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Effectiveness of draught reduction measures at improving building air-tightness

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ABSTRACT: The building sector has a serious detrimental impact on the environment and reducing building energy requirements is an important environmental priority. Draughts (unmanaged air infiltration and exfiltration in buildings) can significantly increase building heating demand. Draught reduction measures (stripping building elements and chimneys balloons) are low cost and suitable for all building typologies and ages. This paper measures the effectiveness of draught reduction measures on reducing building air permeability for six case study houses; three Victorian and three mid-20th century houses.
The air permeability of the buildings in this study ranged from 8-16.4 m^3/m^2hr with the chimneys sealed. A combination of draught reduction measures reduced air leakage from the case study houses by 10-35%. Chimney balloons in unused fireplaces were the most effective means of minimising air leakage by between c.220-500m^3/hr per chimney. The study confirms that draught reduction measures are a viable and efficient method of eliminating unnecessary heat loss from buildings.

KEY WORDS: Draught reduction measures; building air-tightness

1 INTRODUCTION

The building sector has a serious detrimental impact on the environment. In the European Union, the building sector accounts for 40% of the final energy consumption and 36% of the carbon emissions [1]. European policy such as the 2030 European climate and energy framework is providing targets to reduce greenhouse emission and improve energy efficiency. In this context of environmental damage and legislative obligation, it is essential to reduce building energy consumption. Currently, approximately 35% of the EU's buildings are over 50 years old and improving their energy efficiency could reduce total EU energy consumption by 5-6% and lower CO_2 emissions by about 5% [1].

It is important to eliminate unnecessary heat loss and in Ireland, the DoEHLG (2011) estimates that easily avoidable air leakage is responsible for 5-10% of heat loss [2]. Additionally building air tightness becomes proportionally more important as thermal insulation standards improve [3]. The Irish building regulations relating to conservation of fuel and energy for buildings (Technical Guidance Document - Part L 2011) identifies an air permeability of 7 m^3/hm^2 as an upper limit for new builds although there is currently no minimum airtightness standard when upgrading existing dwellings.

Air leakage (air infiltration/exfiltration commonly known as draughts) are air currents caused by air movement into and out of a building. In temperate climates, a common problem is the displacement of warm internal air by cool external air lowering room temperatures. This air leakage is caused by air pressure differences between the interior and exterior of the building. Air tightness has a large effect on heat energy consumption [4 referring to 5] and air movement can also reduce occupant's thermal comfort [4 referring to 5, 6 and 7]. Furthermore, air leakage can cause moisture transfer and accumulation within the building envelope with resulting reduced thermal resistance and material deterioration.

Draught reduction measures are low cost retrofit measures suitable for all building typologies and ages. They are particularly suitable for historic building on account of their low visual impact and reversibility where more invasive retrofitting options (such as external porches and wall insulation) may not be appropriate.

Product manufacturers typically state high potential energy savings. However, it is difficult to accurately quantify the effectiveness of draught reduction measures as their success is dependent on many variables including building typology, age and condition of building elements, type of draught reduction measure and the quality of workmanship at fitting the draught reduction measure. Previous research reports conflicting improvements in airtightness following thermal upgrading [8, 9, 10 and 11]. Furthermore, there are no definitive proportions of air leakage that can be attributed to different building components (such as walls, floors or roofs) due to differing sizes, ages and materials which make them responsible for producing varying results in different buildings [12 and 13]

2 CASE STUDIES, DRAUGHT REDUCTION MEASURES AND MEASUREMENT METHOD

2.1 *Case Studies*

Six case study houses comprising of three red brick Victorian houses (case studies 1-3) and three mid-twentieth century house (case studies 4-6) in Dublin, Ireland were investigated in this research. Both typologies are common throughout the city. The houses were selected considering the retention of original building features and minimal previous draught retrofitting work.

Figure 1. Representative example of the Victorian houses in this study.

Figure 2. Representative example of the mid-twentieth century houses in this study.

The Victorian houses were built between c.1870 – 1890 and largely retained their original building layout and features as detailed in table 1. The houses have suspended timber floors which allow internal warm air to move between the floor boards into the space beneath the floor and out of the building through the ventilation brick, permitting the reverse path for cold air entering the building. The original timber doors had fanlights. All houses retained their original single-glazed sash windows with draught stripping brushes in poor condition in case studies 1 and 2. Fireplaces were present in the two downstairs reception rooms and also remained in the bedrooms of case study 1. All the fireplaces had a large brick-lined flue. The attic hatches were rectangular ceiling openings with sheet timber hatch doors.

