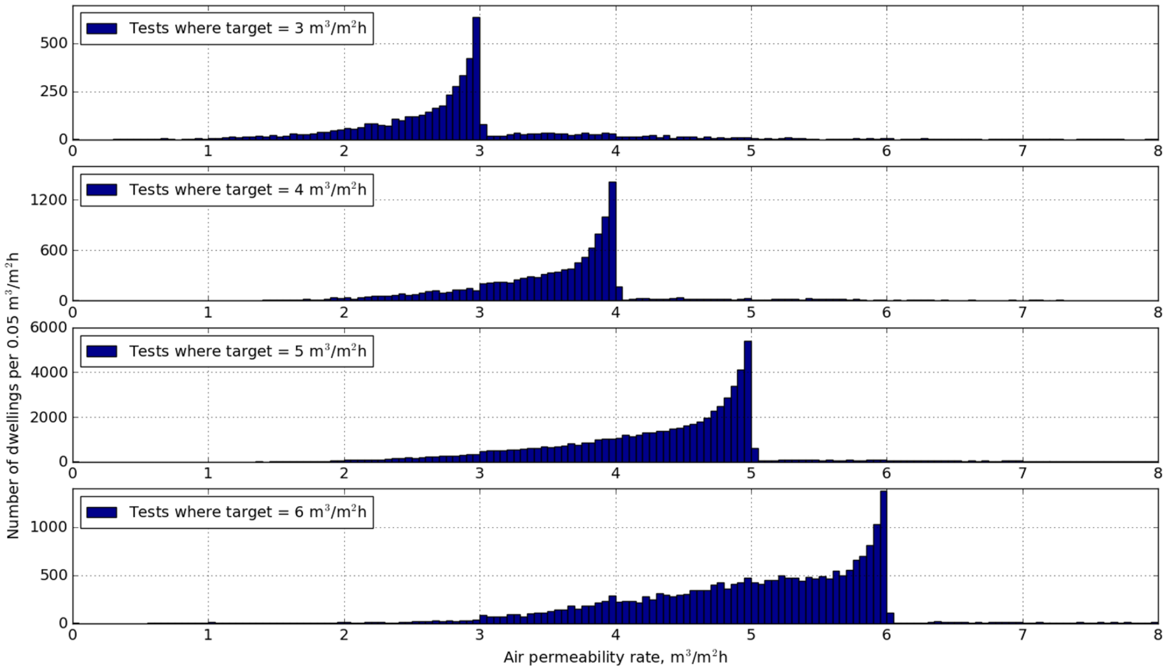

Figure 5. Air permeability distributions grouped by design target for the four most common targets.

In previous studies in the literature (9), statistical analyses have been carried out on the distribution of last tests. However, the nature of the distribution in Figure 4Figure 5 suggest that this would be inappropriate for two reasons. Firstly, central tendency statistics such as mean and standard deviation are not applicable since the distribution shape is far from normal and contains structure which simple parametric descriptions could not describe. Secondly, taking such unusual distributions at face value would overlook an important question: why do these distributions display these particular shapes? Specifically, two features of the distributions stand out: the apparent accuracy of the measurements relative to their design target, and the presence of such accurate measurements in the distribution of first tests. The section below discusses how these features could have arisen and what this may suggest about how regulatory airtightness tests are being undertaken.

2.3 Discussion of data and theory of its origin

The distribution of first tests should resemble the shape of a distribution of measurements. For example, it could be expected to be one or a combination of normal or lognormal distributions (17) for different dwelling types and constructions, with no sharp peaks or sudden falls, possibly skewed as it is constrained to be greater than zero. Indeed, a broadly lognormal shape was observed in the most recent dataset published before compulsory testing was introduced (18). Figure 4A differs from this expected shape due to its sharp peaks and discontinuities, representing very accurate first tests. For example, the most common measurements are within 0.05 m^2/m^3h below each target.

