Domestic Retrofitting Strategies in the UK: Effectiveness versus Affordability

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ABSTRACT: According to the domestic energy fact file 2003, residential space heating constitutes a significant 60% of the total domestic energy consumption. The age distribution of UK's dwelling stock illustrates that three-fourths of the housing stock was built before 1975. Since newer dwellings are built to exacting standards of energy efficiency, there is scope for reduction of a considerable portion of the space heating demand by effective retrofitting of the existing older stock.
This study looks at traditional English dwellings and investigates the extent to which available retrofitting options reduce heating demand, and examines the most affordable measures. The energy demand is calculated using thermal analysis software tools and Energy Index for a case study residence. Some of these measures are identified as night insulation and effective reduction of air leakages. A matrix of retrofitting measures based on effectiveness versus affordability is drawn by comparing various combinations of proposed improvements.

Keywords: domestic retrofit, insulated shutters

1. INTRODUCTION

Residential architecture in the UK today is an eclectic mix of the old and the new; the historic and the modern. Majority of the recent innovations in improving energy efficiency of buildings have been mostly aimed at newly built dwellings, driving them towards zero energy. However, a significant one-fifth of the existing dwellings date back to the late 19th century Georgian and Victorian era, indicating that large scale retrofitting measures would be one of the best tools towards overall increased energy savings.

The proportion of domestic energy consumption in the overall UK energy usage is a significant 30%. Consequently, the proportion of carbon emissions from domestic buildings is one of the highest in the overall emissions in the UK. In order to achieve the UK government white paper's requirement of 60% reductions in carbon emissions by 2050, there has to be a significant increase in the rate at which fabric and end-use efficiency measures are being currently implemented in the UK. [1] Statistics and future predictions have confirmed that space heating is likely remain the biggest drain of energy in the domestic sector. [2]

Recently, there have been many developments in increasing the insulation standards for dwellings, with building regulations demanding stricter compliance measures, which vary in their effectiveness and cost.

The present paper summaries the findings of a study that focused on a single case study residence in a typical English terrace, investigating energy saving retrofit measures and the extent to which space heating requirement, in particular, can be reduced. It further analyses the affordability of these measures, both individually and as packages.

2. TERRACED HOUSING IN THE UK

In the 17th century, a tight row of houses called the 'terrace' was constructed around squares to form an architecturally unified composition to provide the appearance of a large palace. The elevation of the terrace was derived from Palladian models for grand Palazzo facades. The composition and building type continued into the Victorian period. Although grand in appearance, the terrace was being used for the practical purpose of providing houses for the middle and lower classes, which explains its continuation and survival for so long. Even as styles keep changing, this typology unique to domestic English architecture has remained unchanged, giving a sense of identity to the place it belongs to.

The Georgian terraced house consists of a rectangular plan of 3-4 floors, with the smaller sides forming the front and rear facades. The typical Georgian house was zoned such that the entrance door opened up into a long entrance corridor, thus ensuring that colder outside air did not directly infiltrate the heated spaces. The living rooms with the fireplaces were usually on the ground floors, near the entry. The bed rooms were on the higher floors while the kitchen and store rooms were either in the basement or as an extension to the rear, so that the heat gains from the lower floors could contribute to the heating of the upper bedroom floors. Many old Georgian terraces had light wells or courts at the back to provide access to daylight in the basements. The very form of the terrace itself helped to shield it from cold winds and reduce exposed surface area, thereby reducing heat loss. Early English dwellings had leaded casement windows, replaced by Georgian sash windows in the 18th century, which were again replaced by casement windows in the 20th century.

Sash windows are an excellent source of ventilation in summer due to their ability to have an opening at the bottom of the window as well as the top. Hot air can be released from the upper opening (outlet), while this sucks in cooler air from the lower opening (inlet), thereby increasing ventilation. A simple smoke test proves that a double opening sash window creates more ventilation than a single opening casement window with an equivalent area.

