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An investigation of draught reduction measures and their impact on building air quality

R. Walker and S. Pavía.

Dept. of Civil Engineering. Trinity College Dublin.
walkerro@tcd.ie; pavias@tcd.ie; https://www.tcd.ie/civileng/people/pavias/

1. Introduction

The recent cold winter has again highlighted the importance of thermal comfort and energy savings in Irish homes. It is estimated that the building sector accounts for 40% of the final energy consumption and 36% of the carbon emissions in the EU [1]. This environmental impact, coupled with increasingly challenging European policy and legislation, demands an urgent need to improve building energy efficiency.

Draughty houses are a frequent nuisance in Ireland caused by open chimney flues and leaky building elements. The DoEHLG (2011) estimates that easily avoidable air leakage is responsible for 5-10% of building heat loss [2]. Draught reduction measures can be effectual owing to their low cost, ease of installation and reversible/unobtrusive nature, making them suitable for all building typologies including protected structures which form a significant part of our building stock.

Air leakage (uncontrolled air infiltration/exfiltration commonly known as draughts) are air currents caused by air movement into and out of a building. This air leakage is produced by air pressure differences between the interior and exterior of a building and is largely caused by wind, chimneys and ventilation systems. Openings in the building envelope may appear small but can total a large area when summed together. As expected, air tightness has a large effect on heat energy consumption [3 referring to 4]. Furthermore, the impact of a draught on an occupant's thermal comfort can be greater than the actual reduction in room temperature [3 referring to 4, 5, 6]. Air leakage can also transfer moisture into the building envelope with the resulting reduction in thermal resistance and risk of material deterioration.

Product manufacturers typically state high potential energy savings for draught retrofitting measures but their actual effectiveness is dependent on many variables including building typology, age and condition of building elements. Previous research reports various improvements in airtightness following thermal upgrading [7, 8, 9 and 10]. However, 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 [11 and 12].

Furthermore, there are some drawbacks associated with reduced building air permeability as lower ventilation rates increase the risk of accumulation of indoor air pollutants.The EPA reports reduced building ventilation as one of the causes of air quality problems in buildings [13]. Ventilation allows the reduction of indoor pollutants by means of their extraction to the outside and replacement with fresh outdoor air. The impact of building air permeability on the levels of indoor air pollutants is frequently not considered [14] although Prasauskas et al. (2016) observed no significant changes in VOC or NO_2 levels after retrofits [14] but conversely Broderick et al. (2017) measured an increase in the presence of some pollutants following thermal retrofitting in a study of the Irish building stock [15]. This research investigates the success of a range of draught retrofitting measures at reducing air leakage from houses and whether there is a resulting impact on indoor air quality.

2. Materials and Methods

2.1 Description of case study

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 were investigated. The houses were selected considering the retention of original building features and minimal previous draught intervention. The features in the houses are detailed in table 1.

Figures 1 and 2. Representative example of the Victorian houses and mid-twentieth century houses in this study.

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

Case study	Floor	Door	Windows	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,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 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	Draught strip door surround, brush letter flap and keyhole cover
Window	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	Draught stripping around perimeter of hatch and small hooks to fix the hatch door in place
Floor	Draught stripping between floor boards

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

Case study	Door	Windows	Chimneys	Attic hatch
1	1 (5.3m)	5no. (5.1m)	4 with 1 remaining open	3 no. (6m)
2	1 (5.2m)	3no. (3.2m)	2 with 0 remaining open	1 no. (2m)
3	1 (7m)	6no. (7.6m)	2 with 1 remaining open	2 no. (4m)
4	1 (5m)	3no. (3.5m)	2 with 1 remaining open	1 no. (2m)
5	1 (5.1m)	6no (4.6m)	2 with 1 remaining open	1 no. (2.6m)
6	1 (5.1m)	5no. (4.6m)	2 with 0 remaining open	1 no. (2m)

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 was 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 fan was located in various positions in the house depending on which draught retrofitting measure was being investigated. The indoor air temperature varied between 10.1 and 16.8 °C and the external temperature between 1.7 and 12.3 °C. The wind speed was at 3 or below on the Beaufort scale for all tests.

2.4 Air quality measurement

2.4.1 Continuous temperature and RH. Monitoring the temperature and RH over time provided a general overview of the indoor air quality. The internal room temperature and RH were logged at half hour intervals using a Lascar EL-USB 2+ temperature and a humidity logger. Logging was undertaken continuously for 3 months following the application of the draught reduction measures.

