THE IMPACT OF ENERGY EFFICIENT REFURBISHMENT ON THE AIRTIGHTNESS IN ENGLISH DWELLIGS

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ABSTRACT

Fan-pressurisation method was used to test the air infiltration rate of 191 dwellings in England. All tested homes were either pre or post the introduction of energy efficient retrofit measures such as cavity wall insulation, loft insulation, draught stripping and energy efficient heating system. Results show that the average air infiltration rate of the post dwellings is only marginally lower by 4% compared to the pre dwellings. Component infiltration rate based on model prediction indicates the combination of cavity wall insulation, loft insulation and draught stripping potentially reducing infiltration rate by 24%. On the other hand, longitudinal comparison shows a retrofit gas central heating system offsets this effect by contributing 13% increase in infiltration rate.

KEYWORDS

air infiltration, refurbishment, insulation, draught stripping, central heating, English dwelling

INTRODUCTION

As a part of the UK government's commitment to reduce green house gas emissions, measures to improve airtightness in the UK dwellings are being implemented through building regulation and energy efficient refurbishment programs.

Warm Front (WF) is a major energy efficient refurbishment project undertaken primarily to reduce fuel poverty in England by delivering affordable warmth through improved household energy efficiency. The main elements comprising the WF energy efficiency package are cavity wall insulation (CWI), loft insulation (LI), draught stripping (DS) and depending on the householders' qualification, the option of a hot water tank jacket and gas wall convector heaters or a gas central heating system (CH).

In 2001, the "Health Impact Evaluation of Warm Front" study was commissioned to investigate the effect of WF on resident health. Household data from 3099 properties was collected over two successive winters in five urban areas: Birmingham, Liverpool, Manchester, Newcastle and Southampton. A subset of 191 properties was targeted to conduct 221 (78 pre-intervention and 143 post-intervention) air infiltration rate tests. The case study dwellings are classified as pre- or post-intervention depending on the completion status of the WF refurbishment work.

This paper will present the results of the field-measured, whole house, air infiltration rate tests and discuss the effect of different energy efficient refurbishment measures on dwelling infiltration rate. The parameter used to present infiltration rate in this paper is *air permeability* which is used by UK building regulations and expressed in units of $m^3/hr/m^2$ (of exposed building envelope area including the ground floor) at 50 Pascals [2000, CIBSE].

OPPORTUNITIES FOR ACHIEVING AIRTIGHTNESS

Results from past projects indicate that there is a great opportunity of achieving airtightness in UK dwellings by refurbishment work. Studies carried out by Leeds Metropolitan University on a group of 12 properties (Derwentside Project) have shown a 46 to 66% reduction in infiltration rate [1997, BRESCU] while a maximum of 71% reduction was observed in a single case study dwelling following refurbishment measures (York Project) [Lowe, *et al*., 1997]. WF, on the other hand, is expected to have a lesser impact in reducing infiltration rate as a result of fewer delivered airtightness measures as shown in table 1.

TABLE 1
Opportunities of achieving airtightness

Opportunities of Achieving Airtightness	WF	York	Derwentside
Draughtstrip loft hatch and fit securing bolts	X	X	X
Draughtstrip opening windows and external doors	X	X	X
Seal around windows and door frames			X
Seal service holes through timber floors		X	
Seal service penetrations through ceilings			
Seal all remaining plumbing services			
Seal all joints in heating ductwork (where possible)			X
Seal all electric services including faceplates			X
Hardboard across timber floors and seal to skirting		X	
Install cavity wall and loft insulation	X	X	X
Seal air space behind plasterboard dry-lining		X	X
Seal top and bottom of stud partitions			
Add a draught lobby to exterior doors			
Block disused chimney opening			

MEASURING AIR INFILTRATION RATE

Fan pressurisation method was used to measure the whole house air infiltration rate. All open flues and vents were kept open during the test in order to measure airtightness under a normal dwelling condition. Open chimneys were sealed but depending on the circumstance they were left open and only the pressurisation cycle was carried out. The test was accompanied by a thermal imaging camera to record areas of air ingress and missing insulation. The tested dwellings are classified in table 2 which shows that the majority are of masonry construction.

TABLE 2
Case study dwellings (n=191)

age		wall type		building type	
pre-1900	15%	cavity masonry	66%	terraced	57%
1900 – 1950	50%	solid brick	33%	semi-detached	33%
1951 – 1976	32%	timber framed	0.5%	flats	9%
Post 1976	3%	other	0.5%	detached	1%

PRE- AND POST-INTERVENTION AIR INFILTRATION RATE

The comparison of air infiltration rate distribution between the pre- and post-intervention dwellings in figure 1 shows little difference between the two groups with the post- dwellings showing a marginally lower average infiltration rate of 0.7$m^3/hr/m^2$ in table 3. One of the main reasons seems to be the fact that the impact of measures which may result in decreased infiltration rate such as CWI and DS is offset by other measures such as the installation of a CH whose effect is shown by the increase in infiltration rate among the CH properties in table 3.

