The Reduction in Air Infiltration due to Window Replacement in UK Dwellings: Results of a Field Study and Telephone Survey

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Abstract

This paper reports the findings of a field study and telephone survey into the impact of window replacement on air infiltration and moisture problems in UK dwellings. The results of a telephone survey of 250 UK houses suggested that the installation of tight, well sealed replacement windows does not appear to be causing a significant increase in IAQ problems as perceived by the occupants. After having windows replaced only 2% of respondents (5 households) reported worse problems with condensation and only 1% (3 households) reported worse problems with mould. However, the results of "before and after" fan pressurisation tests on ten dwellings suggested that the installation of modern replacement windows reduced the predicted heating season mean background air change rate by an average 0.23 ac/h (standard deviation 0.08 ac/h). Analysis of the results suggests that installation of replacement windows in UK dwellings significantly reduces background infiltration rates, and that 65% of dwellings in the UK would have a predicted heating season mean air change rate below 0.5 ac/h after the installation of new windows. Houses with high moisture production, and low ventilation rates are potentially at risk from increased moisture problems after window replacement and may benefit from the installation of additional controllable ventilation during window replacement. However, the telephone survey which indicates that window replacement has *not* caused worsening IAQ suggests that occupants are ventilating adequately for their moisture production rates. If increased occupant venting occurs, then this may have the detrimental effect of increasing the space heating energy consumption.

Key words: window replacement, air infiltration, dwellings, indoor air quality, measurement.

1. Introduction

In the UK the replacement of old "leaky" single glazed windows with modern air tight double or tripled glazed units has the potential to greatly reduce space heating requirements in dwellings and hence emissions of green house gases (Lowe et al 1999). Such replacement reduces heat loss both through the improved U value of the new unit and also via the reduced infiltration heat loss due to improved air tightness. When eliminating uncontrollable air infiltration, care must be taken that adequate controllable background ventilation is provided to avoid moisture problems such as condensation and mould. The impact on domestic background air infiltration of replacing 'old windows' with modern double-glazed and draught sealed windows, has been previously examined by the authors (Ridley et al, 2003). In a recent study (Hong et al, 2004) 191 English dwellings were pressure tested and the results were used to develop a component model of air infiltration. This model suggests that loose fitting windows and the absence of draught stripping account for 8% of the infiltration in dwellings. A review of the link between ventilation rate, respiratory disease, and mould has been published (Davies et al 2004). Also there is considerable anecdotal evidence of replacement windows causing mould and condensation problems. In this current paper we present the results of a telephone survey and field study measuring the reduction in background infiltration rate achieved by window replacement. The aims of this study were to:

- Assess if window replacement was leading to increased moisture related problems.
- Measure the reduction in air infiltration achieved by window replacement.
- Analyse the data to estimate the typical impact of window replacement.
- Examine the need for controllable ventilation to be fitted during window replacement.

2. Telephone Survey

The aim of the telephone survey was to gain preliminary data to examine if IAQ problems are being caused in dwellings as a result of replacing old “leaky” windows with new airtight units. The Fenestration Self-Assessment Scheme (FENSA) supplied the details of 2,000 properties, which had undergone window replacement since April 2002. This scheme certifies that replacement windows meet the thermal performance standards, (area weighted average U value of 2.0 W/m^{2}K), required by Part L of the English Building Regulations, (ODPM, 2001). A total of 250 dwellings, which had more than 50% of their windows replaced, and where occupants agreed to participate in the study, were selected from the FENSA database. The occupant of the house responded to a telephone survey to ascertain information on:

- Original window type;
- New window type;
- Dwelling characteristics;
- Heating and ventilation;
- Self reported incidence of condensation and mould before and after window replacement.

The surveys were undertaken when the vast majority of the dwellings had experienced at least two months of a heating season with the new windows in place. In 64% of the cases, single glazed wooden framed windows were replaced with double glazed UPVC (plastic) units. After having windows replaced only 2% of respondents (5 households) reported worse problems with condensation and only 1% (3 households) reported worse problems with mould. 32% of the respondents (81 households) had replacement windows that included trickle vents. Of the 5 households reporting worse problems with condensation, 2 had replacement windows that included trickle vents. Of the 3 households reporting worse problems with mould, 2 had replacement windows that included trickle vents. Thus the (albeit few) reported problems do not appear to be confined to replacement windows fitted without trickle vents.

