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'Hitting the target and missing the point': Analysis of air permeability data for new UK dwellings and what it reveals about the testing procedure

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ABSTRACT

Airtightness testing is widely undertaken to assess the as-built performance of dwellings, in support of achieving energy and ventilation strategies. Mandatory schemes operate in some countries, such as the UK, to ensure that dwellings are built in accordance with their design air permeability. However, testing is only useful if the results give a true picture of the airtightness of the building. Previous literature has investigated factors which could influence airtightness test results but has not questioned data quality, despite the pressure on builders to achieve design targets. This paper presents air permeability results from the largest UK dataset, comprising 144,024 dwellings tested under the Air Tightness Testing and Measurement Association (ATTMA) scheme. The data show an unexpected distribution of test results with narrow peaks just within test targets. Such results were not expected theoretically but do reflect findings in other fields where performance-based targets are in place. Such a close match between design and tested airtightness may be achieved by remedial works taking place during the test rather than afterwards. Recommendations are made with respect to quality assurance systems, design guidance and on-site sealing practices to increase the likelihood of long-term airtight buildings being constructed first time.

1. Introduction

1.1. Air permeability rate and the aims of this article

Heat demand reduction in UK housing is an important part of the UK's decarbonisation strategy [1]. One way of minimising heat loss in new dwellings is by limiting infiltration and uncontrolled air leakage, but for the simplest ventilation strategies, this can decrease the supply of fresh air to the occupants below what is necessary for a healthy indoor environment. The balance between heat conservation and fresh air supply should be addressed at design stage by combining an appropriately airtight building fabric with an appropriate purpose-provided ventilation system [2,3].

Achieving airtightness in practice requires a combination of good design of the primary air barrier and good site practice to ensure that the buildings are constructed as designed [4]. General design principles for airtight construction include the use of a continuous airtightness layer in the same plane throughout the structure, that is easy to install, avoiding both penetrations and complex detailing, especially at junctions between elements [5].

The airtightness of a dwelling is measured by a pressure test, a technique that uses a large calibrated fan to create a pressure difference between the inside of the building and the outside. The relationship between airflow and pressure difference is determined using a power law equation and the airflow at a reference pressure difference of 50 Pa (Pa) calculated. The result is then divided by the building envelope area to give an *air permeability rate at 50 Pa*, with units m^3/m^2h.

The pressure test standard used in the UK was developed by the Air Tightness Testing and Measurement Association (ATTMA) [6], based on test method B in the ISO standard for building air permeability measurements [7]. Method B excludes purpose-provided ventilation, which is temporarily sealed for the duration of the test. Each test requires measurements at a minimum of seven different pressure differences ranging from 20 Pa to greater than 50 Pa.

This article's focus is the largest dataset of pressure test measurements available in the UK, collected from 2015 to present through the ATTMA scheme. By combining observations from the data with prior expectations of the spread of measured data and literature presenting examples of data quality issues, a theory is

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generated proposing unanticipated mechanisms that may distort the test results to lead to the observed data. The role of the test procedure and regulatory environment in the creation of the observed distribution of data is explored, along with recommendations for designing or improving an airtightness testing regime.

1.2. Brief history of airtightness, testing and targets in the UK

Since the introduction of energy ratings for dwellings under amendments made to the UK building energy efficiency regulations (Part L) in 1994 [8], dwelling airtightness and associated background ventilation heat loss have been an increasingly important aspect of compliance. However, measurement of air permeability was not initially required; regulations were limited to providing guidance on measures that would limit air infiltration through the building fabric, such as locations of likely unintentional air leakage paths, and methods to seal them [9]. In 1995 the first official version of the Standard Assessment Procedure (SAP) was released, the National Calculation Methodology energy model used for compliance with the Part L regulations, including an optional input for an air permeability test result but no requirement to use it.

Aware of a wide distribution of measured air permeability in new dwellings centred around 12–13 m^3/m^2h at 50 Pa [10], and no tangible incentive to improve it, Lowe et al. [11] argued in 2000 for compulsory pressure testing of a fraction of new UK housing, theorising that this would result in reductions to both the median and standard deviation. They reasoned that the remedial works required upon failing such a test, estimated at 3 man days plus materials, would be more costly and inconvenient than building the dwelling with a sufficiently low air permeability to start with.

