The relationship between airtightness and summertime infiltration rates

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ABSTRACT

All new dwellings in England and Wales are required to undergo a model-based overheating risk assessment prior to construction. An important model input is the building infiltration rate, which is usually estimated using a conversion factor on the dwelling airtightness. There is a paucity of evidence regarding the reliability of these methods in summertime. This aim of this paper is to provide new evidence on the relationship between airtightness and infiltration during summertime. The airtightness of a single test house was repeatedly measured over a three-month period using a blower door. Following this, 15 whole house tracer gas tests were undertaken in the same test house over a summer season to measure infiltration rate. Eleven different infiltration estimation methods were used to calculate the infiltration rate and were compared to the measured infiltration rate. The summertime infiltration rates were predicted to be between 64 and 208% higher than measured. These findings have implications for the reliability of overheating risk assessment and suggest that these uncertainties must be accounted for when designing and modelling buildings to be resilient to summertime overheating.

KEYWORDS

Airtightness; air permeability; infiltration; measurement; tracer gas

1 INTRODUCTION

Airtightness is commonly measured in dwellings in UK dwellings (Love et al., 2017). This is done using a blower door test or a low-pressure pulse test – both are relatively quick and easy methods compared to measuring infiltration rate, which is done using tracer gas techniques, and so infiltration rates are relatively rarely measured. Due to this, the relationship between airtightness and infiltration has long been used to estimate dwelling infiltration rates during the winter heating season (Jones et al., 2016). To allow for estimation of infiltration rates without a tracer gas test, several empirical and theoretical air infiltration models have been developed (ASHRAE, 2013; BRE, 2022; Jones et al., 2016; Shaw, 1981; Walker & Wilson, 1990, 1998; Warren & Webb, 1980). These methods were designed to estimate infiltration, primarily, during the winter heating season – usually using the measured airtightness. It is not yet known, however, whether airtightness can be reliably used to estimate infiltration rates outside of the weather conditions for which they were designed. This is problematic because with the introduction of mandatory overheating risk assessments in newly built homes in England and Wales (HMG, 2021), dwelling airtightness is increasingly being used to estimate infiltration rates in summer (Roberts, Allinson, Diamond, et al., 2019; Roberts et al., 2023). Pasos et al. (2020) have raised concerns about the reliability of the methods using a single test in multiple dwellings. There is a need for multiple tests to be conducted in a single dwelling during summer to quantify the variation in infiltration rates that may be observed under changing weather – which is the aim of this paper.

2 METHODS

2.1 The test house and weather

A single test house constructed in the 1930s with masonry cavity walls and uPVC double-glazed windows and doors was selected as the case study. Indoor dry-bulb temperatures were measured in every room at the volumetric centre at 1-minute intervals using shielded, calibrated sensors. Alongside this, the local weather was measured using a weather station mounted in the test house gardens and on the nearby University campus.

2.2 Measuring airtightness and infiltration rate

Airtightness was measured on 34 different occasions between January and March 2017 in a single test house using a blower door test via depressurisation, following ATTMA Method B (ATTMA, 2016). The same sealing scenario was maintained during the tracer gas tests. Infiltration rates were measured on 15 different occasions throughout the summer period using CO_2 gas as the tracer, detected by a photoacoustic infrared spectroscopy gas analyser which drew air from six monitoring points around the house. The decay method, in compliance with ASTM Standards, was used for all tracer gas tests (ASTM, 2000).

2.3 Infiltration estimation methods

Eleven different infiltration methods were selected for testing following a review of the literature. Each estimated infiltration rate was compared to a measured infiltration rate (of which there were 15 tests). Thus, where applicable, the weather measured during the tracer gas test was used in the infiltration method input. The different infiltration estimation methods required different inputs. These were sourced from publicly available data on the test house (Roberts, Allinson, & Lomas, 2019; Roberts et al., 2018).