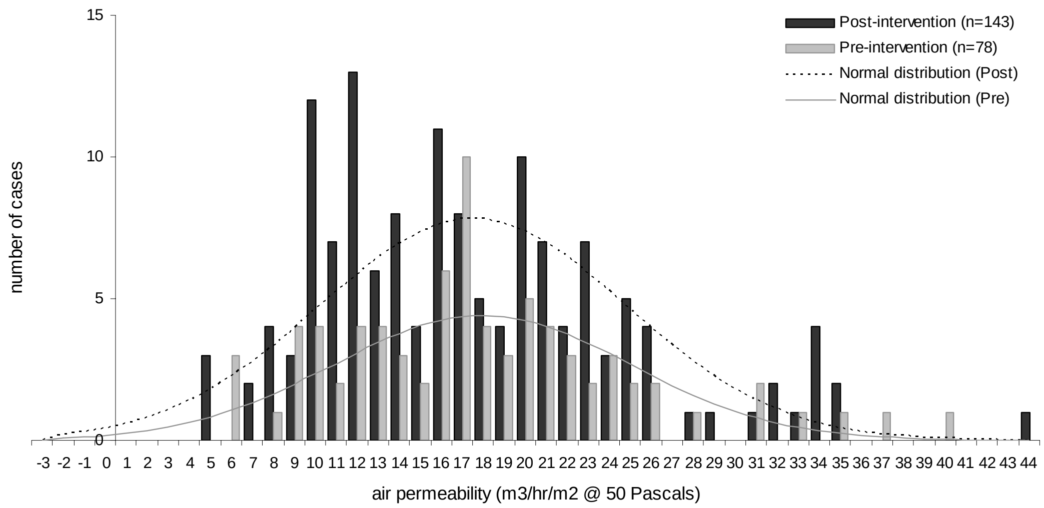

Figure 1: Air infiltration rate distribution for pre- and post-intervention WF dwellings

TABLE 3
Mean and standard deviation of air infiltration rates (n=221)

WF Scheme	Pre-WF ($m^3/hr/m^2$)	Post-WF ($m^3/hr/m^2$)	% Change
All properties	17.7 (s.d. 7.1), n = 78	17.0 (s.d. 7.2), n = 143	-4%
w/o CH	19.1 (s.d. 7.8), n = 22	16.5 (s.d. 7.3), n = 51	-14%
w/ CH	17.1 (s.d. 6.8), n = 56	17.2 (s.d. 7.2), n = 92	+1%

CH: Gas Central Heating System

TABLE 4
Change in air infiltration rate based on longitudinal cases (n=21)

Intervention		Sample Size		Infiltration Rate Change ($m^3/hr/m^2$)		% Change	
CH only	w/ PU	12	4	+1.8	+ 3.0	+13%	+21%
	w/ PA		8		+ 1.1		+9%
CH w/ PU + LI + DS		2		+2.1		+10%	
CH w/ PU +PA + DG		2		-0.3		-3%	
CH w/ PA + CWI		2		-3.5		-27%	
CWI		1		-3.6		-19%	
New Boiler		2		+0.2		+2%	

CH w/ PU: Central heating system with plumbing installed under floor boards
CH w/ PA: Central heating system with plumbing installed above floor boards
LI: Loft insulation; DS: Draught stripping; DG: Double glazing; CWI: Cavity wall insulation

Longitudinal test results from a subset of 21 properties further supports the observation where a decrease in infiltration rate is recorded following CWI and double glazing - not a WF measure - while an increase of 13% is observed following the CH measure alone. This increase is not the result of an additional flue since the flues are of balanced type but from the plumbing work associated with the WF supplied radiators. Table 4 shows a pronounced increase in infiltration rate (21%) among the dwellings whose radiator pipes are installed below the suspended floor boards at ground floor level.

COMPONENT INFILTRATION RATE

Because of the small sample size involved in the longitudinal study and the majority of these properties having received only a CH, a statistical model based on multiple regression is used to estimate the effect of component contribution to infiltration rate based on the 221 measured samples. The model shows that 31% (R^2=0.314) of variability in infiltration rate is explainable by the components listed in figure 2 (P-*value* = 4.9×10^{-12}). The components that most significantly affect (P-*value* < 0.05) infiltration rate are indicated as grey bars.