This apparent accuracy indicates that some process of measurement and intervention has already occurred by the time of the first recorded test. In 92% of sites, the first test was the only recorded test, indicating that the building had received all interventions by this stage.

This raises the question of what processes are occurring during the test procedure to lead to these measurement results. There are currently only a small number of studies which conclusively evidence bad practice during airtightness testing, such as studies in York and Swindon (10, 19) which found tape and other temporary sealing on gaps in the fabric. Other studies do not provide such conclusive evidence but allude to potentially widespread occurrence of dependence on secondary sealing to bring airtightness to the correct standard. For example, a review of the 2006 Building Regulations on energy (Part L) by focus groups with building control groups and other stakeholders concluded that:

"A perception lingers that it is too easy to be able to apply mastic extensively to bring the air test result to compliance"(20)

Similar conclusions were stated in a study of new dwellings in France:

"…it seems reasonable to think that for those houses, the envelope airtightness has been modified just before the measurement. Actually, testers often perform a preliminary test, and the house owner or builder use mastic to seal off some leaks before the tester performs another measurement, in order to comply with the requirement." (21)

The small scale studies showing post-construction sealing, the above review studies indicating its potential prevalence and discussions with the ATTMA scheme manager (22) are combined here to generate a theory of how the observed data could have arisen, shown in Figure 6. The theory is based on the premise that interventions have already taken place by the time the test is lodged. There are two types of intervention process. One process which could recreate the sharp peaks in Figure 4A is *in-test sealing*, and is shown schematically on the right of Figure 6. In this process, the air permeability test engineer maintains a test fan pressure of 50Pa whilst at the same time progressively making small sealing interventions (e.g. by applying sealant, adhesive tape or adhesive film) to improve the building air permeability until the indicated air flow rate through the fan shows that the air permeability would just meet the design target, at which point the full regulatory pressure test in accordance with the ATTMA TS1 standard is carried out.

Another possible process, shown schematically on the left of Figure 6, is *post-test remedial measure sealing.* Here, a repeated sequence of full pressure tests, remedial measures and re-tests are carried out until the measured air permeability is below the target. The ATTMA process requires that all tests including initial tests and all re-tests are lodged. However, it is possible that some testers are only recording the final tests. This post-test sealing process would not lead to the same measurement precision relative to the target as in the case of the in-test sealing due to the lack of immediate feedback on the success or otherwise of the remedial measures. The degree of test precision suggested by the dominance of the sharp peaks in the actual final test distribution when combined with the minority of lodged re-tests in the database would indicate that the results are likely being dominated by the in-test sealing process rather than post-test sealing.