The eleven infiltration estimation methods are as follows, with individual inputs listed in Roberts et al. (2023):

1. ASHRAE Basic (ASHRAE, 2013), called the Effective Leakage Area model in the EnergyPlus dynamic thermal model.
2. ASHRAE Enhanced (ASHRAE, 2013), called the Flow Coefficient model in EnergyPlus.
3. K-P (Kronvall-Persilly)[1] UK or the “divide-by-20” method. Uses a divisor of 20 to reduce the blower door AP_{50} to infiltration. The method is applied differently in the UK and US – in the UK air permeability (AP_{50}) is used (Poza-Casado et al., 2020).
4. K-P US or “divide-by-20”, dividing by N_{50} following the US convention.
5. Lawrence Berkeley Laboratory (LBL) method (M. Sherman & Grimsrud, 1980; M. H. Sherman & Modera, 1986).
6. Modified divisor $N_{50}/30$ – as suggested for low-rise buildings (Liddament, 1996).
7. SAP Algorithm (measured wind) (SAP, 2014).
8. SAP Algorithm (reference wind) (SAP, 2014).
9. SAP $AP_{50}/20$ (SAP, 2014).
10. SAP $AP_{50}/20$ (SAP, 2014).

[1] Frequently misattributed to Kronvall and Persily (Kronvall, 1978; Persily, 1983) as described by (Jones et al., 2016).

11. Sherman Simplified method (M. H. Sherman, 1987). This method usually requires annual average wind speed and indoor-outdoor temperature difference, but in this analysis the averages during each tracer gas test interval were used.

3 RESULTS

Comparing the measured infiltration to that predicted by the eleven infiltration estimation methods showed that the mean measured infiltration rates are overpredicted by the methods by between 64-208%. The ASHRAE Enhanced method was closest to the measured infiltration rate, but still significantly (p <0.001) higher than measured (Figure 1). The K-P US (N_{50}/20) predicted furthest from the measured infiltration rate. A divisor of 58 would be required, in this example, to reliably predict infiltration in summer using AP_{50} alone.