The mid-twentieth century houses also retained their original layout with a mixture of original and replacement features. All floors were likely concrete and carpeted over. Case studies 4 and 5 retained their original glazed and timber door with the later addition of an external porch while case study 6 has a replacement timber door c.1990. Their window typology varies as original mid-20thcentury windows are uncommon and mostly replaced. Case studies 4,5 and 6 had replacement uPVC windows, original timber windows and replacement timber windows c.1990 respectively. Two open fireplaces were present in each mid-twentieth century house and had smaller lined flues than the Victorian houses. The mid-twentieth century houses also had sheet timber attic hatch doors.

Table 1. Building features in the case study houses. All houses had sheet timber attic hatch doors.

Case Study	Floor	Door	Window	Chimneys
1	Suspended timber floor	Original timber door with fanlight	Sash windows with draught stripping in poor condition	3 large and 1 small chimney
2	Suspended timber floor	Original timber door with fanlight	Sash windows with draught stripping in poor condition	2 large chimneys
3	Suspended timber floor	Original timber door with fanlight	Sash windows	2 large chimneys
4	Concrete and carpet	Original glazed and timber door with external porch	uPVC windows	2 medium chimneys
5	Concrete and carpet	Original glazed and timber door with external porch	Original mid-20th century timber windows	2 medium chimneys
6	Concrete and carpet	Replacement timber door c.1990	Replacement timber windows c.1990	1 medium and 1 small chimney

2.2 *Draught reduction measures*

The draught reduction measures investigated in this research were selected based on their low cost, low visual impact, reversibility and relative ease of installation with little construction expertise as per table 2. It was important that all measures adhered to the fundamental conservation principles for historic buildings of minimum intervention and reversibility.

Suitable draught retrofitting measures were installed in the houses following discussion with the homeowners (table 3). Chimney balloons were only installed in fireplaces that were mostly unused and windows were not stripped in kitchens, bathrooms or bedrooms in some instances where the occupants liked the windows to provide fresh air during the night.

Table 2. Draught reduction measures.

Building element	Draught reduction measure
Chimney	PVC chimney balloon inserted snugly in flue
Door	Exitex standard door surround, brush letter flap and keyhole cover
Window	Q-Lon draught stripping around perimeter of window. Lower sash only of the sash windows. E-shaped EPDM rubber draught strip to windows of case study 5.
Attic hatch	Q-Lon draught stripping around perimeter of hatch and small hooks to fix the hatch door in place
Floor	DraughtEx draught stripping between floor boards

Table 3. Number of retrofitted features along with their total approximate perimeter in brackets.

Case study	Door	Windows	Chimneys
1	1 (5.3m)	5no. (5.1m)	4 with 1 remaining open
2	1 (5.2m)	3no. (3.2m)	2 with 0 remaining open
3	1 (7m)	6no. (7.6m)	2 with 1 remaining open
4	1 (5m)	3no. (3.5m)	2 with 1 remaining open
5	1 (5.1m)	6no (4.6m)	2 with 1 remaining open
6	1 (5.1m)	5no. (4.6m)	2 with 0 remaining open

2.3 *Air permeability measurement*

Airtightness testing (air permeability) was undertaken using the fan pressurization method in accordance with BS EN ISO 9972:2015. A Retrotec 2000 fan and DM2 Mark II gauge micromanometer were used to carry out the testing. Data was manually logged. A five point test (pressurisation) was undertaken between 40 and 60PA at c.5Pa intervals by altering the fan speed. The indoor air temperature varied between 10.1-16.8 °C and the external temperature 1.7-12.3 °C. The wind speed was at 3 or below on the Beaufort scale for all tests.
The fan was initially installed in the back door for measurement of the air permeability of the whole house. The fan was later installed in different locations in the house depending on the retrofit measures. An air permeability measurement of the space was taken before and after each retrofit measure was applied. For example, when measuring the effectiveness of door stripping, the fan was located typically in the door opening between the kitchen and hall and all the other internal doors closed. A measure of air permeability would be taken before and after the door was stripped and the reduction in air permeability between the two measurements attributed to the ability of the door stripping to reduce air leakage. In order to avoid measurement errors, the selection of the location of the fan was intended to ensure that the air permeability of as small a space as possible was measured. Measurement errors are related to the size of the flow rate and smaller areas have smaller flow rates reducing any associated measurement error. The data was manually analysed. The measured air flow rate was corrected taking account of temperature variation between the interior and exterior. The air flow rate through the building was plotted against the corresponding pressure differences on a log-log plot to provide an air leakage graph. The plot is used to determine the air flow coefficient (C_L) and air flow exponent (n). The air leakage rate at 50Pa is calculated using these values.
The relationship between pressure and air flow rate is set out in equation 1.