3. Pressure Testing of Houses

Ten dwellings, in which more than 50% of windows were due to be replaced, were identified by 4 window installers located in the SE of England in the period July to October 2004. The dwellings were tested, both before and after window replacement, to determine air infiltration rates, using standard fan pressurisation testing as prescribed by BS EN 13829 – ‘Determination of the Air tightness of Building Envelopes by the Fan Depressurisation Method’ (BS 13829). The leakage characteristics of the tested dwellings were then deduced and reported in terms of both the number of air changes per hour at 50 Pa and air infiltration at normal operational pressure. Note that the air infiltration rate at normal operational pressure is assumed to be adequately represented by the ‘divide by twenty’ rule (Sherman 1998). The results of the fan pressurisation tests on the ten dwellings suggest that the installation of modern replacement windows reduced the predicted heating season mean background air change rate by an average 0.23 ac/h (standard deviation 0.08 ac/h).

However, there are two reasons why this may not be typical of the impact that whole house window replacement has. Firstly, three of the properties tested did not have all their windows replaced. Instead only 86%, 70% and 60% of the windows were replaced. A simple extrapolation predicts that had they had all their windows replaced then the average background air change rate for all the properties would probably have been reduced by 0.26 rather than 0.23 ac/h. Secondly, 5 of the dwellings had doors replaced at the same time as windows. Although the main door does not impact on the pressure test results, because this is where the “blower door” is installed, other doors do. Thus the results presented here overestimate the impact of windows. For the purposes of this study it is assumed that these two effects cancel each other out. We therefore assume that the ‘as measured’ reduction in the average background air change rate of 0.23 ac/h is a reasonable indication of the reduction that would arise if 100% of windows (and no doors) were replaced in all the properties.

In total, six out of the ten properties had a predicted heating season mean air infiltration rate of below 0.5 ac/h after replacement compared to only two prior to replacement. Before window replacement, one out of the ten dwellings had air infiltration rates below the whole building ventilation rate recommended in the Review of Part F of the UK Building Regulations (ODPM, 2004) compared to six after window replacement. The results of the fan pressurisation testing suggested that the installation of tight well-sealed replacement windows could cause a significant increase in moisture related IAQ problems.

4. Discussion of Field Results

The results of the telephone survey and the fan pressurisation tests appear to lead to contradictory conclusions. Why might this be the case? Issues involved may be:

- The telephone survey results were 'self reported' and subjective;
- No information is available as to the moisture production rates of the telephone survey dwellings;
- Despite the fact that the background air infiltration rate may be 'too low' in some of the telephone survey properties, it may be the case that appropriate ventilation is indeed taking place via 'correct' window opening habits;
- Regarding the properties that were tested, it may be the case that the installers were 'trying harder' because they knew that the testing was to be undertaken;
- The sample size of the tested properties was small – only ten properties, although the standard deviation was small and the results statistically significant.

In order to estimate the impact on the stock that such experimental results might lead to, we will now consider the distribution of background infiltration rates in UK dwellings measured by the Building Research Establishment (BRE) (Stephen 1998). The average infiltration rate during pressure testing at 50 Pa in that study was found to be 13.1 ac/h, equivalent to a background infiltration of 0.65 ac/h.

