AIRTIGHTNESS AND VENTILATION OF SOCIAL HOUSING IN IRELAND – A REVIEW OF FIELD MEASUREMENTS AND OCCUPANT PERSPECTIVES PRE- AND POST- RETROFIT

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ABSTRACT

Airtightness and controlled ventilation are important factors affecting energy use and indoor air quality. Airtightness tests were carried out on nine naturally ventilated social houses in Ireland. Subsequently, four of the houses were retested following energy efficient upgrading. The upgrading largely consisted of improving fabric insulation and where required the mandatory installation of passive wall vents. Interviews were conducted with the occupants to gain their perspectives of airtightness and ventilation in their homes. The occupants of the upgraded houses were interviewed pre- and post- the process.
The paper compares the results obtained to that assumed in the Dwelling Energy Assessment Procedure (DEAP), which is Ireland's National Methodology for calculating the energy performance of dwellings. The location of the most onerous visible air leakage paths, identified using a smoke pencil are presented.
As an unintentional side-effect, fabric upgrading considerably improved the airtightness of the dwellings. However, due to lack of cognisance of airtightness principles, simple airtightness techniques which would further improve results were not integrated into the upgrading process. The survey revealed that although occupants understand that ventilation is important, their understanding of required ventilation levels and control is limited. Airtightness levels in one house were high, but the house was under-ventilated resulting in condensation and potential for mould growth on external walls. Whilst a number of houses had considerable levels of uncontrolled infiltration leading to occupant comfort levels being compromised. Overall occupants were happy with the upgrading but had a number of concerns about the newly installed passive vents.
The paper takes a novel approach combining quantitative and qualitative data gaining an insight into occupant attitude and behaviour. The paper highlights the importance airtightness and controlled ventilation in naturally ventilated houses. The paper discusses the potential to reduced air leakage to a level where mechanical ventilation with recovery (MVHR) becomes viable and can be integrated as part of the upgrading process.

KEYWORDS

Ventilation, Dwelling Airtightness, Testing, Occupant Perspective

1 INTRODUCTION

Social housing, accounts for approximately 8.6% (130000 units) of all housing in Ireland (ICSH, 2006). Nationally, Local Authorities are in the process of upgrading their older exiting housing stock, aspiring to increase living and comfort standards for occupants in unison with reducing energy use in the dwelling. This paper forms part of a study focused on the assessment energy use patterns in Irish social housing and the real effect of fabric upgrading.
It is a well-recognised in temperate climates, like Ireland, that a large proportion of heat loss from dwellings is as a result of air infiltration. However, there has been little attention given to improving airtightness as part of standard retrofitting strategies.

Building technologies and technical standards continually advancing, but to date there is little research relating to user interface with these buildings and a particular lack of knowledge relating to airtightness and ventilation.

This paper evaluates the technical findings from airtightness testing, comparing measured modelled airtightness levels and compliance with Building Regulations. The outcome of energy efficient retrofitting is then assessed and combined with surveys of occupant perspective of airtightness, existing practices and perceived effect of upgrading the houses.

2 BACKGROUND

While climate corrected energy use for each dwelling in Ireland decreased by 28% from 1990 to 2011, mainly as a result of improved energy performance of new housing stock, overall the housing stock has been identified as being one of the least energy efficient in the EU-27 (Lapillonne *et al.*, 2012, Howley *et al.*, 2012). In 2011 the "average" dwelling consumed 19,875 kWh of energy, based on climate corrected data, approximately 60% of which was used for space heating (Howley *et al.*, 2012, Janssen, 2004). Considering estimated heat loss due to 'easily avoidable air leakage' accounts for between 5 and 10%, up to 2000kWh of heat energy per dwelling is wasted annually in Ireland (DEHLG, 2008a).