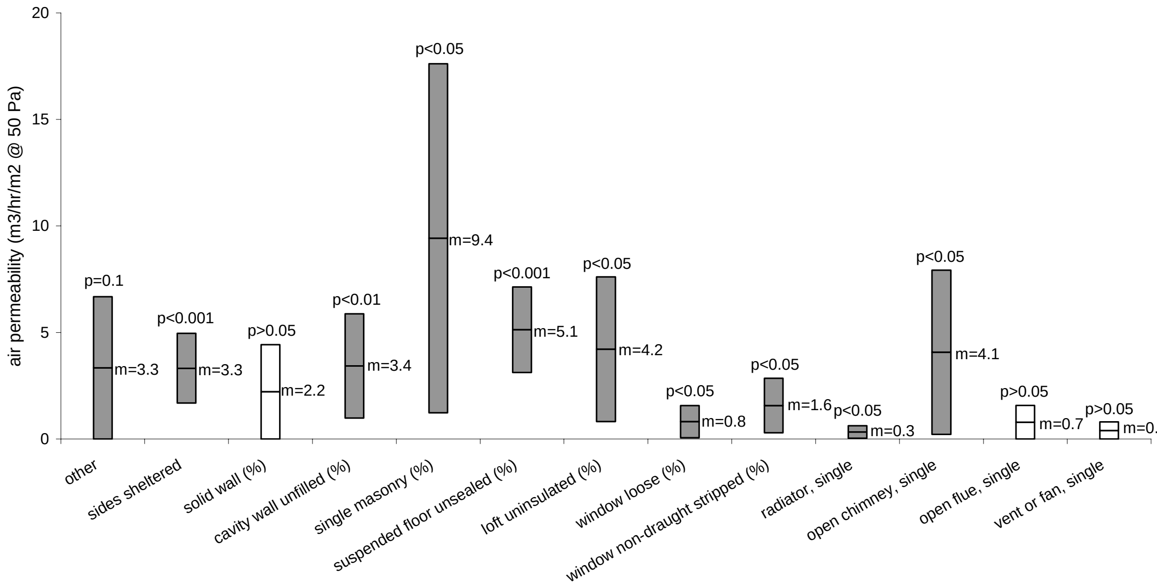

Figure 2: Component infiltration rate at 95% confidence interval range
(m: median; p: P-*value*)

The model indicates that a combination of CWI, LI and DS, which are the primary WF airtightness measures, should achieve a 24% reduction in infiltration rate based on the range median. The reduction will increase to 37% if the suspended floors are sealed and a further 47% if an unwanted chimney is closed.

The largest range is shown by the *single masonry* category which refers to a single withe inner brick wall with an exterior timber tile finish on battens. The wide effective range reflects the difficulty in determining the quality of this wall type where the inner masonry layer is hidden from view. The model shows that the potential impact of this wall type on infiltration rate can be significant while its construction nature does not allow retrofit CWI.

Increase in sheltered sides increases air permeability by $3m^3/hr/m^2$. In other words, a unit wall of a semi-detached house is leakier than a detached house. The reason behind this oddity is due to the way in which the *air permeability* parameter is based on exposed wall surface area while discounting the effects of inter-dwelling air exchange. Building Research Establishment (BRE) study shows inter-dwelling infiltration through walls can contribute from zero to 20% of total infiltration rate [1998, Stephen].

LI can reduce air permeability by $4m^3/hr/m^2$. However, post-intervention survey as in figure 3 shows that this potential benefit is frequently lost as a result of missing LI along the ceiling edges near the eaves where retrofit installation is physically difficult to carry out. Without LI over the wall plate, air can travel up the cavity wall space if CWI and closers are missing or behind the drywall finish with poorly sealed surrounds.

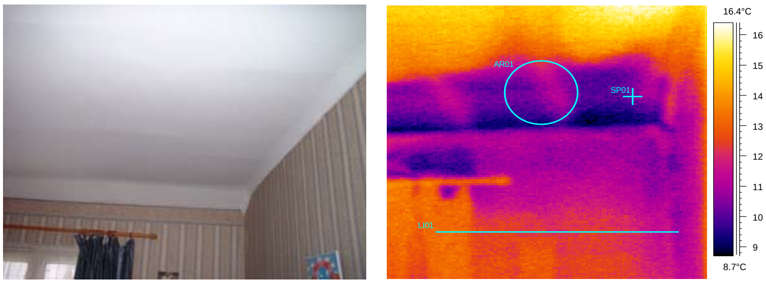

Figure 3: Thermographic image shows missing loft insulation behind the ceiling finish near the eaves

A single retrofit radiator increases air permeability by $0.3m^3/hr/m^2$. If the effect of the WF supplied radiators - normally five - is taken into account, the potential increase from a CH can be $1.5m^3/hr/m^2$ which is similar to the increase of $1.8m^3/hr/m^2$ observed in the longitudinal comparison of table 4.