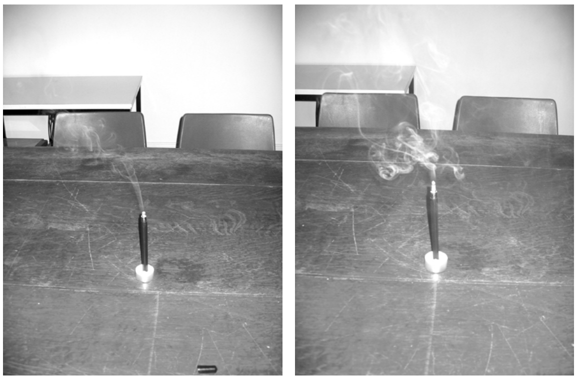

Figure 1: Smoke test illustrating ventilation achieved through a single opening casement window (left) and a double opening Georgian sash window (right)

Window shutters: Most Georgian windows had shutters in the early 20th Century, though these disappeared gradually due to disuse and repair. Shutters were used on ground and first floors, mainly for security purposes. Shutters consisted of either wooden panels or louvers set in a frame. External shutters were more common, although there are evidences of internal shutters too. While mostly used for security, they also performed the function of night insulation, reducing heat loss from the windows at night. Today, shutters are more commonly seen in European countries than in the UK where only the hoods on the window lintels, used to hide the blinds, remain.

3. RETROFIT OPTIONS IN THE UK

In the UK, the primary methods of reducing the heat loss from the building fabric and ventilation are loft insulation, cavity insulation, double glazing, draught proofing and hot-water tank lagging. Of these, the most affordable and least disruptive – loft insulation and hot-water tank lagging – have reached saturation level. Replacement double glazed windows have been implemented in 70% of UK's dwellings, while cavity insulation measures have only reached up to 30% of their potential from 1970 to 2001. [2]

4. CASE STUDY RESIDENCE

4.1 A representative mid-terrace house case study residence

This study will concentrate on retrofitting strategies and simulations for a flat in a terraced house typology, where the existing elements will be improved without any major architectural interventions. The case study is a 2 bedroom flat of 67.5 m^2 area on an intermediate floor in a terrace that the author was a resident of during the winter. (Fig 2) This flat is situated on the first floor of the 4- storey mid-terraced house (Basement + 3 floors). The terraced house itself is located in Kilburn, in North-West London. The window to floor ratio is 20% in the case study, 10% on the south façade and 10% on the north façade, as measured on site. The south windows are unobstructed in this case study, while the north windows are obstructed by the terrace across the road. The reason for using a flat in an intermediate floor of a terrace is that the main heat losses will be through the windows, walls and ventilation. The aim is to focus on these three elements as it is clear from the domestic energy fact file 2003 that they are the main contributors to heat loss while roofs, floors and doors only account for 20% of the total heat loss. [2]

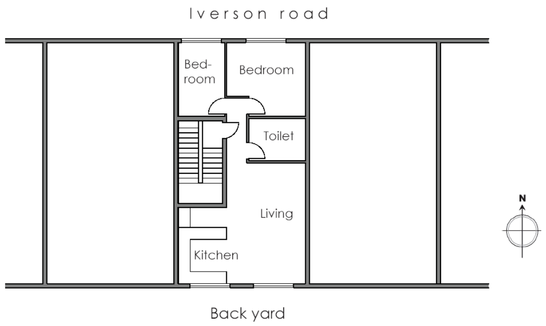

Figure 2: Plan of the case study residence in a mid terrace apartment building

4.2 Occupancy and Heating Patterns

Occupancy: The case study house is occupied by a couple. The number of occupants, i.e, two, is considered fairly representative of the general occupancy pattern in the UK, where the average household size has reduced to 2.3 in 2001 from 3 in 1970. Both types of occupancy – continuous and transient – will be tested in the simulations.

Heating patterns: The simulations will be run for all possible patterns of heating that are generally observed in the UK. According to the domestic energy fact file 2003, the design temperature of UK dwellings has increased over the years due to the advent of central heating and 21°C is the indoor winter temperature that all UK dwellings are estimated to saturate at by 2050. Therefore, the design heating set point is assumed to be 21°C for the simulations.