Approximately 50% of the current Irish housing stock was built pre- 1979, when the minimum energy performance building regulations were introduced and mandatory airtightness testing was first introduced for new dwellings in 2008. Consequently, as a result of the recent downturn in Irish construction, almost all dwellings in Ireland have being constructed prior to any minimum mandatory airtightness levels. Technical Guidance Document (TGD) Part L states 'To avoid excessive heat losses, reasonable care should be taken to limit the air permeability of the envelope of each dwelling' and set a reasonable air permeability upper limit of $10m^3/hr/m^2$(DEHLG, 2008b). In 2011, this limit was revised down, to a not very onerous, 7 $m^3/hr/m^2$ (DEHLG, 2011). Unsurprisingly, there is still no minimum airtightness standard when upgrading existing dwellings. However, cognisance must be paid to the point made by the Energy Saving Trust (EST, 2005) that air permeability in dwellings is made up from a myriad of entry points in the fabric and making airtightness improvements difficult when retrofitting.

Ireland's temperate oceanic climate and average annual temperature of about 9^0 Celsius (C), summer mean maximums and minimums of about 19^0 C and 2.5^0 C respectively, means that dwellings are predominately naturally ventilated (MET Eireann, 2012). Due to Ireland's geographical location and exposure to the Atlantic Ocean to the west there is significant wind speed climate variation. However, Technical Guidance Document Part F – Ventilation (DEHLG, 2009), dictates a uniform standard irrespective of location. Though a small country, this uniformity is not optimal from a technical design standpoint. Consequently, there is no guarantee of sufficient ventilation all year around, with excessive heat loss on cold and windy days and risk of overheating on calm warm days. The relationship between airtightness and space heating demand is complicated by occupant behaviour and their routine of opening and closing windows and vents.

3 DWELLING ENERGY ASSESSMENT PROCEDURE

To comply with the European Directive 2002/91/EC, Ireland has adopted the Dwelling Energy Assessment Procedure (DEAP) as the official methodology for calculating the energy performance of buildings. The DEAP calculation framework, based on IS EN 13790, draws heavily on the calculation procedures and tabulated data of the UK Standard Assessment Procedure (SAP), itself based on the BRE Domestic Energy Model (BREDEM), and is adapted for Irish conditions (BRE, 2009). The methodology applies equations and algorithms to estimate natural airtightness levels of the dwelling based on dwelling profile, including number of stories, structure type, presence of suspended wooden ground floors, and the level of draught stripping of the windows and doors. This natural airtightness is used energy performance calculation. If airtightness test results are available, DEAP uses the (Kronvall, 1978) derived “rule of thumb” method where the natural infiltration rate is 1/20 of the air permeability under test conditions. This study uses the DEAP methodology estimated results for each dwelling, multiplied by 20, to give an estimate of air permeability under test conditions, q50.

4 DWELLING TYPOLOGY AND OCCUPANT PROFILE

The nine single family local authority owned semi-detached and terraced houses were built circa 1980. Combined terrace and semi-detached houses account for the largest proportion, 44.8%, of dwellings in Ireland (CSO, 2007). The occupancy profile outlined in Table 1 is typical for social housing units in Ireland with a number of parents and children, older couples and people living on their own. The average floor area of the three-bedroom two-storey (Figure 1a) and two bedroom single storey houses (Figure 1b) is 80m^2 and 50m^2 respectively, with the exception of house D which has a single storey extension to the rear, giving an increased floor area of 87m^2. All dwellings have load bearing external cavity walls and are naturally ventilated. Ground floors are slab-on-grade with suspended timber first floors. Ground floor internal walls are of solid block construction, with stud partitions at first floor level. The attic space is of typical cold roof construction with insulation between ceiling joists. Previous refurbishment schemes upgraded all windows to double glazing and back boiler heating systems were replaced with natural gas central heating. Where passive wall vents were not installed during original construction, windows with integrated trickle vents were fitted. There is no mechanical ventilation in the kitchen or bathrooms.