$$V_l = \dot{C_l}(dP)^n \qquad (1)$$

V_l = Air leakage rate (m^3/hr)
C_l = Air flow coefficient
dP = Induced pressure difference between interior and exterior (Pa)
n= Air flow exponent

The results are expressed as the air permeability rate (q50) @ 50Pa as set out in equation 2.

$$Q_{50} = \dot{V}_{50}/AE \qquad (2)$$

Q_{50} =Air permeability @ 50Pa
V_{50} = Mean air leakage rate @ 50Pa
AE = Envelope area (external walls m2)

2.4 *Homeowner perception of the effectiveness of draught reduction measures*

Homeowners were asked to rate their perception of the improvement in the reduction of draughts for each draught reduction measures and the total overall improvement in a short questionnaire, four months after the installation of the draught reduction measures. They were asked to rate their perception of improvement on a five point scale with 1- very poor, 2 – poor, 3 –average, 4 – good and 5 – very good.
They were also asked if any problems such as dampness or mould had arisen in the four month period following the installation of the draught reduction measures.

3 RESULTS

3.1 *Effectiveness of the draught reduction measures overall*

Table 5 shows the air permeability of each case study house. Building air permeability is commonly expressed with chimney openings sealed. Therefore, these permeability figures can be used to compare the performance of the case studies in this research with other buildings in literature and reports. This project investigates the impact of closing chimney flues with balloons. It was therefore also necessary to measure the building air permeability of the houses with the chimneys open. The results are summarised in Table 5.

The differences between the post retrofitting values (chimney flue either open or sealed) depend on the number of fireplaces that were left open (no chimney balloon) following retrofitting. The houses with the same post retrofitting values (case studies 2 and 6) have no open flues in the houses while case studies 1,3,4 and 5 retained one usable fireplace.

Table 5. Building air permeability before and after the draught reduction measures, including and excluding the chimney openings.

Case Study	House surface area (m^2)	Total air flow rate (m3/hr)	Air permeability (m^3/m^2h) Chimney open		Air permeability (m^3/m^2h) Chimney closed	
			Baseline	After retrofitting	Baseline	After retrofitting
1	373.1	6974.7	18.7	14.3	14.4	13
2	405.2	7041.0	17.4	13.2	16.4	13.2
3	433.2	6558.6	15.1	13.5	13.1	12.1
4	291.6	2973.4	10.2	8.6	8.0	7.3
5	315.5	5049.4	16.0	11.3	13.2	10.1
6	252.9	3102.1	12.3	8.0	8.6	8.0

Building air permeability in this study ranged from 8.6-16.4 m^3/m^2hr with the chimney sealed (typical requirement for standard air permeability measurement in buildings). These results are in line with research by [14] on the Irish building stock who reported mean air permeability of 7.5 m^3/hm^2 for houses built between 1944 and 1975 (likewise case studies 4 and 6). Similarly,the results of this study (showing a range between 8.1-15.1 ACH at 50 Pa) agree with BRE studies reporting permeability range between 10 and 16ACH at 50 Pa [12]. The figures differ from Ahern et al. (2013) who calculated values for detached houses [15].

Following draught reduction measures, the building air permeability of the case study houses was reduced to 7.3 - 13.2m^3/m^2hr. The Irish building regulations relating to conservation of fuel and energy for buildings (Technical Guidance Document - Part L 2011) identifies a performance level of 7 m^3/hm^2 as an upper limit for air permeability for new builds (currently, no minimum airtightness standard when upgrading existing dwellings exists) therefore, all the case study buildings exceed the upper limit of this standard. The post retrofit values are also slightly above Broderick et al. (2017) [16] (5.53-8.61 m^3/hm^2) who undertook a substantially more intensive retrofit with insulation and replacement windows and doors.