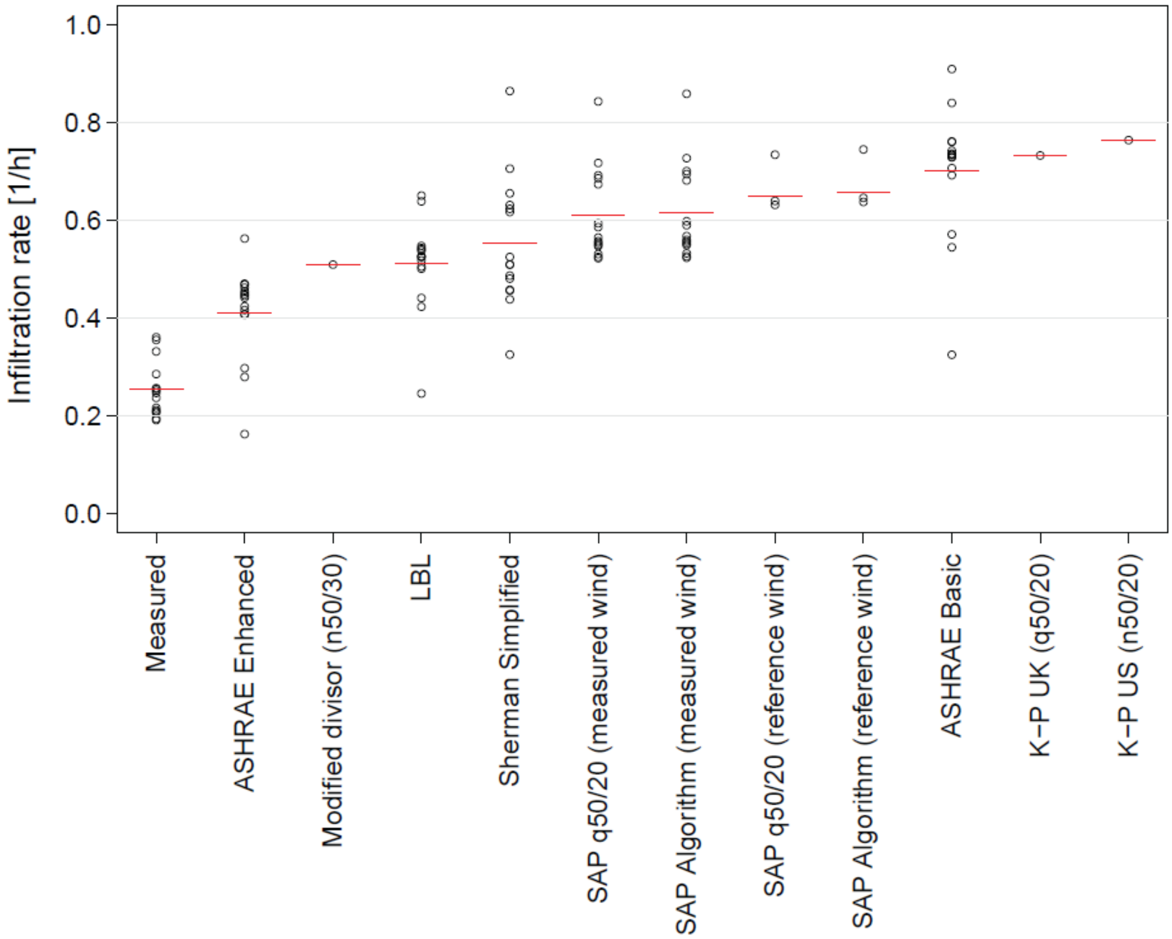

Figure 1: A comparison of the measured infiltration rates (tracer gas) and the estimated infiltration rates from each of the methods. Each data point represents one of the 15 measured or estimated infiltration rates. The mean value for each of the methods is indicated by the red horizontal bars. Arranged in ascending order from the lowest mean infiltration rate value

In some case, individual predictions of infiltration rate were close to the corresponding measured value (Figure 2). The ASHRAE Basic, ASHRAE Enhance, LBL model, and the Sherman Simplified method all had minimum errors of <0.10 ach (positive and negative, i.e., greater and lesser than measured). The infiltration estimation methods which accounted for the weather conditions (and indoor-outdoor temperature) were generally more reliable estimators of infiltration than those which did not. The use of a locally-available wind speed improved the predictions for the SAP methods. The slope of the regression line for each estimation method is indicative of each method's response to those weather conditions (Figure 2). The ASHRAE Enhanced, LBL and Sherman Simplified methods all appear to respond correctly to the change in weather conditions, with the slope angle of the lines close to 1, i.e. the line of quality, albeit significantly above (Figure 2).