In 2012, four of the nine two-storey houses in this study were upgraded by the local authority as part of the Social Housing Improvement Programme (SHIP). This central government funding can only be drawn down by a local authority if they carry out eligible energy efficiency works. Eligible upgrading pertinent to airtightness undertaken in the case study houses included:

- placing full-fill cavity wall insulation;
- laying 300mm of attic insulation to meet the current Part L building regulations;
- replacing existing open fires with a Stanley Cara ‘Insert Stove’;

Table 1: Dwelling and occupant profile

Dwelling	Classif-ication	Orient-ation	Number of Occupants	Occupant age				
				5 – 17	18 – 25	26 – 45	46 – 55	56 – 65
A	2[1],T[2]	E-W	1				F	
B	2,S	E-W	2					F[3]M[4]
C	2,S	E-W	3	M	M	F		
D	2,T	E-W	3		M		F M	
E	2,T	N-S	3	M F		F		
F	2,S	N-S	3	M F		F		
G	2,T	N-S	1				F	
H	1,S	N-S	1					F
J	1,S	N-S	2					M F

[1] 1 or 2 storey high [2] T = Terrace, S = Semi-detached [3] Female [4] Male

(a) three-bedroom two-storey

(b) two bedroom single storey

Figure 1: Typical case study dwellings

- draught stripping around attic hatch and fitting two holding down latches. Replacing existing window and door draught stripping where compromised or missing;
- in compliance with Part F of the building regulations (DEHLG, 2009), where necessary, background passive ventilation was installed with constant open vents fitted to the kitchen and living room and 'Hit & Miss' vents fitted to all other rooms. In each of the houses a new mechanical wall vent were installed to the main bathroom with an automatic overrun (after switch off), located on external wall wired into bathroom light switch;
- where vents were in place, the opening was cleaned and new vent covers provided internally and externally;
- House B and D had all windows and doors replaced.

With the exception of draught stripping there is a clear absent of any intentional airtightness improvement works.

5 AIR PERMEABILITY TESTING

The location of individual air-leakage paths are often difficult to identify by visual inspection, in dwellings. Thus, assessing the building envelope as a whole, using the standardised blower door test, is the only reliable means of assessing building air-tightness. Due to the variety of methods used to deal with intentional openings during testing, direct comparison of blower door test results between countries is often difficult (Carrié and Rosenthal, 2008, Caillou and Van Orshoven, 2010). In 2012, standardised blower door tests were carried out on the nine case study houses to establish airtightness characteristics pre- upgrading and repeated on the four upgraded houses approximately one month after completion. Testing was carried out in accordance with ATTMA (The Air Tightness Testing and Measurement Association) Technical Standard for dwellings (ATTMA, 2010). The Technical Standard is generally compliant with IS EN 13829:2001 Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method. Prior to testing, dwellings were surveyed and the internal envelope area (AE) and volume (V) accurately calculated. Testing to determine the air permeability was largely compliant with Method B, of EN 13829; external doors and windows, intentional vents, attic hatches, letterbox and extract fans were closed but not sealed; open fireplaces were sealed.

The Retrotec Q46 Automated Blower-Door used for the tests has Maximum Flow at 50 Pascal test pressure of 9,514m^3/h and Minimum Flow at 10 Pascal of 65m^3/h and incorporates regulated variable frequency speed controllers to prove a stable speed control, making it suitable for testing dwellings. The fan was secured to the front door using the Retrotec soft panel frame. Pressure and flow rate were controlled using a laptop, connected to a DM-2A Automatic Micro-manometer, which controlled the fan. In addition to the DM-2 the test this software continuously logged a number of parameters including fan flow, test pressure and the area measurements.

Both pressurisation and depressurisation test cycles were undertaken to a pressure differential across the envelope of 55 Pascals. A software generated best fit straight line was used to automatically calculate the air permeability at 50 Pascals. The average of both results was recorded as the air permeability for the building. Averaged results are an important component of the test as leakage paths have complicated shape and different aerodynamic characteristics depending upon air flow direction. The 'value effect' can also occur where by a component can be pushed up during pressurisation and pulled down generating a seal during depressurisation. Stephen (Stephen, 1998) has shown that pressurisation and depressurisation results can differ by up to 20%. During testing, wind speed and ambient temperature conditions were measured using a hand held thermo-anemometer to ensure compliance with IS EN 13829:2001. Simultaneously with the airtightness testing in-depth visual and smoke pencil testing was carried out to identify the key air leakage locations. Though it is easy to visually identify a number of common leakage paths it is assumed that up to about 70% of the air leakage is through cracks and other invisibale locations (Stephen, 2000).