Using the experimental data obtained during this study (which suggests that replacing old leaky windows with modern sealed windows would reduce the stock averaged, heating season mean background infiltration rate by 0.23 ac/h) the new predicted heating season mean infiltration rate would be in the region of 0.42 ac/h which is below the widely recommended level of 0.5 ac/h. Figure 1 shows the distribution of air infiltration rates, using

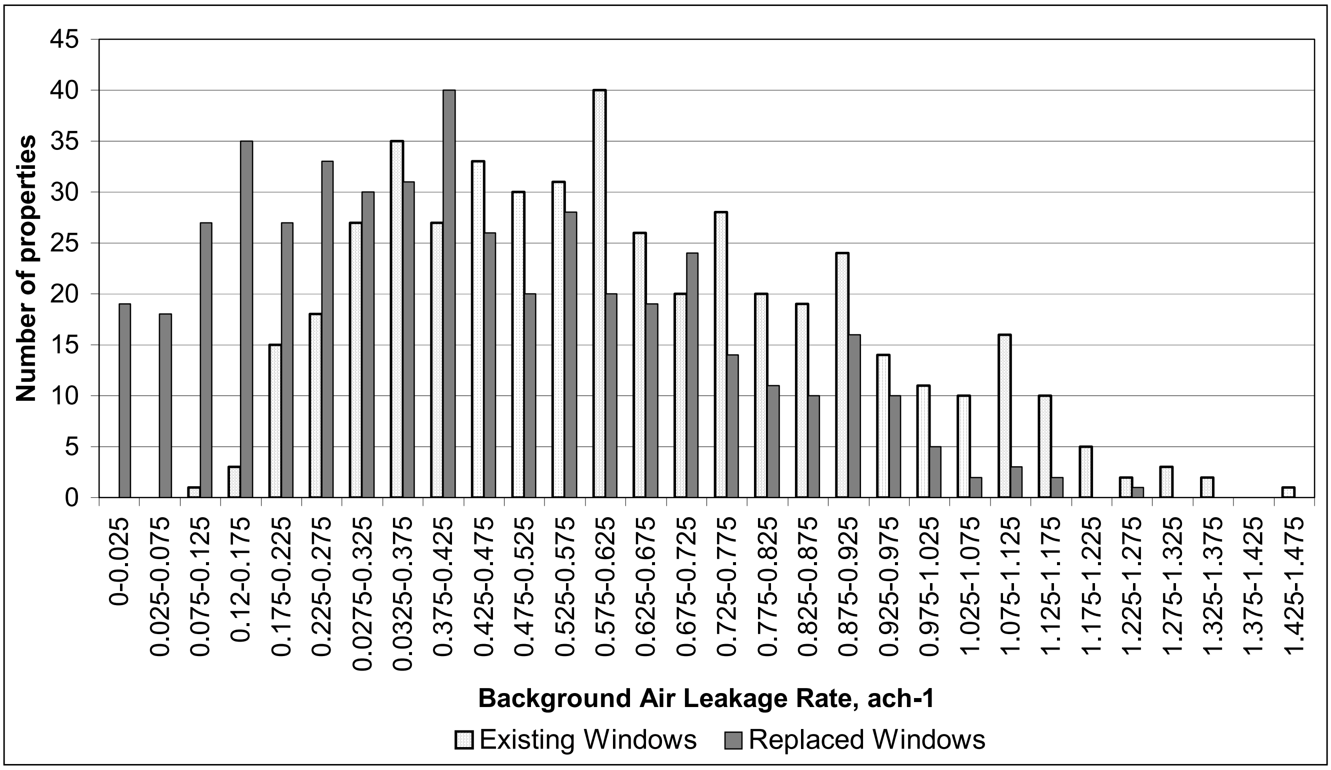

Figure 1. Distribution of air infiltration rates predicted from BRE pressure test data, before and after the possible effect of the installation of new windows.

the BRE pressure test data, before and after the possible effect of the installation of new windows.

If one assumes that the BRE pressure test data applies predominately to dwellings with relatively old, 'leaky' glazing and is typical of the UK building stock it is possible to use this data to make an estimate of the percentage of UK properties that would have a predicted heating season mean background air change rate less than 0.5 ac/h as a result of simply replacing old windows with new. Assuming the reduction in predicted heating season mean air infiltration rate of 0.23 ac/h (as a mean value measured during this project), applying this to the BRE data set suggests that 65% of dwellings in the UK would have a predicted heating season mean air change rate below 0.5 ac/h after the installation of new windows. The telephone survey undertaken for this study suggests that slightly less than one third of these houses are being fitted with background ventilators which should increase ventilation to adequate levels. It appears that fitting some form of controllable background ventilation during window replacement would be beneficial in dwellings with inadequate air infiltration in order to maintain a healthy indoor air quality.