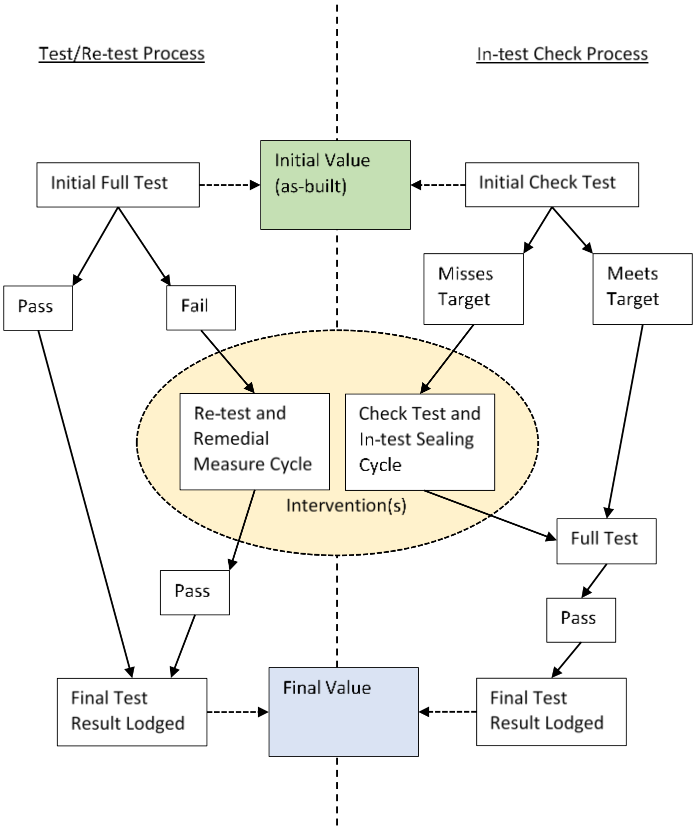

Figure 6. Theory of how the observed distribution of tests was generated.

3.0 Discussion

A theory has been generated from the available data that pressure to achieve targets is leading to creative ways of passing the regulatory airtightness test using either secondary sealing or temporary sealing. Two implications are discussed below concerning airtightness and ventilation.

3.1 Effect on airtightness

Mandatory tests have not had the intended consequence of ensuring a distribution of air permeability with a median value well below their respective design targets and with a spread narrow enough to contain a specified proportion of tests (e.g. 90% or 95%) below each target (7). The distribution is instead concentrated at the targets. Furthermore, a proportion of the dwellings are hypothesised to have been built to a substandard airtightness at the point of completion and have been sealed during or before the regulatory test.

We return to the premise behind the argument for compulsory testing: that remedial works are more expensive than building to the correct airtightness on first attempt. This is logical only if remedial works involve expensive modifications to the primary air barrier, whereas the evidence set out in the above section instead points to secondary sealing of more accessible leakage areas. This is likely to be due to the difficulties in sealing primary leakage pathways, which are hidden behind building finishes such as plasterboard, flooring and boxed in services.

Since secondary seals are known to deteriorate (20), this could increase ventilation heat loss and draughts and decrease ventilation system effectiveness. However, there is insufficient evidence in the literature to quantify the potential deterioration over time.

A possible alternative approach used by testers to meet the air permeability target is that of temporary sealing carried out solely for the purposes of the passing the test. Where this process is undertaken, the recorded test result would not provide the real airtightness value of the dwelling.

Further analysis of the data using a Bayesian inference model (in forthcoming publication) has been carried out to estimate the distribution of airtightness before any post completion sealing has been carried out.

3.2 Effect on ventilation

A second consequence of the current regime of targets and testing concerns the ventilation strategy for the dwellings. The distribution of measured airtightness for each type of ventilation system is summarised by the box plot in Figure 7.