6 TEST AND INSPECTION RESULTS

Pre-upgrading air leakage paths identified by the smoke pencil test and simple observations were similar to those identified in previous research (Sinnott and Dyer, 2012, EST, 2005, Sherman and Chan, 2003, Jaggs and Scivyer, 2006). The most significant and easily accessible leakage paths from the perspective of upgrading, identified in Figure 2, are:

(a) the waste and services pipes enclosed within a timber box-out which penetrates directly into the unheated attic space;
(b) unsealed penetrations in timber first floor. There is typically an unsealed path along the floor joists and into the empty cavity space;
(c) penetrations into the stud partition walls allowing air to transfer to the attic into the floor void;
(d) poorly maintained and sealed attic hatches;
(e) poorly maintained window and door seals.

Considering poor and under-ventilation, many of the existing passive wall vents had been partially or fully obstructed. Figure 2(f) shows a vent which had been painted over a number of times. Also a number of vents were completely blocked by miscellaneous items and debris.

The results of the testing pre- and post- upgrading are presented in Figure 3. The DEAP calculated airtightness of the houses ranged from 8.4 $m^3/hr/m^2$, for both single storey houses, H & J, to 11.2 $m^3/hr/m^2$ for house F. The variation in predicted airtightness is based predominantly on number of storeys and percentage draught stripping.

The results demonstrate the large range in measured air permeability from 3.9 – 17.1$m^3/hr/m^2$. The 10.9 $m^3/hr/m^2$ mean results is consistent with the findings of a similar study by Sinnott and Dyer (Sinnott and Dyer, 2012). Overall 44% of the results exceeded DEAP predicted airtightness levels. For house C which had the highest measured air permeability of 19.7$m^3/hr/m^2$, DEAP underestimated the result by 47%. Superficially this house is identical to the other two storey houses. However, during testing the dwelling occupant explained that to limit cold draughts she places towels around the kitchen units. A visual inspection identified a large hole under the counter where pipework enters the internal service duct, shown in Figure 4(a), allowing uncontrolled airflow from the attic into the room. Figure 4(b) shows a missing floor board under the bath and a number of pipes from the hotpress and penetrations through

