The effect of refurbishment and trickle vents on airtightness: the case of a 1930s semi-detached house.

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ABSTRACT

As UK homes are insulated and draught proofed in an attempt to reduce wintertime heating demand they become more airtight. Any reduction in infiltration could have a detrimental effect on indoor air quality. Controllable background ventilation provided by trickle vents is one method of maintaining indoor air quality.

A 1930s semi-detached 3-bedroom house was refurbished with double-glazed windows, trickle vents, doors and loft insulation. 167 blower door tests were carried out pre- and post-refurbishment between January and March 2017 to understand the repeatability of the test and quantify how trickle vents affect airtightness.

The refurbishment reduced air leakage by 29% from 20.8 to 14.7m^3/h/m^2 at 50Pa (with all windows and trickle vents closed), but still in excess of the current UK regulations for new builds (10m^3/h/m^2 at 50Pa). Opening trickle vents provided limited additional ventilation, only increasing air change rate by 1.8m^3/h/m^2 with all vents open. The test was found to be repeatable with a standard error of 0.07m^3/h/m^2 at 50Pa with no relationship between the test result and wind speed or direction.

The results lead to two important conclusions. Firstly, after refurbishing older homes of this type, infiltration rates are still well above recommendations for adequate indoor air quality. Secondly, the omission of trickle vents in older homes may not unduly diminish indoor air quality.

KEYWORDS

Houses; refurbishment; airtightness; measurement; trickle vents.

1 INTRODUCTION

Houses are refurbished to improve energy efficiency and airtightness to reduce heating energy demand and improve thermal comfort. This can reduce unintended infiltration, potentially allowing indoor pollutants to build up (Sullivan, et al., 2013). Poor indoor air quality (IAQ) occurs when the presence of airborne pollutants impairs the health or comfort of building occupants. To ensure good IAQ, ventilation must be at a sufficient level to provide outdoor air for breathing, dilution and removal of pollutants and odours, control of humidity and provision of air for fuel-burning appliances (HM Government, 2010). Such ventilation may be provided by operable windows but in modern houses trickle vents are installed to ensure the provision of a steady, draught free, background airflow. Trickle vents are integrated into windows frames and can be manually opened or closed.

Hong (2004) measured airtightness using fan pressurisation in 191 English dwellings pre- or post-refurbishment. Refurbishments included loft insulation, cavity wall insulation, draught proofing and new central heating systems. Only a small improvement in airtightness (0.7m^3/h/m^2 at 50Pa) was found between pre- and post-refurbishment dwellings, owing to the improvement in airtightness from measures like cavity wall insulation and draught proofing being offset by new envelope penetrations. The same study states that whilst loft insulation can contribute to a $4m^3/h/m^2$ at 50Pa increase in airtightness, poor installation such as leaving large gaps at the eaves can render this measure ineffective (Hong, et al., 2004).

Oreszczyn, et al. (2005) conducted blower door tests on 10 houses that had replacement windows and found a mean reduction in air change rate of 0.2 ACH. They suggest that the installation of new windows could have a significant effect on the airtightness of homes and that 65% of UK homes installed with new windows could have air change rates below 0.5 ACH. The authors suggest that the installation of trickle vents might be beneficial to improve IAQ, but did not directly test this.

Gillott, et al. (2016) measured the airtightness of a recently built test house constructed in the style of a 1930s semi-detached house during a phased retrofit programme. Replacement of single-glazing with double-glazing, and loft and cavity wall insulation reduced infiltration by 12%. Draught-proofing yielded a 41% reduction. Sealing envelope pipe penetrations reduced infiltration by 11%. Floor sealing at the skirting boards reduced infiltration by 33%.

Purpose-provided openings like trickle vents are specified for installation in new build homes to ensure ventilation rates are sufficient to ensure good IAQ (HM Government, 2010). However, monitoring of exhaled CO_2 in newly-built dwellings shows that trickle vents may be ineffective in providing sufficient fresh air with Sharpe et al. (2015) reporting CO_2 concentrations up to 1571ppm in bedrooms with trickle vents open, compared to 972ppm with windows open. In an energy-efficient dwelling, bedroom CO_2 concentrations of 3500ppm were measured, despite trickle vents being open (McGill, et al., 2015).