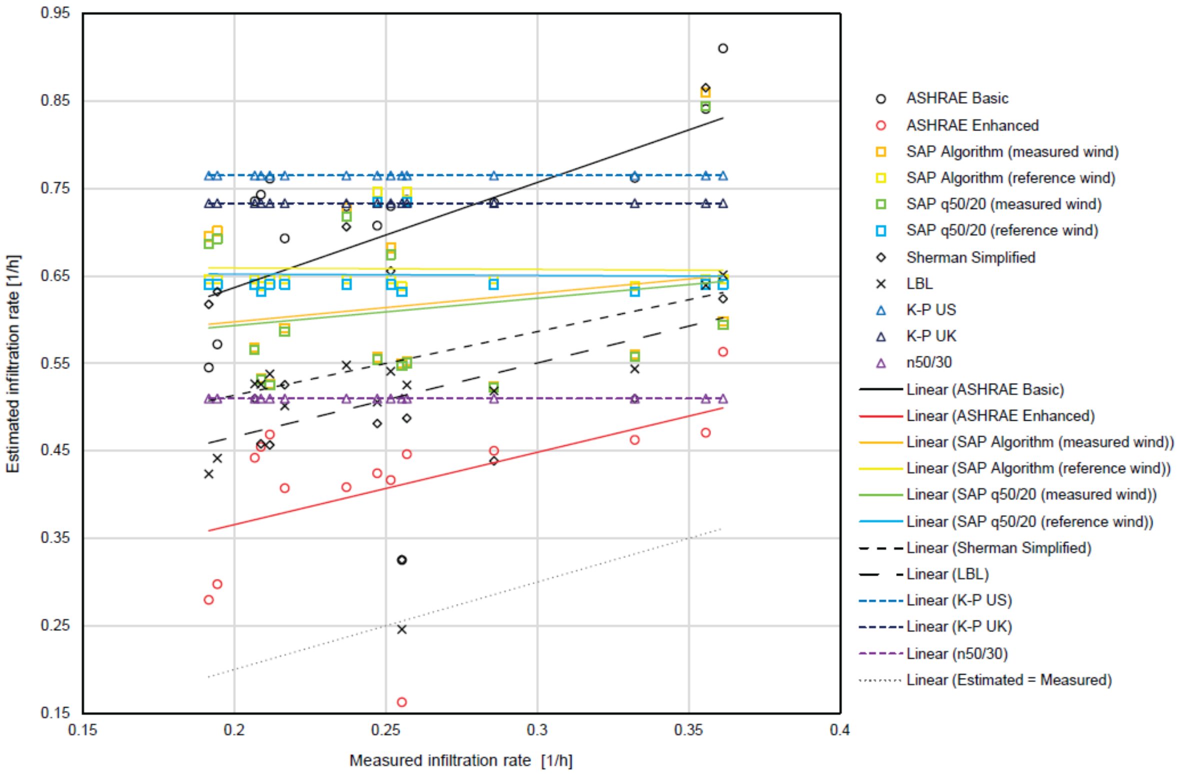

Figure 2: Measured infiltration rate plotted against estimated infiltration rate. Each data point represents one of the 15 tracer gas tests and the corresponding infiltration estimation method prediction.

4 DISCUSSION

Infiltration estimation methods were designed to predict infiltration rates in dwellings during the winter season. Due to their growing application to the summer season for overheating risk assessments in UK Building Regulations (HMG, 2021) this paper has found that their estimations of infiltration are unreliable and will add to modelling uncertainties in dynamic thermal models (Roberts, Allinson, Diamond, et al., 2019).

For the test house in question, a divisor of AP_{50} and N_{50} of 58 was suggested for, rather than the commonly used 20. Similarly, Pasos et al. (2020) has suggested a higher value, of 39. Seeking a single divisor for airtightness (or air permeability) may be a futile endeavour for anything other than low-resolution, low reliability estimation of annual infiltration rates. This is because there are complex geometrical considerations and infiltration is highly dynamic and weather dependent (Jones et al., 2015). This paper has shown that the estimations are sensitive to weather during the summer season. The methods which accounted for the wind speed, indoor-outdoor temperature differences, and perhaps other information. Although it is not always possible or practical to obtain local weather data, there are clear benefits to doing so with respective to estimation reliability. These findings have implications for the reliable prediction of overheating risk and cooling demand. Overheating risk may be higher than models predict, as ventilative cooling is not as high as assumed by modellers. This could mean that appropriate and necessary passive overheating mitigation strategies are not implemented at the design stage. This could lead to overheating in new homes and the subsequent uptake of energy intensive air-conditioning. Further work should investigate the precise effect this has on overheating risk assessment. The ASHRAE Enhanced method estimated a mean infiltration rate that was both closest to the measure infiltration rate and the gradient of the regression line (Figure 2) was similar to the gradient of the line of equality. Thus, it appears that this method was reliably sensitive to the changes in infiltration rate. Therefore, the ASHRAE Enhanced method shows the greatest promise and further investigation and refinement of this approach for estimation of infiltration rate in summer is recommended.

4.1 Limitations

This study was conducted on a single test house. Whilst it benefits from multiple measurements of airtightness and infiltration under many different weather conditions, further investigation is needed to understand the reliability of infiltration estimation in different homes with different levels of airtightness and exposure to wind.

5 CONCLUSION

The key conclusions are the following:

1. None of the eleven infiltration estimation methods trialled was a reliable estimator of the mean infiltration rate measured in the test house.
2. If the commonly used K–P “divide-by-20” rule of thumb is used to estimate infiltration in summertime, the divisor for AP_{50} and N_{50} should be replaced by 58 in the example of this single dwelling. However, attempts to define a single value to reduce blower door data (AP_{50} or N_{50}) to infiltration rate is futile when considering the highly dynamic and weather-dependent nature of infiltration.
3. Infiltration estimation methods which account for wind speed (especially when locally measured), indoor-outdoor temperature differences, and perhaps other information about the building and wider site are recommended to achieve more reliable estimates of infiltration, but still differences between the measured and estimated infiltration remained.
4. The ASHRAE Enhanced infiltration estimation method was closest to the mean measured infiltration rate and demonstrated a similar rate of increase in estimated infiltration in line with the measured value. Thus, this method holds the greatest potential for adjustment and adaptation to be more suitable for estimating infiltration in typical UK homes during summer.
5. Incorrectly estimating infiltration could lead to incorrect assumptions regarding overheating risk.

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