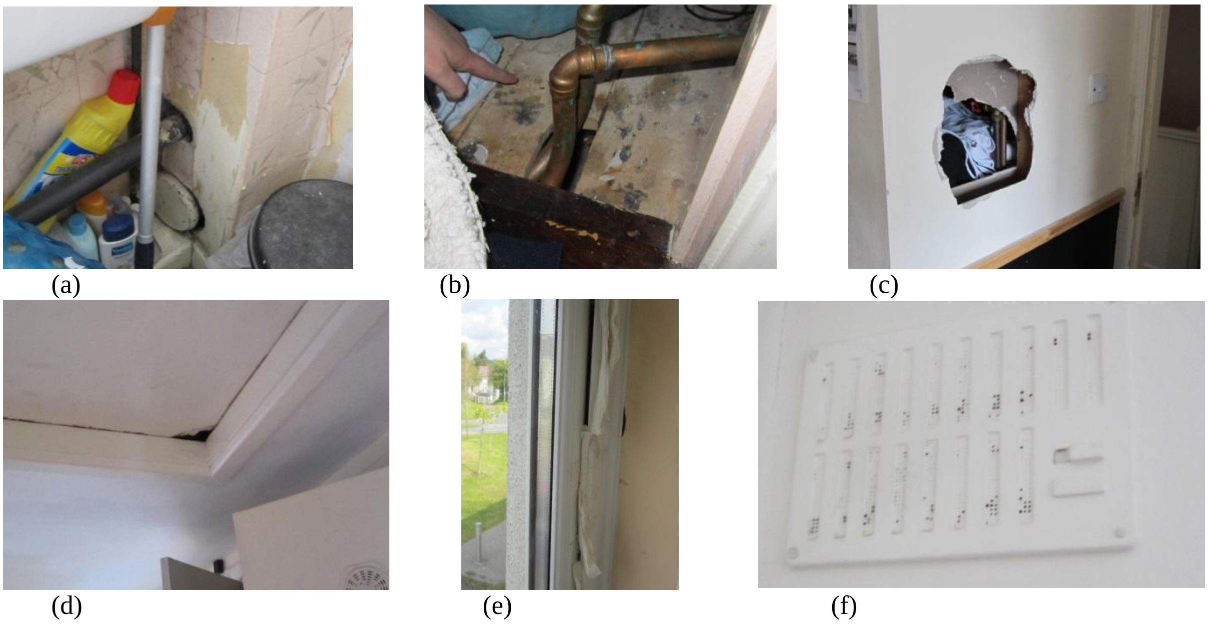
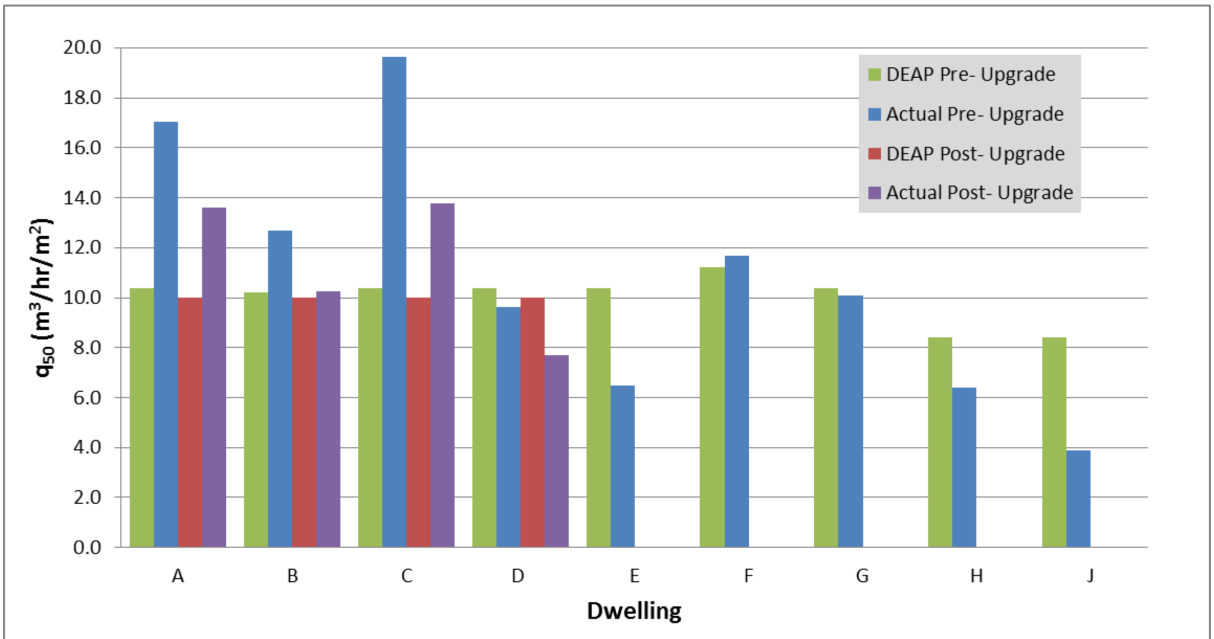


Figure 2: Typical leakage paths identified during inspection



Dwelling	Pre - Retrofit			Post - Retrofit			
	% Draught Stripped	*DEAP Calculated, Q_{50} [$m^3/h.m^2$]*	*Measured, Q_{50} [$m^3/h.m^2$]*	*% Draught Stripped*	*DEAP Calculated, Q_{50} [$m^3/h.m^2$]*	*Measured, Q_{50} [$m^3/h.m^2$]*	Improvement *[%]*
A	90	10.4	17.1	100	10.0	13.6	20.2
B	93	10.2	12.7	100	10.0	10.2	19.3
C	90	10.4	19.7	100	10.0	13.8	29.9
D	88	10.4	9.6	100	10.0	7.7	20.2
E	90	10.4	6.5	100			
F	70	11.2	11.7	100			
G	90	10.4	10.1	100			
H	88	8.4	6.4	100			
J	90	8.4	3.9	100			

Figure 3: Measured and DEAP esitmated dwelling airtightness

the walls such as the extractor from the tumble dryeras shown in Figure 4(c) provide leakage paths. Figure 2(c) shows a large hole in the bedroom timber stud wall allows air to leak into the wall space.