The 2002 edition of Part L introduced two options for airtightness compliance, either by following the design and construction guidance of Robust Thermal Details [12] or an air permeability test result of less than 10 m^3/m^2h at 50 Pa, when tested according to the CIBSE TM23 standard [13]. Subsequently, Johnston et al. [4] demonstrated that a sample of 25 dwellings taken from 5 large developers constructed according to these regulations had a mean air permeability of just over 11 m^3/m^2h, suggesting that the provisions of Part L (2002) did not result in buildings with air permeability consistently below the maximum 10 m^3/m^2h. However, they presented an action research approach to demonstrate that with careful design and feedback from pressure testing results, air permeability in new dwellings was more likely to achieve below 10 m^3/m^2h [5].

Air permeability testing was consequently introduced as mandatory for new dwellings in the 2006 building regulations, using the first ATTMA testing standard (TS1, based on BS EN ISO 9972:2015), based on the CIBSE TM23 standard. Whilst testing is 'mandatory', not all dwellings are tested. Instead, there is a required minimum sample for each dwelling type on a development, based on the size of the development and the number of dwellings. Dwellings not tested are penalised in their energy calculation 2 m^3/m^2h to the mean tested values for dwellings of the same type constructed on the site. Using the most recent statistics on pressure testing [14] and housebuilding completions [15], ̃73% of dwellings built in the first half of 2016 underwent airtightness tests, suggesting that this penalty has promoted wider testing than the minimum possible.

Whilst all new UK dwellings must achieve an air permeability less than 10 m^3/m^2h when tested [16], the design air permeability is often set well below this value to meet CO_2 emissions and building fabric energy efficiency targets [17]. The result of the pressure test should then be less than or equal to the design air permeability to ensure that the building complies with regulations. The example set of building fabric parameters used to show compliance with the CO_2 target in Part L 2013 [16] includes an air permeability of 5 m^3/m^2h. This parameter set may be used as a recipe for builders to follow, leading to a peak in distribution of design air permeability at this value. Other integer designs targets are sometimes used although no targets have a physical basis. It is sometimes possible that the site design target is more stringent than the compliance design target to ensure compliance [18].

1.3. Data quality concerns

Since mandatory testing was introduced in 2006, the competence of testers, and quality and reliability of test results have been of concern [19]. Results of airtightness tests carried by researchers shortly after compliance tests have tended to show significantly higher air permeabilities than were recorded for regulatory purposes. For example, Building Performance Evaluation projects in Southampton and York showed air permeabilities measured by researchers 7–66% higher than the regulatory tests [20,21]. However, a round robin exercise in Belgium [22] indicated that variability in results between testers due to factors such as test set-up was no more than 7%.

One cause of this discrepancy relates to sealing. The ATTMA test protocol guidance on test preparation [23] allows some forms of temporary sealing under special circumstances where, for example, a single building component is missing or broken [24]. It is also permissible to use sealant or mastic to seal around secondary leakage pathways such as the junction between the skirting boards and floor. However, these types of seals can fail over short timeframes due to the relative haste in application and the lack of preparation [25]. This type of 'secondary' sealing and its associated rapid failure mechanisms has been proposed to account for an observed increase in air permeability from sequential tests carried out on the same dwellings [21].

Evidence from fieldwork suggests that limitations on temporary sealing are sometimes exceeded in order to pass the test. For example, site visits undertaken post-pressure testing as part of building performance evaluation projects showed evidence of extensive temporary sealing using adhesive tape in excess of that allowable under the test standard [20,26]. A site inspection undertaken by UCL of a development in Hampshire immediately after the compliance pressure test showed

evidence of adhesive tape being used to seal around leakage pathways such as the boiler and consumer unit as shown in Fig. 1.

The low level of confidence in the competence and adherence to procedure of some testers [27] led to the introduction of a Competent Persons Scheme in 2016 for airtightness testing and mandatory lodgement of test results through purpose-built software. Regulations do not require testers to be part of the scheme.Despite the ongoing concern about data quality, academic analyses of air permeability rates using data collected for compliance assessment purposes rarely address the test procedure or the validity of the reported permeabilities. For example, Chan et al. [28] analysed a secondary dataset of 147,000 dwellings in the US, of which a subset of tests were carried out for compliance purposes. The analysis included no treatment of data quality other than metrological uncertainty in the testing method and inferences made of missing parameters to calculate air permeability from test results. A UK-based study by Pan [29] in 2011 cited the classification used by the Energy Saving Trust [30,31] to group factors which may influence air permeability into design, specification, construction and testing [30,31]. Pan used statistical methods to test the influence on permeability of a number of previously unresearched variables in the design, specification and construction groups. The result most relevant to this paper is that a modest correlation was observed between air permeability and design target. However, testing procedure was not examined. The stated reason for this was the existence of a testing protocol and therefore that "... *all these test-*