Minute cracks, unsealed penetrations and other paths that are difficult to classify make up the *other* component which contributes $3m^3/hr/m^2$ to infiltration rate. WF measures may have limited effect in reducing this component which possibly reflects the general construction quality of the dwelling and its deterioration through age. A more detailed component classification may reduce the effect of the *other* component while increasing the significance level (R^2 value) of the prediction model.

Poor component classification can be attributed to the low significance level (P-*value* >= 0.05) of the *open flue, single* & *vent or fan, single* components. No detailed survey was made between the flues of open gas fire and those of modern gas fires with grilled front. Similarly, the condition of permanent vents such as air bricks was not surveyed in detail.

COMPARISON OF COMPONENT INFILTRATION RATE DISTRIBUTION

The model prediction is compared in figure 4 with BRE's component infiltration rate which is based on reductive sealing method from 35 UK dwellings [1998, Stephen]. For the comparison, the effect of WF CWI is related to the BRE drywall surrounds sealing because no record was made about the type of internal wall finish in the WF study. The effect of loft hatch is omitted in the WF model because of its poor significance level. The contribution from open chimneys and flues are all omitted because the BRE data excludes their effects. Also, the CH contribution is excluded since its effect on infiltration rate is significant only as a retrofit measure, a condition unique to the WF project.

The comparison of component infiltration rate between the WF and BRE data is not straight forward due to difference in component classification. In the case of the *permanent vents*, the model is predicting the effect from a single vent or fan (1%) whereas the BRE prediction is based on several vents (9%) typically found in UK dwellings. The large difference between the CWI (11%) and the dry wall *surrounds* sealing (2%) and likewise between *loft uninsulated* (14%) and the *loft hatch* (2%) indicates that their effects can't be compared directly. BRE's *remainder* component which makes up 71% of the total infiltration rate can be equated to the model's *solid wall* (7%), *single masonry* (31%), *suspended floor* (17%) and *other* (11%) components which in combination contribute to 66% of the total. The model predicted effect from *no draught stripping* and *window & door loose* which make up 8% of the total is less than BRE predicted16% possibly because the model does not take into account the contribution from well sealed and draught stripped windows and doors.

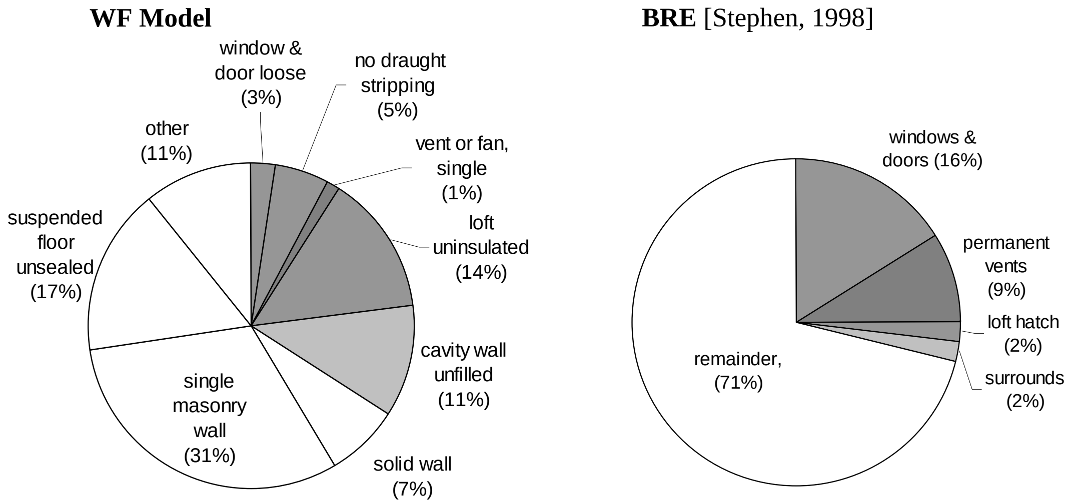

Figure 4: Comparison of component infiltration rate

CONCLUSION

The combination of Warm Front delivered cavity wall insulation, loft insulation and draught stripping can reduce English dwelling air infiltration rate by about 24%. On the other hand, retrofit gas central heating system increases infiltration rate which is particularly sensitive to the way in which the peripheral piping work is installed. To achieve airtightness, the radiator pipes should be installed exposed above the suspended floor, or if installed below the floor, accompanied with a robust sealing procedure around penetrations and along the seams of floorboards temporarily lifted for installation.

ACKNOWLEDGEMENTS

This study was funded by a grant from the Department for Environment, Food and Rural Affairs (DEFRA) and the Welsh Assembly Government. We are grateful to Energy Saving Trust under whose contract the services were carried out and to EAGA Partnership for their support. We are also grateful to the householders for their warm welcome into their homes.

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