The heating patterns tested in this study will be:

a. Continuous occupancy continuous heating - The house will be heated for 24 hrs to 21°C (ex: Elderly couple)

b. Continuous occupancy intermittent heating - The house will be heated for a total of 16 hours at a stretch and heating will be switched off for the night.

c. Transient occupancy intermittent heating - The house will be heated for the hours of the day that the occupants are in the house, namely 6am-10am in the morning and 5pm-10pm in the evening. Heating is turned off at night. (ex: Working couple)

4.3 Design and testing of passive retrofit strategies for generic case study

Two different methods of calculating heating requirements are used in this study. The effects of individual retrofitting measures are studied in detail and optimised using Thermal Analysis Software (TAS). The Energy index method [4] is then used to calculate the overall energy saved in kWh/m^2 using various combinations/packages of these retrofit measures. The energy efficiency improvements due to various parameters are then studied with their cost effectiveness and suitable combinations of affordable retrofitting packages are derived. The BASE CASE as used in the calculations is defined as the case study terraced flat with external un-insulated brick cavity walls with 50mm cavity, single glazed windows with wooden frames and un-insulated internal partition walls. The UK AVERAGE terraced flat is assumed to be a case study with features similar to the average flat in the UK derived using building statistics in the domestic fact file 2003 – A typical UK flat has double glazed windows and un-insulated brick cavity walls, with air infiltration rates of 0.8 to 1 ach. The following U-values are assumed for the case study, based on BRE studies of average U-values in the UK [5]:

Un-insulated cavity walls: 1.4 W/m^{2}K
Single glazed windows: 5.0 W/m^{2}K
Double glazed windows: 2.9 W/m^{2}K
Insulated cavity walls: 0.5 W/m^{2}K

An initial test was carried out and confirmed that the results obtained from TAS and EI are in agreement. Both methods indicate that the energy required for space heating of the base case residence is about 105 kWh/m^2.

4.4 TAS Simulations - Optimisation of parameters

The TAS simulation is run for a 3d model of the case study house. The model includes the surrounding houses in the terrace and terraced houses opposite the road, for greater accuracy. The south side is left unobstructed, as there is only a back yard and no houses behind the south side of the house. All results are measured in terms of kWh/m^2, in order to compare with Energy index and UK averages as a whole.

A. Effect of replacement double glazing and insulated shutters:

The reduction in heating requirement due to the addition of insulated shutters to single and double glazing is studied in the simulations. Research papers have found that replacement double glazing has a reduction in air infiltration of 0.2 to 0.3 ach. [6] This is taken into account in these simulations. From the graph (Fig 3), It is observed that there is a significant reduction of 40 kWh/m^2 achieved by replacement double glazing (without shutters). The largest effect of insulated shutters is on single glazing. In the context of heating patterns, the effect of shutters is the largest on continuous heating due to large savings through the night, thereafter diminishing for intermittent heating and transient occupancy. There is a significant reduction in heating load in the mornings because the shutters help to maintain a higher temperature at night.

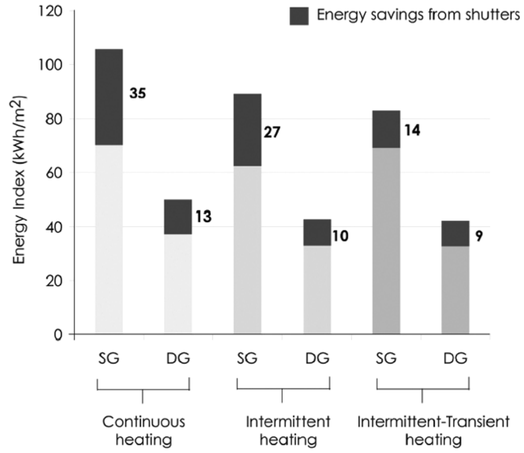

Figure 3: Energy savings using insulated shutters on single / double glazing for different heating patterns *(Based on TAS Simulations)*

The simulations are also run to test effect of insulated shutters on varying window to floor ratios. (Fig 4) The energy savings of shutters on single glazing with the largest window to floor ratio is significant.