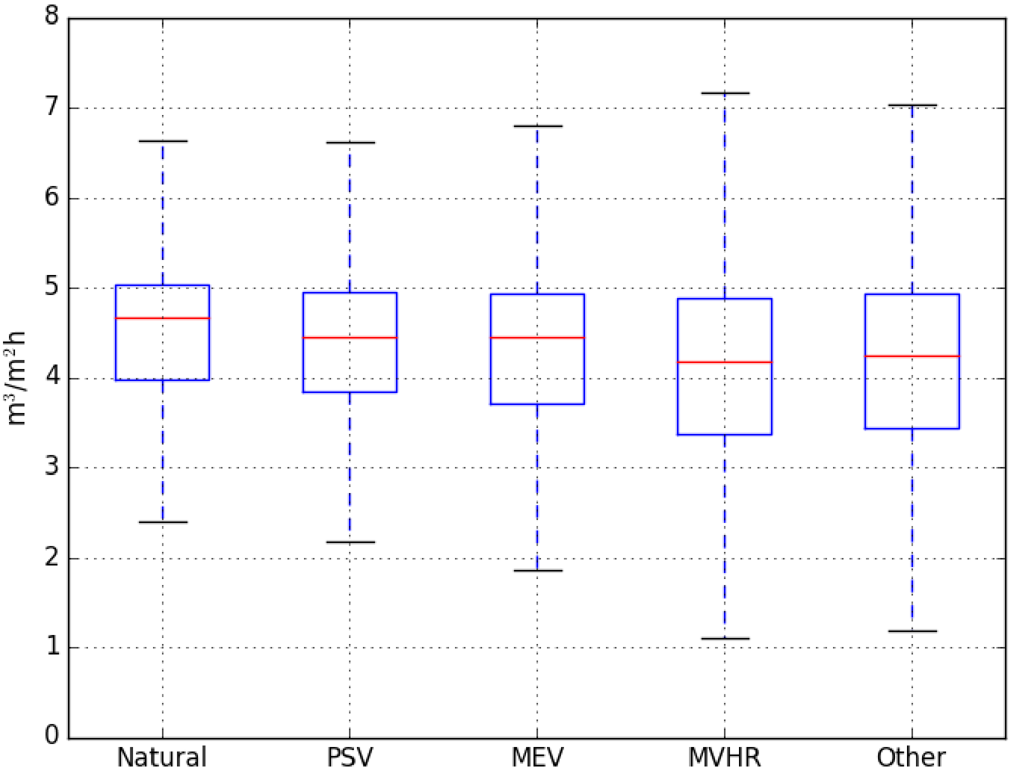

Figure 7. Airtightness by ventilation strategy.

Figure 7 shows very similar distributions of measured air permeability for all ventilation strategy. This is perhaps unsurprising, since Figure 3 highlighted the similarity of airtightness design targets between ventilation system categories. It is therefore concluded that either designers are not optimising the requirements for air permeability to match their approach to ventilation, or that disconnect exists between the ventilation design and the setting of the air permeability target in the energy calculation methodology.

The lack of synergy between the ventilation strategy and airtightness strategy is potentially concerning. Within the allowable range of air permeability in UK regulations (0-10 $m^3/h.m^2$), natural ventilation strategies would be expected to be associated with design air permeabilities towards the higher end of the range. Sufficient air leakage through the building fabric is then combined with simple intermittent through-the-wall vents and to some extent user behaviour to provide adequate fresh air. Yet, the majority of naturally ventilated dwellings in the ATTMA dataset have a stated airtightness design target of 5 $m^3/h.m^2$.

Conversely, at the lower end of the permitted airtightness range, the ventilation systems would be expected to provide the majority of fresh air supply to the dwelling, with mechanical ventilation systems being used in combination with low air permeabilities so that energy is not wasted heating more incoming air than necessary (23). Yet, from the data, the mechanical systems are not associated with distinctly lower design or measured airtightness values compared to natural ventilation systems.

In summary, the regulatory processes driving airtightness and ventilation do not appear to be working in tandem. Building design is therefore not being optimised, leading to the potential for energy savings for MVHR systems being under-realised and the possibility of poor air quality in naturally ventilated houses.

3.3 Reflection and Recommendations

The data presented in this article suggest that in a proportion of new dwellings, airtightness design targets are only being met after post-completion interventions have been carried out. If this is true, it indicates that builders are struggling to develop processes that can deliver airtightness on a consistent basis in order to meet targets as currently defined by the designers to satisfy the energy requirements of the Building Regulations. Furthermore, there is no relationship between design/measured airtightness and the as-built ventilation strategy.

These observations present an opportunity to step back and review the purpose and formulation of airtightness design targets in the UK and also to review the relationship between UK Building Regulations Part L (energy) and Part F (ventilation) (24) and how these impact on dwelling design. This has been recognised and tackled to some extent by existing industry bodies. The trade-off between energy and ventilation is discussed in CIBSE Guide A (25) but specific guidance is not given; more quantitative guidelines are given in BCA (26), and benchmarks of airtightness for naturally and mechanically ventilated dwellings are given in BSRIA (27).

One proposed implementation of this concept would be that ranges for design air permeability or air leakage in Part L are explicitly linked to the ventilation system requirements in Part F. It is suggested that ranges of airtightness are used to avoid the current situation where considerable effort is being made by testers to seal buildings to gain very marginal improvements in airtightness that would ultimately have little impact on energy or ventilation performance. Instead the target airtightness ranges could be defined as a range of acceptable bands of performance. It may be advantageous for the airtightness target range to be a requirement of the client at the contractual stage. A suggested set of air permeability ranges is shown in Table 2.