A larger improvement in the building air permeability values was observed when including open chimneys. In this case, the building air permeability ranged from 10.2-18.7 m^3/m^2hr and reduced to 8-14.3 m^3/m^2hr following draught reduction measures. The results show that a combination of draught reduction measures can minimise air leakage from houses by 10-35%.

No definitive relationship between building age and building air permeability was observed with the exception of case study 5, the nineteenth century buildings have a higher air permeability than the mid-twentieth century buildings. It is however important to note that only case study 5 of the mid-century houses retains its original windows.

3.2 Effectiveness of individual draught reduction measures

Table 6 shows the reduction in the measured air flow value following the installation of the draught reduction measures. Results with an asterix are those within the margin of error of the measuring equipment (the difference in the air flow measurement before and after the draught reduction measures is less than 5% of the air flow measurement).

Chimney balloons in unused fireplaces are the most effective means of minimising air leakage by between c.220-500m^3/hr per chimney (measured using the air blower door test). Chimney balloons reduced house air leakage by approximately c.3-15% per chimney. The air blower door test measured a difference in flow rate below 12% (with one exception) between the air flow rate of the chimney with the chimney balloon and the fully sealed chimney. This indicates that, when the balloon is appropriately sized and fitted, it is effective at stopping most of the air leakage through the chimney and allows ventilation of the flue.

Stripping the windows and doors yielded small improvements in air flow leakage typically 1-3%. Despite many of these readings being within the margin of error of the measuring equipment, they all show a consistent downward trend. Furthermore, these results agree with Stephens (1998) who attributed 2% of building leakage rates to window and door surrounds [12]. The main exception to the small improvement in window draught stripping are the original timber windows in Case Study 5 which had a large number of openings and were noted by the owners as being particularly leaky. This indicates that these elements can, in certain circumstances, significantly contribute to building air leakage.

Stripping attic hatches reduced air leakage by 0.5-4% per hatch. Stephens (1998) attributed 2% of building leakage rates to attic hatches so these improvements are in line with his findings [12].

The results also evidenced that draught stripping suspended timber floors is a highly effective means of reducing air leakage from houses, reducing building air leakage by up to 16% (case study 2). The effectiveness of this measure is dependent on the level of underfloor ventilation. Two of the Victorian houses (case studies 1 and 3) have missing/blocked vent bricks and, consequently, draught stripping the floor had little impact at reducing draughts. Interestingly, in both cases, the owners noticed a reduction in the cold air coming from the floor. It is likely that the draught stripping didn't reduce cold air

infiltration from outside through the floor boards but minimised the effect of air being cooled by the ground beneath the house and subsequently rising through the floor boards.
The measured results do not show similar improvements in air leakage values for the draught reduction measures of the building elements (windows, doors etc.) in different buildings. This is similar to the findings of other researchers who attributed this to the variety of building components, ages and finishes.

Table 6. Effectiveness of individual draught reduction measures at reducing air flow rate (m^3/hr)

Case Study	Door	Window	Attic	Chimney	Floor	Total
1	44*	210	140*	1114	125*	1633.9
2	n/a*	91.9*	n/a	445.2	1136	1673.7
3	144.6*	144*	72*	288.5	76*	725.1
4	63.7*	29.3*	97.3	271.6	n/a	461.9
5	61.1*	705	205.3	502.4	n/a	1473.8
6	n/a*	86.8*	62*	920.0	n/a	1069.5

*within the margin of error of the measuring equipment

The following chart shows the percentage contribution of each retrofit measure towards draught reduction in each case study house.