The current UK building regulations do not require the installation of trickle vents in refurbished windows where they did not already exist (HM Government, 2010). However the building regulations do state that if the room is not otherwise adequately ventilated it would be good practice to fit trickle vents. In existing dwellings, habitable rooms should have trickle vents sized to a minimum of $5000mm^2$ equivalent area[1] (EA) and in wet rooms $2500mm^2$ EA (HM Government, 2010).

This paper aims to quantify the effects of refurbishment on airtightness in a UK house and assess whether trickle vents installed to building regulation standards are capable of providing sufficient fresh outdoor air for satisfactory indoor air quality. Data are presented from 167 blower door tests pre- and post-refurbishment of a 1930s semi-detached house, including various trickle vent opening areas. Comment is made on the repeatability of the blower door test method.

[1] A measure of the aerodynamic performance of a ventilator. It is the area of a sharp-edged circular orifice which air would pass through at the same volume flow rate, under an identical applied pressure difference as the opening under consideration (HM Government, 2010).

2 METHODS

2.1 Test house description

Figure 1 – Ashby Road Test Houses pre-refurbishment, only the left house was used

Figure 2 – Ashby Road Test Houses post-refurbishment, only the left house was used

The test facility comprises a matched pair of two adjoining unoccupied semi-detached two-storey houses. In this study, the left hand house (Figure 1 and Figure 2) was used. The house is located in a residential area of Loughborough, UK (52.7721° N, 1.2062° W). The front of the house faces south towards a front garden and a road, the rear of the property faces north to a large back garden and adjoins the other house to the east. There are neighbouring houses of similar roof heights to the east and west.

The house has a total floor area of 90m^2 including both floors and a total volume of 216m^3 (Figure 5). The house was built in the 1930s in a manner typical of the era with uninsulated brick cavity walls and suspended timber floors ventilated below by air bricks. Until 2016 the houses had been largely unrefurbished since their construction (Figure 1) apart from open fireplaces in the living and dining rooms which were removed, bricked up and plastered. During the summer of 2016 the single-glazed wooden-framed windows were replaced with uPVC double glazing throughout which included replacement of 3 existing wooden doors with uPVC doors. The roof was retiled at the same time and the loft insulated with the loft hatch insulated but not draught-stripped. Prior to this in 2015, existing wooden fascia and soffits at the eaves were replaced with uPVC (Figure 2). Refurbishment works and associated U-values are listed in Table 2. Prior to commencement of testing all wall and fireplace vents were internally sealed with aluminium tape. Air bricks ventilating the subfloor were left unblocked (see Figure 5 for locations).

The new double glazing was installed with trickle vents to the building regulation specification for existing dwellings (HM Government, 2010). To comply, habitable rooms must have a minimum 5000mm^2 EA and wet rooms (kitchen and bathroom) 2500mm^2 EA. Trickle vents could be manually opened or closed using a flap shutter (Figure 3 and Figure 4).

Table 1 - Trickle vent locations (by room) and sizes

Room	Number of vents	Trickle vent equivalent area (mm^2)	Trickle vent geometric free area (mm^2)
Living room	4	5000	6400
Dining room	3	5000	6400
Kitchen	2	2500	3200
Bathroom	2	2500	3200
Rear bedroom	4	5000	6400
Front bedroom	4	5000	6400
TOTAL	19	25000	32000

Figure 3 – Trickle vent closed

Figure 4 – Trickle vent open

Indoor temperature data were collected in the houses via Grant U-type thermistors[2] connected to a DT85 Datataker in order to provide inputs to blower door fan control software and for comparison with measured airtightness. A thermistor was placed in the volumetric centre of every room and shielded from incoming solar radiation. Outdoor temperature data were collected using the same thermistor as used indoors and connected to the same data logger. The outdoor sensor was shielded in a naturally aspirated EML SS1 sensor shield (EML, 2017) and placed to the north of the houses to further reduce interference from solar radiation. Indoor and outdoor temperatures were logged at one minute intervals during testing. All thermistors were calibrated prior to placement using a temperature-controlled water bath and calibrated thermometer.