5. Theoretical Modelling Impact of Window Replacement on IAQ

To predict the impact that changes in air infiltration may have on the IAQ, theoretical modelling has been carried out in this study using 'Condensation Targeter II' (Oreszczyn and Pretlove, 1999). As a base case, a typical UK dwelling in compliance with the current Building Regulations was modelled. The ventilation rate and moisture production rate are varied to assess how such changes impact on the risk of mould growth in the dwelling.

A total of 140 simulations have been carried out with different combinations of ventilation and moisture production rates. The ventilation rates were input directly into the Condensation Targeter model and represent both the background infiltration rate and the additional occupant ventilation. They represent a typical range of ventilation rates found in UK dwellings. The moisture production rates modelled were 2 kg/day, 4 kg/day, 6 kg/day, 8 kg/day, 10 kg/day, 12 kg/day and 14 kg/day. These figures represent the typical range of moisture production rates likely to be found in UK dwellings. Figure 2 shows a risk of mould for the different

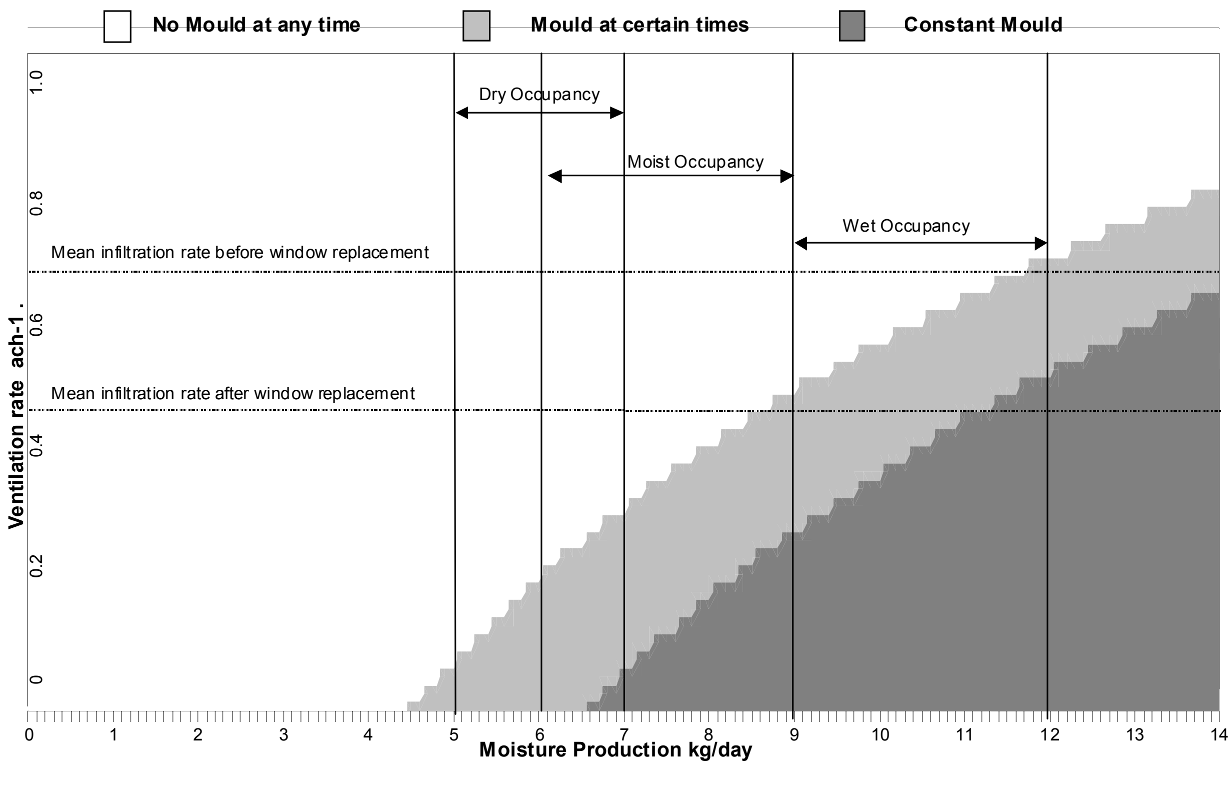

Figure 2. Risk of mould as a function of ventilation and moisture production rates.