(a) (b) (c)

Figure 4: House C major leakage paths

Sub-dividing the dwellings by number of storeys reveals that the two single storey houses not only performed better than predicted by DEAP, but achieved the highest levels of airtightness. House J seems to have an optional result at 3.9 $m^3/hr/m^2$; less than 50% of that predicted by DEAP. However, during the testing the occupants stated as a means of minimising heat loss they had blocked up as many vents, gaps, and holes as that they could. Without any form of mechanical ventilation house is under-ventilated, made evident by a number of issues including, noticeable stale air upon entry, high humidity levels resulting in condensation and staining on the north facing external walls, as shown in Figure 5. Without regular drying, with a towel, the occupants report that mould growth can be prevalent.

Figure 5: Staining on external wall due to condensation

House H, identical footprint to house J, at 6.4$m^3/hr/m^2$, again performed better than DEAP predicted but there was no evidence of condensation or mould growth, demonstrating that the house is adequately ventilated, whilst being relatively airtight.

Airtightness improvement works were not specified, with the exception of draught stripping to the windows and attic hatch. However, the upgrading had a positive effect on airtightness by between 19.3 and 29.9%, with an average airtightness improvement of 22.4%. Though the four houses are not statistically significant the pattern is clearly positive. Notably, post upgrading, 3 houses still exceed the DEAP calculated values. DEAP calculated overall improvement of less than 4%, from 10.4 to 10 $m^3/hr/m^2$, by providing 100% draught stripping. It is clear in this study that the methodology underestimates the positive effect of upgrading. The real improvement in airtightness is as a result of a number of works carried out including, upgrading a number of windows and doors, the full-fill cavity wall insulation which acts in some way to seal the myriad of crack and block easy leakage from around floor joists into the cavity space, the fixing of the attic hatches and replacement of the open fires with stoves.

7 SURVEY RESULTS

Interviews were conducted with all adult occupants in each of the nine households to establish their perceived living and comfort standards and to gain their perspectives of airtightness and ventilation in their homes. The semi-structured interviews were undertaken in the occupant's home and rather than a question and answer sessions were conversational in form. Interviews were repeated with the four houses post- upgrading to establish if there was a benefit to the indoor environment. The interviews were digitally recorded and relevant sections analysed in detail and the key findings are presented in this paper.

The nature of social housing means occupants in general spend more time in the homes than private homeowners, either due to lack of employment as a result of the recession or lack of disposable income. On average each house is occupied by at least one occupant 22 hours per day. Overall, the householders believe they have a 'fairly good' to 'very good' standard of living. However, a number of the occupants suffer from chronic health problems such as diabetes. As a result, they say they feel the cold more. Overwhelmingly the householder's express that their priority is to run the house with minimal expense. Consequently, they are keen to maintain heat within their homes, even if it means compromising airflow by blocking up vents or leaving window trickle vents closed. In general occupants who are local authority tenants have done little or no remedial work to prevent heat loss through infiltration citing: they are not capable of carrying out the works; they do not have the money to hire a professional and ultimately the onus is on the council.

7.1 Pre-upgrading

A number of the households complained of draughts throughout the house and over the winter period they need place draught excluders at the front and rear doors. House D stated that given a particular wind direction they can feel draughts around the 'poorly fitted windows, doors and attic hatch'. The occupants of house C, which has the worst overall test result of $19.7 m^3/hr/m^2$ place towels around the kitchen units under the sink during winter. As shown in Figure 4a the service duct seems to be the worst offender. Somewhat surprisingly the adult female says that always sleeps with the window slightly open, regardless of season. This may be a sign of under ventilation in the bedroom, which has no passive vents.