Wind data was sourced from the University weather station approximately 1km from the test house and measured at one minute intervals.

Table 2 – Pre- and post-retrofit U-values of construction elements. U-values from SAP (BRE, 2014).

Building element	**Pre-retrofit**	**Estimated U-value (W/m^2K)**	**Post-retrofit**	**Estimated U-value (W/m^2K)**	**Area (m^2)**
Roof	No loft insulation, pitched with clay tiles.	2.3	300mm fibreglass, pitched with clay tiles over vapour-permeable membrane	0.16	45.6[a]
External walls	Brick internal/external uninsulated cavity	1.6	No change	1.6	81.6
Internal partition walls	Brick covered with gypsum plaster, wallpaper and paint	2.1	Re-painted	2.1	53.9
Party wall	As internal partition walls	0.5	Re-painted	0.5	42.2
Floors (except kitchen)	Suspended timber boards with carpet tile (linoleum in bathroom)	0.8	No change	0.8	40.2
Floors (kitchen)	Solid concrete and linoleum cover	0.7	No change	0.7	5
Windows	Single-glazed, wooden framed	4.8	New uPVC double glazing	1.4	20.3[b]
External doors	Wooden, single-glazed sections	3	New uPVC with double glazing	1.4	5.5

[a] Horizontal area (not pitched).
[b] Total area including frames.

[2] Accuracy ±0.2°C (Grant Instruments (Cambridge) Ltd., 2017)

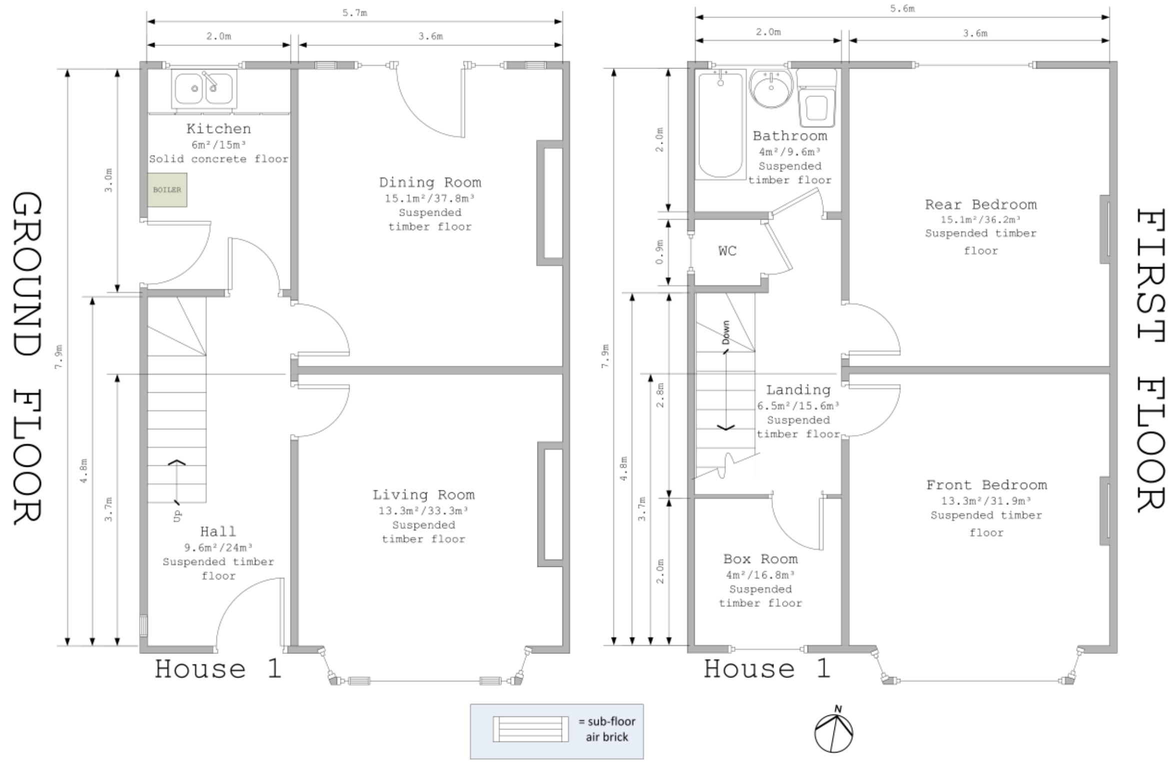

Figure 5 - Floor plan of house 1 (right side wall is a party wall).