Air permeability design range (m3/h.m2 @ 50Pa)	**Ventilation system**
< 1	Very low energy dwellings with MVHR
1-3	MVHR
3-5	MEV and PSV
5-7	Natural Ventilation
7-10	Natural Ventilation

Table 2: Proposed ranges of design air permeability and associated ventilation strategy

Developers would then be required to demonstrate that the dwellings at completion have a measured air permeability within the range specified in the design. However, in order to avoid the same problems as observed in the data presented in this article where the test values are clustered around the maximum value of the range, builders would also have to demonstrate for compliance purposes that the mean or median test result and a specified percentage of the overall test distribution lie within the declared range and that there are no outliers within a specified band. This assessment of the distribution of performance could be at the site level for large sites, but could also be assessed across a portfolio of sites, especially for smaller developers where the sample size is likely to be small.

This compliance approach may give builders and designers the opportunity to develop more effective design and construction processes, to think about performance distributions and to understand variation in airtightness and how it might be controlled using different approaches to building design and/or on-site quality control processes. This is in contrast to the current system where the emphasis is on the performance of individual dwellings and doing whatever it takes to ensure each one has a test result below its design target. In addition, the suggested approach reinforces the link between energy and ventilation in the regulations.

Nevertheless, there is a sizeable literature on performance-based targets leading to gaming of the system the targets are trying to manage (28-30); therefore any approach based on measuring outcomes might be subject to manipulation in some way. The recommendation made above of inspection of and improvement of construction process as opposed to simply regulation of outcome has potential to discourage bad testing practices. However, there may be alternative solutions to that suggested here.

4.0 Conclusion

In this article we outline a theory of airtightness testing that indicates that gaming of the UK airtightness test procedure is taking place. This theory is inferred from the unexpected shape of the distribution of regulatory test results and as such is not conclusive proof that such gaming or manipulation of the process is occurring. However, the theory concurs with smaller scale studies which found evidence of both secondary and temporary sealing after completion of the dwellings.

More field studies of airtightness compliance tests are therefore needed to better understand what types of process occur to ensure dwellings meet their design air permeability, their prevalence and the motivating factors for developers, designers and airtightness testers. Specifically, there is a need to understand the pressures on design teams and construction teams to meet targets and how this manifests into testing practice.

The main consequence of meeting targets by post-completion sealing is likely to be a stock of new buildings that are less airtight than would be expected from the targets set by the energy regulations. Further work is therefore required to quantify the longevity of secondary sealing and the factors that could influence seal lifetime such as surface preparation, sealant type and leakage pathway. The nature of the current regulations for airtightness and ventilation performance may result in sub-optimal ventilation design. The recommendation given in this article is therefore to take the pressure off meeting exact design targets set by energy regulations and to consider how airtightness design could better incorporate both energy and ventilation strategy.