2.4.2 Indoor air quality measurement – CO_2, CO, PM10 and VOCS. The indoor air quality was measured following the installation of the retrofitting measures to ensure that the reduction in building air permeability did not result in poor indoor air quality. A 3M EVM7 device measured indoor levels of CO_2, CO, PM10 and PIDS over a five hour period. The PID detector was calibrated with isobutylene with a correction factor of 1. The equipment was located in the most frequently occupied space in the house. The readings were taken over a short time period with varying occupancy levels and behaviour in each case study.

3. Results

3.1 Effectiveness of the draught reduction measures overall

The results show the air permeability of the case study houses before and after retrofitting with the draught reduction measures (table 5). Air permeability in buildings is typically measured with chimneys sealed therefore, these results are included for comparison with other published data. The results with the chimneys open are also included to show the effectiveness of the chimney balloons. The difference in post retrofitting values (between chimney open and sealed) is dependent on the presence of an open flue in the building with some homeowners wishing to continue to light open fires.

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

Case	House surface area (m^2)	Total air flow with chimneys open prior to retrofitting (m^3/hr)	Air permeability (m^3/m^2h) Chimney open		Air permeability (m^3/m^2h) Chimney sealed		Air Change Rate (ach @50Pa) (chimney sealed)
			Baseline	After retrofitting	Baseline	After retrofitting	Baseline
1	373.1	6974.7	18.7	14.3	14.4	13	14.0
2	405.2	7041.0	17.4	13.2	16.4	13.2	15.1
3	433.2	6558.6	15.1	13.5	13.1	12.1	12.5
4	291.6	2973.4	10.2	8.6	8.0	7.3	8.1
5	315.5	5049.4	16.0	11.3	13.2	10.1	14.0
6	252.9	3102.1	12.3	8.0	8.6	8.0	8.7

The building air permeability in this study ranged from 8.6-16.4 m^3/m^2hr with the chimney sealed similarly to other published data [11,16] Following draught reduction measures, the building air permeability of the case study houses was reduced to 7.3 - 13.2m^3/m^2hr. This is above the upper limit for air permeability for new buildsof 7 m^3/hm^2 set out in Technical Guidance Document - Part L 2011.

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% however, no definitive relationship between building age and building air permeability was observed. A breakdown of the individual draught retrofitting measures shall be published in the upcoming Civil Engineering Research Ireland conference (CERI 2018).

3.2 Indoor air quality and its relationship with building permeability

The air quality was measured for four case study houses (1, 3, 4 and 5) as per table 6. The average temperature and relative humidity were measured over three months (13/01/2017-12/04/2017) (figure 4). The air quality was monitored over five hours when the living area was occupied on a typical evening (morning for case study 5) with the windows closed as per table 6 and figure 5-7. As the readings were only taken over a very limited time period with different occupancy levels and behaviour, the results can only be view as an individual incidence in time.

The relative humidity mostly varied between optimum conditions(40%-60%RH)for the duration of the three month testing period which is indicative of good levels of ventilation (figure 4).

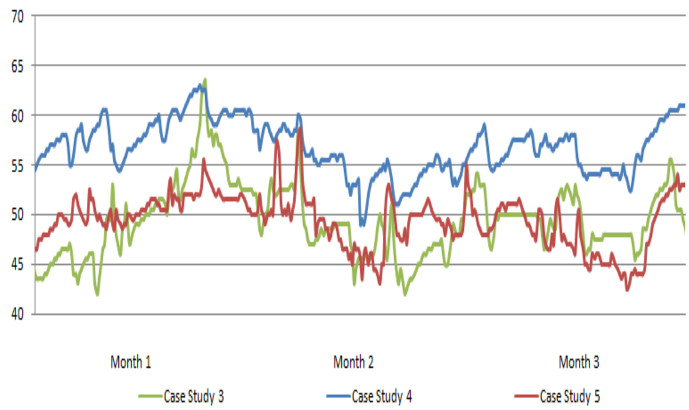

Fig 4. Internal RH in case studies 3, 4, and 5.

CO_2 is not technically an air pollutant and concentrations in indoor air provide an indication of ventilation rather than absolute air quality. The average CO_2 levels (table 6) are within the appropriate guidelines for moderate air quality (c.1200 - EN 13779:2007** (IDA 3 - moderate IAQ [17]). All case studies show rising and falling CO_2 levels (figure 5) as the occupancy of the room changed throughout the monitoring period. This indicates that there is sufficient air infiltration into the room to dilute accumulations of CO_2. Case study 1 has the lowest background levels of CO_2 and also the lowest increase in levels of CO_2 which can be attributed to only a single person in the room.

Particulate matter concentrations (PM10) are within the safe ranges in all case studies (table 6 and figure 6) of 50 µg/m^3 over 24hours [18]. Case studies 1 and 4 with incense and an open fire have the highest levels of particulate (PM10) present. The particulate concentration falls in case study 1 following the extinction of the incense stick at the beginning of the monitoring period.