2.2 Air tightness measurement

The airtightness of the house was measured with a Model 3 Minneapolis Blower Door via depressurisation. This method was selected due to its speed and simplicity compared to other methods for determining air change rates such as tracer gas techniques. The blower door test method uses the relationship between flow through the envelope and the pressure difference across it to quantify airtightness (Sherman, 1987).

In accordance with a standard testing protocol (ATTMA, 2016), all external doors and windows were closed and internal doors propped open. Water traps in sinks and baths were filled with water and wall vents and fireplace vents were sealed with aluminium tape. Gas central heating was turned off during testing. Trickle vents were opened or closed depending on the testing phase. The same operator conducted all tests, apart from the pre-retrofit test. At points during testing, direction of fan airflow was reversed to pressurise the building and smoke sticks used to qualitatively examine air leakage of particular building elements.

The air tightness measurements were conducted in three phases: pre-retrofit; post-retrofit with all vents closed; and post-retrofit with various amount of trickle vent opening. To determine which envelope opening to place the blower door into, six tests were carried out: two with the blower door in the front door, two in the side (kitchen door), and two in the rear door (dining room) on the same day. This examined which door was most suitable to use because sealing the blower door in a particular opening removes what could be a substantial leakage area from the results. The front door has a semi-circular upper portion and despite filling the arched portion with a wooden panel, a perfect seal could not be achieved (Figure 6). The kitchen door entered into a very small room and the internal door partially blocked the air-flow to the fan (Figure 5 (floorplan) and Figure 7). Therefore the rear dining room was selected as the door to use for all tests (Figure 8).

Figure 6 – Front door with a semi-circular wooden panel to fill the gap in the upper arch.

Figure 7 - Kitchen (side) door has potential interference from internal doors.

Figure 8 – Blower door apparatus set up in the rear door (dining room). All main tests were conducted from this opening.

The air infiltration data which forms this research was gathered from 167 separate blower door tests. One pre-retrofit (no trickle vents installed) (Beizaee, et al., 2015) and 166 post-retrofit.

Pre-retrofit airtightness data was collected on 3 July 2013 (Beizaee, et al., 2015) via a single test. Post-retrofit airtightness testing was conducted on 13 days between 4 January 2017 and 15 March 2017. 34 blower door tests were carried out with trickle vents closed, but not sealed (excluding the extra four tests on the front and side doors). This phase of testing provided comparison to pre-retrofit measurements, a baseline measurement for comparison with trickle vent opening and allowed comment on the repeatability of the testing under various internal/external environmental conditions. Ten additional tests were conducted with the trickle vents fully sealed with masking tape to test the airtightness of the brand new trickle vents in their closed position. Trickle vents were sealed and blower door tests performed on 3 February and 13 February to provide a variety of indoor/outdoor conditions. Trickle vent testing comprised 118 tests with at least one trickle vents open.

2.3 Data analysis

Data were analysed to compare pre- and post-refurbishment airtightness, the impact of trickle vent opening, and the repeatability of the fan pressurisation test. The results of a blower door test quantify the envelope leakage at an elevated pressure of 50Pa (Sherman, 1987). To derive a value for an estimate of the infiltration rate at normal pressure the K-P model was used by dividing ACH_{50} by 20 (Persily, 1982).

Air temperature data and wind data were averaged for the duration of each individual test to enable comparison between tests.

3 RESULTS

3.1 Pre- and post-refurbishment air tightness

The refurbishment reduced mean air leakage (q50) by 6.1m^3/h/m^2 (29%) with all windows and trickle vents closed (see Table 3 for summary of results). However, the post-refurbishment q50 value is still in excess of the current regulations for new builds (10m^3/h/m^2).