combinations of moisture production and ventilation rate. The fitted curves were derived using the modelling results from 140 simulations. By combining the modelling results summarised in Figure 2 with details of typical daily moisture production, as defined in BS5250, it is shown that for a ventilation rate of 0.2 ac/h the risk of mould is low only for moisture production rates below 6 kg/day, i.e. a dry occupancy by a family of 4 or less.

It can be seen, therefore, that installing replacement windows, without trickle ventilators, may mean - for the average property in the UK - moving from a situation where the risk of mould growth is low (except for cases of very high moisture production) to a situation where there is a high risk of mould growth for all but 'dry' occupancy. Note that all the above scenarios apply to the base case dwelling only.

6. Replacement Window Equation

The pressure tests from the field study provide appropriate data to test the theoretical 'replacement window equation' (Ridley et al, 2003). This equation, which was developed using laboratory measurements of window air permeability, predicts the reduction in infiltration that can be expected when a given number of windows are replaced in a dwelling.

Therefore, knowing the number of windows to be replaced, the volume of the house and the flow characteristics of the old windows, the change in the air infiltration rate of replacing old windows with new can be estimated using the following formula:

$$(A_o - A_n) = 1882\left(\frac{N}{V}\right)C_o \qquad (1)$$

where:

$(A_o - A_n)$ = reduction in predicted heating season mean air change rate of house after window replacement (ac/h)

N = number of replaced windows

C_o = flow coefficient of the old window

V = volume of the house (m^3).

To test the equation, five windows from three of the tests house were removed intact and tested in an air permeability test rig according to British Standard BS 5368 in order to measure C_o. Table 1 compares the change in infiltration rate, as predicted by Equation 1, with measured values. Note that in the cases where the flow coefficients of two windows from the same property were measured, the average value of C_o is used in the calculation. In the property where the removed window was found to be very leaky, Ref 03/10, there is a reasonable agreement between predicted and measured reduction in infiltration rate.

In the other two cases, where the removed windows were found to be relatively airtight, there is a poor agreement between predicted and measured reduction in infiltration rate. The results suggest that in these two cases, reduced infiltration between the window/wall joint or around the replaced door were responsible for the observed reduction. The results suggest that, in some cases, installing new windows reduces infiltration through the joint between window and wall. Thus, even when the removed windows are tight, a significant reduction in infiltration can still result.

Table 1. Comparison of measured and predicted change in infiltration rate after window replacement.

Ref No.	Average C_o [-] measured	N/V	$(A_o$-$A_n)$ calculated from Equation 1.	$(A_o$-$A_n)$ measured
01/10	0.00018	0.03	0.01	0.23
03/10	0.004	0.04	0.37	0.34
08/10	0.000004	0.04	0.0003	0.06

7. Trickle Vents

According to the results presented thus far, it appears that some form of controllable background ventilation would be beneficial in dwellings with inadequate background air infiltration. An estimate of the change in air infiltration resulting from the introduction of trickle ventilators to a house with new windows when the flow coefficient and exponent have been measured in accordance with CEN/TC 156 prEN 13141-1 (CEN/TC 156, 2002) is given by Ridley (2003):

$$(A_t - A_n) = 180\left(\frac{T}{V}\right)C_t(50)^{n_t} \qquad (2)$$

where,

A_t = infiltration rate of house with trickle ventilators (ac/h)

A_n = infiltration rate of house without trickle ventilators (ac/h)

T = number of trickle ventilators

C_t = flow coefficient of trickle ventilator

n_t = flow exponent of trickle ventilator.