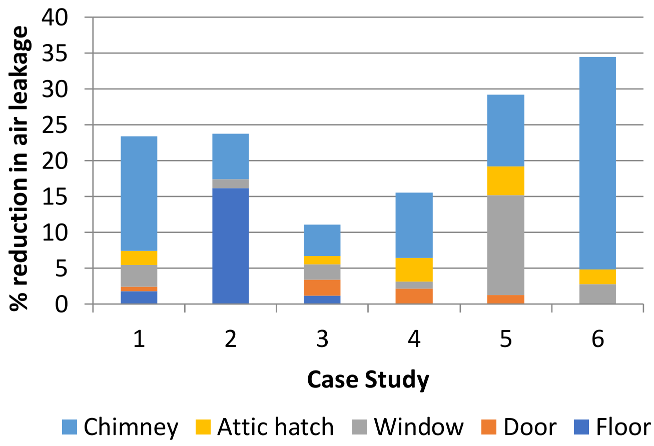

Figure 3. Percentage reduction in air leakage from each case study house.

Table 7. Data from figure 3

Case Study	Door	Window	Attic	Chimney	Floor	Total
1	0.6	3.0	2.0 (3)	16.0 (3)	1.8	23.6
2	n/a	1.3	n/a (1)	6.3 (2)	16	24.5
3	2.2	2.2	1.1 (2)	4.4 (1)	1.2	11.4
4	2.1	1.0	3.3 (1)	9.1 (1)	n/a	16
5	1.2	14.0	4.1 (1)	9.9 (1)	n/a	28.9
6	n/a	2.8	2.0 (1)	29.7 (2)	n/a	34.5

() Number of elements

It is difficult to fairly compare the effectiveness of different draught reduction measures. Case study house 1 and 2 reduced their air flow rate by the greatest quantity (table 3) but case study 5 and 6 showed the greatest percentage improvement on account of their lower initial total leakage rate. Older buildings may also have greater ability to reduce the total air flow loss (m^3/hr) than newer buildings on account of greater scope for draught reduction measures such as suspended timber floors and more chimney openings. However, the percentage improvement in draught reduction for elements such as windows and door may be viewed as smaller on account of their larger initial air leakage. The improvement by each measure also depends on the size of the opening and condition of the building element.

3.3 *Effectiveness of draught reduction measures and homeowner perception*

A short questionnaire rated the perceived reduction in draughts following the installation of the draught reduction measures as shown in table 7.

Table 7. Homeowner's perceived improvement in the reduction of draughts for each draught reduction measure and total overall improvement.

Case Study	Door	Window	Attic	Chimney	Floor	Total
1	5	3	4	3	4	4
2	3	4	4	4	3	3
3	3	4	3	2	3	3
4	2	2	2	2	-	2
5	4	4	4	4	-	3

*Five point scale with 1- very poor, 2 – poor, 3 –average, 4 – good and 5 – very good in a short questionnaire four months after the installation of the draught reduction measures.
**Case study 6 did not complete a questionnaire.

There was a strong disagreement between real and perceived effectiveness of draught reduction measures by homeowners. The chimney balloons are the most effective means of minimising draughts yet they were consistently considered by homeowners as less effective than window and door retrofitting which had a significantly lower impact.It is possible that the chimney balloons reduced the stack effect in the houses and consequently reduced air infiltration around the windows and doors.
No homeowner identified any new problem (such as damp or condensation) arising following the installation of the draught reduction measures.

4 CONCLUSIONS

The results show that a combination of reversible, draught reduction measures with low visual impact, suitable for all building typologies can minimise air leakage from houses by 10-35% significantly improving the air tightness of buildings and therefore are a viable, low-cost option for eliminating unnecessary heat loss from buildings.

Following draught reduction measures, the building air permeability of the case study houses was reduced to 7.3 - 13.2m^3/m^2hr, getting closer to the upper limit for air permeability for new builds (7 m^3/hm^2) of the Irish building regulations.
Chimney balloons in unused fireplaces are the most effective means of minimising air leakage lowering infiltration by 3-15% per chimney.Stripping the windows and doors yielded small improvements in air flow leakage reduction, typically 1-3% while stripping attic hatches reduced air leakage by 0.5-4% per hatch. The results also evidenced that draught stripping suspended timber floors is a highly effective means of reducing air leakage from houses, reducing building air leakage by up to 16%. The effectiveness of this measure is dependent on the level of underfloor ventilation.
There are factors that determine the improvement in draught reduction for different building elements such as their initial air leakage, the size of the openings and the condition of the building element.
Furthermore, there was a strong disagreement between real and perceived effectiveness of draught reduction measures by homeowners.

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