Table 3 - Summary of blower door test results

Pre-refurbishment			Post-refurbishment		
q50 ($m^3/h/m^2$)	n50 (ACH_{50}) (1/h)	ACH (1/h)	q50 ($m^3/h/m^2$)	n50 (ACH_{50}) (1/h)	ACH (1/h)
20.8	21.5	1.1	14.7	15.3	0.8

Using smoke sticks it was found that the new windows were well sealed, as were the trickle vents with flaps in the closed position. Air leakage identified by the smoke sticks was higher around plumbing and electrical penetrations, the insulated loft hatch, and the interface between the wall and the ground floor above the suspended, ventilated timber floor.

3.2 Impact of trickle vent opening

There was a linear relationship between the measured air tightness and the open geometric free area of trickle vents (r^2=0.86) (Figure 9). Comparing sealed trickle vents with closed trickle vents, the mean q50 values were similar, 14.4$m^3/h/m^2$ (n = 10) and 14.7$m^3/h/m^2$ (n = 34), respectively. Compared to having no trickle vents open, when half the trickle vents required by the building regulations in new build properties was used, q50 increased by 6.7% (to 15.7$m^3/h/m^2$). Doubling the number of trickle vents to building regulation standard increased q50 by 12.2% to 16.5$m^3/h/m^2$ (n50 = 17.24 ACH_{50}), an increase of 1.8$m^3/h/m^2$ at 50Pa or 0.1 ACH at atmospheric pressure.

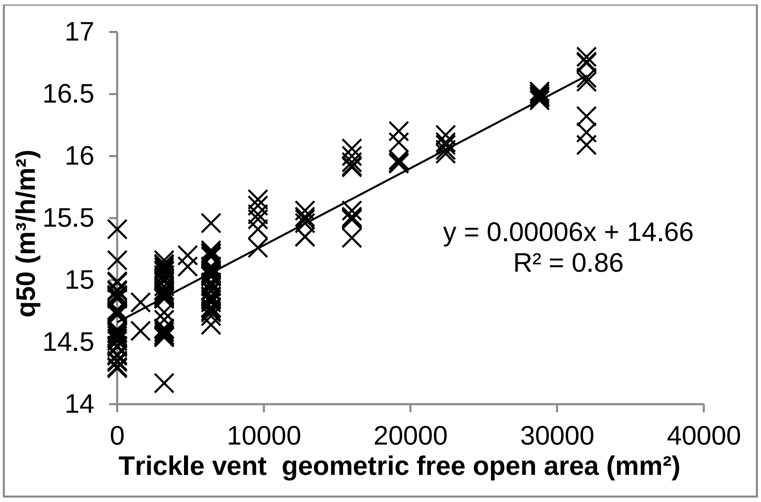

Figure 9 – Comparison of measured q50 to the geometric free area of trickle vent opening.

3.3 Repeatability of blower door test under various conditions

To test the repeatability of the blower door test method under a variety of internal and external conditions, 34 samples of measured airtightness with trickle vents closed collected over 13 days were used for analysis. The mean q50 value was 14.7$m^3/h/m^2$ with a standard deviation of 0.2$m^3/h/m^2$ and a standard error of 0.07$m^3/h/m^2$.

ATTMA (2016) notes that where wind speeds are higher than 6m/s the test results could be invalid. The maximum wind speed recorded during testing was 6.8m/s. Figure 10 shows no discernible relationship between q50 and wind speed. Therefore at this test site, under the wind regime experience the fan pressurisation test method can be applied under a variety of wind speeds without influencing the results. Similarly, measured q50 remains close to the mean value regardless of wind direction (Figure 11).