There are no established safe PID (photoionization detector for volatile organic) levels owing to the fact that PID levels measure the presence a combination of many different gases, all with different safety limits. PID levels are shown in figure 7. The results for case studies 1, 4, and 5 show consistent low levels during the testing. Case study 3 has an elevated PID peak for a short period before dropping and stabilising showing that adequate air infiltration has diluted the high VOC concentration. Carbon monoxide remains below 1PPM for the duration of testing and within acceptable limits.

Table 6 – Air quality in the four case study houses.

Case	Ave temp °C	Ave RH %	CO_2 PPM	CO (PPM)	PM10 mg/m3	PID PPM	Occupancy
	Average over 3 months		*Average over 5 hours*				
1	-	-	739.39	Never above 1PPM	0.05	1.45	1 person, incense
3	17.5	54.4	979.20	Never above 1PPM	0.03	2.40	2 people
4	16.0	57.2	940.70	Never above 1PPM	0.05	1.50	2 people, fire on
5	18.0	51.4	1014.8	Never above 1PPM	0.02	0.15	2 people

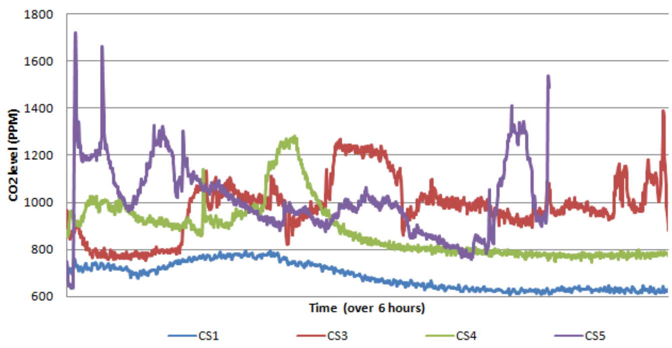

Figure 5. CO_2 levels (PPM) for case study houses over five hour monitoring period

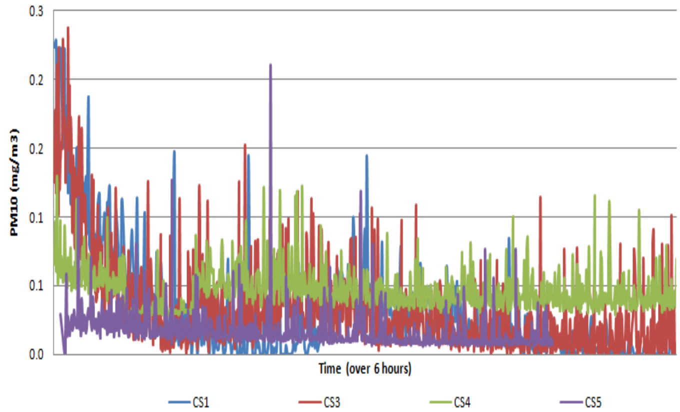

Figure 6. PM 10 levels for case study houses over five hour monitoring period.

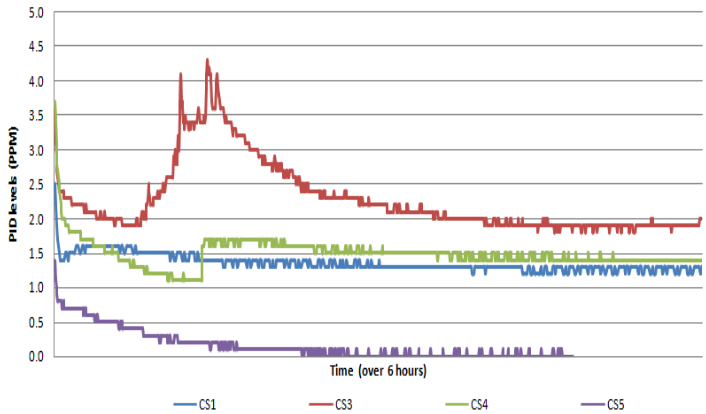

Figure 7. PID levels for case study houses over five hour monitoring period

Conclusion

The results show that draught reduction measures substantially reduced air leakage from the houses by 10-35%. The indoor air quality for CO, CO_2, PM10 and PIDs was acceptable at the building air permeability rates measured in this study (between 8.6-14.3

m^3/m^2hr). The findings indicate that draught reduction measures are effective at minimising unnecessary heat loss from buildings. Further project findings including the effectiveness of the individual measures shall be published at the Civil Engineering Research Ireland conference 2018.

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