References

1. Office of the Deputy Prime Minister. Approved Document L1A: Conservation of Fuel and Power in New Dwellings. 2006 edition. London: Office of the Deputy Prime Minister,; 2006.
2. Johnston D, Miles-Shenton D, Bell M, Wingfield J. Airtightness of buildings - towards higher performance. Final Report - Domestic Sector Airtightness. Department for Communities and Local Government 2011.
3. Stephen R. Airtightness in UK dwellings: information paper. BRE2000.
4. Office of the Deputy Prime Minister. Proposals for amending Part L of the Building Regulations and Implementing the Energy Performance of Buildings Directive: A consultation document. London: ODPM, 2004.
5. Limiting thermal bridging and air leakage: robust construction details for dwellings and similar buildings, (2001).
6. Love J, Wingfield J, Smith A, Biddulph P, Oreszczyn T, Lowe R, et al. 'Hitting the target and missing the point': Analysis of air permeability data for new UK dwellings and what it reveals about the testing procedure. Energy and Buildings. 2017;155:88-97.
7. Lowe R, Johnston D, Bell M. Review of possible implications of an airtightness standard for new dwellings in the UK. Building Services Engineering Research and Technology. 2000;21(1):27-34.
8. ATTMA. Technical Standard L1. Measuring air permeability in the envelopes of dwellings. September 2016 Issue. Amersham2016.
9. Pan W. Relationships between air-tightness and its influencing factors of post-2006 new-build dwellings in the UK. Building and Environment. 2010;45(11):2387-99.
10. Johnston D, Miles-Shenton D, Wingfield J. Post-construction and initial occupation report on a small development of six dwellings, York. Leeds Metropolitan University, 2012.
11. UCL and Crest Nicholson Operations. Centenary Quay Fabric and District Heating Performance Study - Phase 1: Post Construction and Early Occupation. Innovate UK, 2013.
12. Littlewood J, Alam M, Goodhew S. A New Methodology for the Selective Measurement of building Performance and Safety. Energy Procedia. 2017;111:338-46.
13. Coxon R. The trouble with airtightness. isurv. 2011 23 September 2011.
14. Department for Communities and Local Government. Air tightness testing scheme statistics: April 2016 to March 2017. 2017.
15. Approved Document L1A: conservation of fuel and power in new dwellings, 2013 edition with 2016 amendments, (2016).
16. Scottish Government. Building Standards technical handbook 2017: domestic. Livingston: Scottish Government Building Standards Division; 2017.
17. Squires GL. Practical physics: Cambridge university press; 2001.

18. Grigg P. Assessment of energy efficiency impact of building regulations compliance. Watford: Building Research Establishment, 2004.
19. Oxford Brookes University. Building Performance Evaluation: Code Level 5 Homes Lyndhurst Crescent, Swindon. Final report: Domestic Buildings. Phase 1: Post construction and early occupation. Digital Catapult Building Data Exchange: Innovate UK, 2011.
20. Bell M, Smith M, Palmer J. Review of the implementation of Part L 2006. London: Department for Communities and Local Government, 2010.
21. Bailly A, Guyot G, Leprince V, editors. 6 years of envelope airtightness measurements performed by French certified operators: analyses of about 65,000 tests. 36th AIVC Conference " Effective ventilation in high performance buildings"; 2015; Madrid, Spain.
22. Cope B. Personal Communication ed. Personal Communication 2017.
23. Banfill PF, Simpson S, Gillott MC, White J. The potential for energy saving in existing solid wall dwellings through mechanical ventilation and heat recovery. European Council for an Energy Efficient Economy, summer study. 2011:6-031.
24. HM Government. The Building Regulations 2010: Approved Document F1: Means of Ventilation. 2010 edition incorporating 2010 and 2013 amendments. London: HMSO; 2015.
25. CIBSE. Guide A: Environmental Design London: CIBSE; 2015.
26. BCA. BCA Technical Guidance Note 20: Ensuring adequate ventilation to naturally-ventilated dwellings with high levels of as-built air tightness. Published online 2015.
27. BSRIA. Designing and Constructing for Airtightness. Bracknell: Charlesworth Press; 2013.
28. Smith P. On the unintended consequences of publishing performance data in the public sector. International journal of public administration. 1995;18(2-3):277-310.
29. Goodhart CA. Problems of monetary management: the UK experience. Monetary Theory and Practice: Springer; 1984. p. 91-121.
30. Strathern M. 'Improving ratings': audit in the British University system. European Review. 2009;5(3):305-21.

Acknowledgements

The authors would like to thank Barry Cope (ATMMA) for provision of the data in this article and Ian Cooper from Eclipse Research for comments on the content. This work was carried out with funding from the RCUK Centre for Energy Epidemiology under EP/K011839/1.