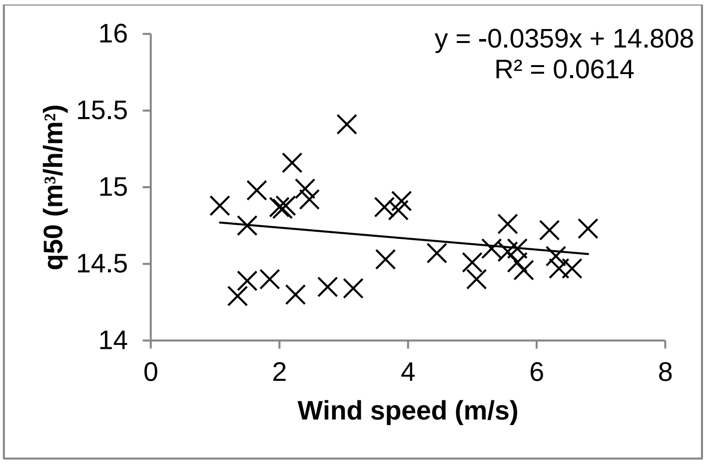

Figure 10 – Comparison of measured wind speed to measured q50.

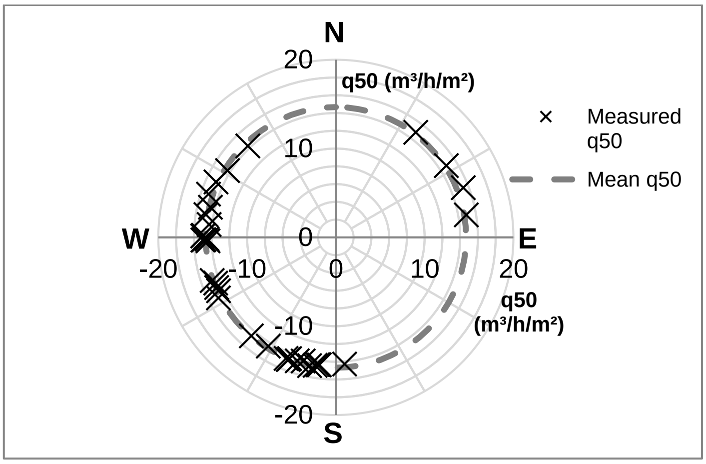

Figure 11 - Comparison of measured wind direction to measured and mean q50. North is top.

Indoor temperatures ranged from a maximum of 20.8°C to a minimum of 14.5°C. Outdoor temperatures ranged 15.3°C to 5°C. The maximum and minimum difference between indoor and outdoor temperature was 13°C and 0.9°C respectively. No clear relationship between ΔT and q50 values was found (Figure 12).

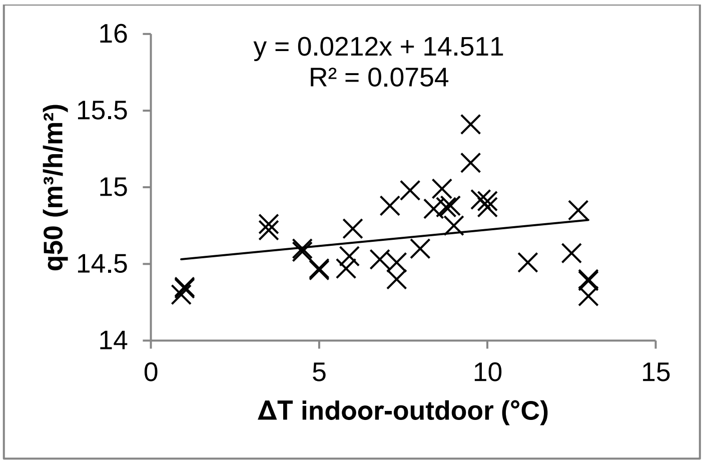

Figure 12 – Comparison of measured indoor-outdoor temperature against measured q50.

4 DISCUSSION

Effect of refurbishment on airtightness

The air change rate of the dwelling, post-retrofit with trickle vents closed was 0.8 ACH. Studies have shown that health risks to humans rarely occur until air change rates fall below 0.5 ACH (Oie, et al., 1999; Emenius, et al., 2004; Emenius, et al., 2004). Therefore there is minimal risk to human health because of poor IAQ, even after retrofit, in a house of this type.