If the aim of installing trickle ventilators in replacement windows is to offset any increase in air tightness, this can be tested using Equations 1 and 2. If one trickle vent is installed in each replaced window, and $n_t \approx 0.6$ then, to maintain the same infiltration rate, $C_t \approx C_o$. If we wish to reduce the average predicted heating season mean infiltration rate of a UK house from 0.65 ac/h to 0.5 ac/h, then $C_t \approx 0.65C_o$ (assuming the reduction in predicted heating season mean air infiltration rate is 0.23 ac/h). If the flow coefficient of the old window is less than or equal to 0.004, then the flow coefficient of the trickle ventilator should be greater than 0.0026.

8. Conclusions

Analysis of the air infiltration tests undertaken for this study clearly shows that window replacement reduces the background air change rate in all properties tested. The predicted heating season mean background air change rate was reduced on average by 0.23 ac/h with a standard deviation of 0.08 ac/h. In six out of ten dwellings the replacement windows reduced the predicted heating season mean background air infiltration to below 0.5 ac/h. It is important to note that the sample of 10 dwellings is small and may not be representative of the UK stock. However the reduction in predicted heating season mean air infiltration rate was very consistent across the sample with only one property showing a reduction of less than 0.19 ac/h (and for this property the windows replaced were relatively modern and when measured were found to be 'airtight').

Assuming a reduction in predicted heating season mean air infiltration rate of 0.23 ac/h, as the mean value measured during this project, and applying this to the BRE data set suggests that 65% of dwellings in the UK would have a predicted heating season mean background air change rate below 0.5 ac/h after the installation of new windows.

Condensation Targeter suggests that installing replacement windows, without trickle ventilators, may mean - for the average property in the UK - moving from a situation where the risk of mould growth is low (except for cases of very high moisture production) to a situation where there is a high risk of mould growth for all but 'dry' occupancy.

It would appear that the installation of suitable trickle vents in replacement windows might be beneficial.

Results of the telephone survey suggest that window replacement is not resulting in increased moisture problems, suggesting that occupants are ventilating adequately for their moisture production rates.

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References

British Standard BS 5368 Part 1: "Test Method, Air permeability". BSI UK.

BS EN 13829: "Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method". BSI, UK.

CEN/TC 156: (2002) "Ventilation for buildings – Performance testing of components/products for residential ventilation – Part 1: externally and internally mounted air transfer devices", prEN 13141-1(e) CEN.

Davies M, Ucci M, McCarthy M, Oreszczyn T, Ridley I, Mumovic M, Singh J and Pretlove S: (2004) "A Review of Evidence Linking Ventilation Rates in Dwellings and Respiratory Health – A Focus on House Dust Mites and Mould". *International Journal of Ventilation*, **3,** (2), pp155-168.

Hong SH, Ridley I and Oreszczyn T: (2004) The *Warm Front* Study Group. "The Impact on Energy Efficient Refurbishment on Air tightness in English Dwellings". *Proc. Air Infiltration & Ventilation Centre (AIVC) Conference*, September 15-17, Prague.

Lowe R., Oreszczyn T and Robinson P: (1999) "Review of Existing Window Energy Rating Systems and Outline of Possible Systems for the UK". *International Conference on the Use of Glass,* Bath, pp209-220.

ODPM: (2001), "Approved Document L1 - Conservation of fuel and power in dwellings: 2002 Edition". The Stationary Office, UK.

ODPM: (2004) "The Building Act 1984, The Building Regulations 2000, Review of Approved Document F- Ventilation: A consultation package", ODPM, London, England.

Oreszczyn T and Pretlove S: (1999) "Condensation Targeter II: Modelling surface relative humidity to predict mould growth in dwellings", *Building Serv Res Technol*, **20**, (3), pp143-153.

Ridley I, Fox J, Oreszczyn T and Hong SH: (2003) "The Impact of Replacement Windows on Air Infiltration and Indoor Air Quality in Dwellings", *International Journal of Ventilation* **1**, (3), pp209-218.

Sherman M: (1998) "The use of Blower Door Data", Lawrence Berkley Lab Report 35173. LLBL USA.

Stephen, RK: (1998) "Airtightness in UK dwellings: BRE's test results and their significance", Building Research Establishment, *BRE 359*. UK.