The issue of the service duct was raised in a number of the two storey houses. In house B, the occupants have rearranged their home so that the service duct is in the corner of their living room and the draughts cause some discomfort when sitting on the sofa. The occupants also say that the passive vent above the food preparation area in the kitchen 'make it's very cold when working ….it's awful'.

The real outlier is house J. The female occupant suffers from chronic osteoarthritis and finds mobility difficult. As a result she feels the cold very much and keeps the ambient temperature in the house very high. The occupants have blocked up as many air leakage paths as they could. Consequently, a wave of stale and humid air hits the visitor upon entering the house. The male occupant believes that the dwelling environment contributes to his wife's illness but they have no option as they have to keep the temperature up.

7.2 Post-upgrading

In general terms all the occupants are happy with the upgrading saying that they feel that their houses are warmer. However, a number of issues were raised during the second interview. The female occupant of house A says her bedroom is 'freezing' because if the installation of the new wall vents in each room. Before the upgrading there were trickle vents in the windows but they were always closed 'to keep the heat in'. The householder also says 'with the vents you can't enjoy the television because of the noise' from breeze moving through the vents. Overall she describes the upgrading as positive but 'the only thing I can't stand are the air vents ….. the noise drives me bananas'.

The occupants of house B, which always had wall vents, were disappointed that there was no improvement made to the service duct and there is still substantial air ingress resulting in discomfort. They are happy with the new windows and doors. The vent in the kitchen was moved to a different location which has 'improved the working environment'. The new mechanical vent in the bathroom worked initially, but the external grill was later replaced and some expanding foam was inadvertently deposited around the blades, preventing it from working and partially blocking the vent pipe.

The female adult in house C really does not like the newly installed vents and because it causes draughts in the house and she can also hear noise coming from the street 'which is very annoying'. Following the second scheduled interview she now plans to block up at least some of the vents. However, she still 'has the habit' of opening her bedroom window at night.

Again, the occupants of house D occupants find their house warmer 'but the new vents were causing problems'. There is a newly installed vent in the sitting room and the adult male says 'it was freezing sitting under the one in the sitting room..... now it is sealed with tape. The extractor fan in the bathroom is also turned off and sealed with tape because 'it was too noisy when having a bath'. The occupants open the window to purge the room with fresh air when required.

8 CONCLUSIONS

This paper combines quantitative air permeability results with qualitative interview data, gaining a whole house integrated understanding of building airtightness and its effect on indoor environment. The uniform nature of the houses makes the sample unrepresentative of the national housing stock. However, the vast majority of houses in Ireland are of cavity wall, cold roof construction and it could be expected that similar trends would be revealed through widespread testing.

Typical expected leakage paths were prevalent; however, anomalies were found in each house. Johnston (Johnston *et al.*, 2011) suggests that achieving $6m^3/hr/m^2$, with good design, using existing techniques at little increased cost is genuinely achievable for new build. Due to the number of inaccessible leakage paths this would be challenging for existing dwellings. Nevertheless, there is considerable scope to improve airtightness when upgrading by simply paying attention to detail, sealing around all pipes and penetrations, improving window seals, sealing conduits and being generally aware of airtightness improvements.

Broadly occupants have a negative attitude towards design vents, viewing them as letting heat out and noise in. It is clear that the adoption of a user centred design approach when developing a ventilation strategy for new and existing dwellings is the only way to remove the potential for occupant discomfort.

All houses pre- and post- retrofitting, excluding House J, excessed $5m^3/hr/m^2$, which is generally considered to be the threshold when MVHR becomes viable. Traditional upgrading practices are disruptive to the householder offering an opportune time to improve airtightness levels to a standard where MVHR could be implemented. The local authority should consider installing an MVHR in House J, as it already surpasses this threshold and would improve air quality and occupant comfort.

It is clear that DEAP needs to include a greater number of variables where calculating airtightness to yield realistic results. The first step to enhance this model is through extensive testing of a range of buildings and development of a national database. The failure of the majority of the houses to meet the minimum airtightness standards set down for new construction should be seen as a potential opportunity to achieve real energy reduction when upgrading houses.

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