Even after significant refurbishment, the house was not particularly airtight in comparison to a new build property in the UK, where building regulations specify a maximum q50 of $10m^3/h/m^2$ (HM Government, 2014) or compared to the UK average of $11.5m^3/h/m^2$ at 50Pa (Stephen, 1998). Recent studies which have found air quality issues in refurbished and newly built homes are generally concerned with deep refurbishments or those built to Passivhaus standard or similar (Less & Walker, 2014; Langer, et al., 2015; Derbez, et al., 2014). It is unlikely that existing homes, such as the one studied will suffer air quality issues unless a deep refurbishment is undertaken, with a particular focus on airtightness.

Oreszczyn et al. (2005) measured a mean reduction in air change rate of 0.23 ACH after new double-glazing was installed in 10 dwellings. This study found a very similar reduction, 0.3 ACH, but unlike the aforementioned study included loft insulation and door replacement.

This study found that replacement glazing (in combination with loft insulation) was considerably more effective in increasing airtightness than the findings of Gillott, et al. (2016) which was for a house of similar construction and layout. However, this study used a real original 1930s house, which prior to refurbishment had wooden-framed single-glazing. Gillott, et al. (2016) upgraded wooden-framed single-glazing to double-glazing, but the house was built in 2007 to a 1930s construction style. Therefore the single-glazing was likely to be in better condition than in the 1930s house in this study. Gillott, et al. (2016) mention this issue in their paper, which leads to the conclusion that draught proofing and floor sealing is the most effective measure in improving airtightness. However, the findings of this study indicate that in a real house, with poorly fitting single-glazing in decaying wooden frames, replacing windows could improve airtightness.

Effect of trickle vent opening on airtightness

Opening all trickle vents to UK building regulation standards provided only a small increase in air change rate of 12.2% (from 14.7 to $16.5m^3/h/m^2$ at 50Pa, all closed to all open respectively).

A study in Scottish dwellings found that once trickle vents are set in position, open or closed, they are very rarely changed again (Sharpe, et al., 2015). However in older, less airtight homes, such as the one studied, air quality issues are not likely to arise regardless of what position the trickle vents are left in.

Limitations and further work

A limitation of this study is that indoor air quality is not measured directly, because indoor pollutants like humidity, CO_2 and VOCs are not generated due to the houses being unoccupied and largely unfurnished. Therefore all assumptions on provision of indoor air quality are based solely on measured airtightness. This is problematic because the relationship between ventilation rates and IAQ is complex due to transient effects, the characteristics of specific sources, and other factors (Persily, 2016).

Further limitations include wind data being sourced from the University weather station 1km away from the test house. Due to the nature of local topography and sheltering or canyoning effects of surrounding buildings and trees the onsite wind speed and direction may have differed somewhat from the data used.

Further work could explore how further refurbishment, such as insulation of the brick cavity, draught proofing and addressing the gaps around the ventilated suspended timber floor affects the airtightness of the house. The use of tracer gas to directly measure ventilation rate, rather than air leakage at elevated pressure could provide a true measure of infiltration rather than airtightness at elevated pressure.

5 CONCLUSIONS

The results lead to two main conclusions. Firstly, refurbishing older homes of this type is unlikely to have a negative impact on indoor air quality because measured airtightness exceeds standards for new build dwellings. Therefore, the omission of trickle vents, which are not stipulated in building regulations for existing dwellings may not unduly diminish indoor air quality in older, less airtight homes.

Refurbishing a 1930s semi-detached house with loft insulation and new double-glazing reduced air leakage of the dwelling by 29% ($6.1m^3/h/m^2$) from 20.8 to $14.7m^3/h/m^2$ at 50Pa in what was, and remains, a leaky house in comparison to current UK standards for new builds. Trickle vents provided limited additional ventilation of $1.8m^3/h/m^2$ at 50Pa (from 14.7 to $16.5m^3/h/m^2$ at 50Pa, all closed to all open respectively), an increase of 12.2% when opened to UK building regulation stipulated levels. Whilst not a concern for a leaky home such as the one studied, this could have negative implications for air quality in a more airtight home which relies on trickle vents to provide sufficient background ventilation.

The blower door test was found to be repeatable with a standard error or $0.07m^3/h/m^2$ at 50Pa based on 34 tests with trickle vents closed. There was no relationship between air tightness and wind speed or direction, or the indoor/outdoor temperature difference.

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