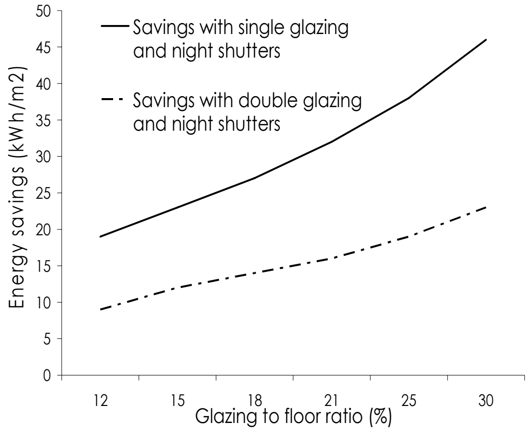

Figure 4: Energy savings using insulated shutters on single and double glazing with varying window to floor ratios *(Based on TAS Simulations)*

B. Effect of Shutter closure timings

The simulations for the previous tests assumed that the shutters were closed at 7pm in the evening and opened at 7am in the morning. But in the winter months of December and January, sunrise is after 7.45am and sunset is as early as 3.45 pm. This indicates that there is scope for savings by closing the shutter for longer in the mornings and evenings. The following test calculates the reduction in heat requirement corresponding to shutter closure timings for continuous occupancy.

The graph (Fig 5) shows that a further savings of about 5 to 8 kWh/m^2 can be achieved just by optimum usage of the shutter during winter days.

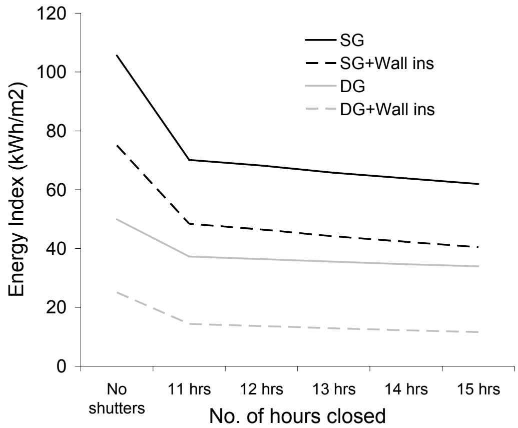

Figure 5: Optimising energy savings from insulated shutters by increasing shutter closure timings *(Based on TAS Simulations)*

C. Effect of reduction in air infiltration

There is an associated decrease in air infiltration with every retrofitting measure that is implemented. The effect of overall reduction of air infiltration is calculated by running simulations assuming that all the measures have been implemented and reducing the air change rate from 1 ach to 0.5 ach. (1 ach being the average air infiltration in an average Georgian building and 0.5 ach being the minimum required for effective ventilation)

The graph (Fig 6) shows that a savings of 25 to 30 kWh/m^2 can be achieved simply by reducing the air changes per hour from 1.0 to 0.5. To achieve maximum benefit, a post-construction pressure testing should be done and all leakages fixed. BRE case studies have shown that if the original Victorian or Georgian building is not too leaky (air infiltration rate of about 0.8-1 ach) it is possible to achieve an air infiltration rate of 0.5 ach or lesser using best practice retrofitting measures. [7]

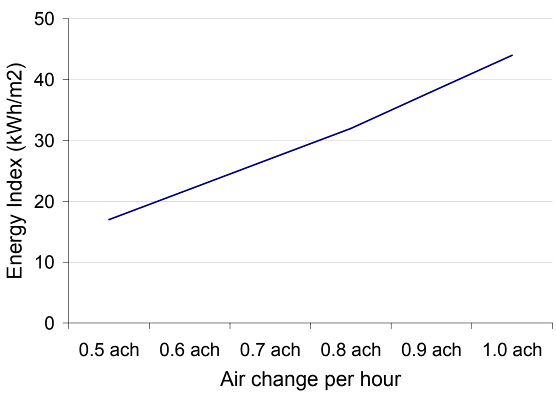

Figure 6: Energy saved due to reduction of air infiltration from 1 ach to 0.5 ach *(Based on TAS Simulations)*

D. Thermal Zoning

Thermal zoning can be implemented in cases where individual thermostats are installed in different rooms. The heating set point for bedrooms can be lower than that of the living room. (ex. 21°C for living rooms and 19°C for bedrooms) It is observed from TAS that about 9 to 12 kWh/ m^2 of heating load reduction can be obtained by this measure alone.

4.5 Energy Index study of the base case

A hierarchy of retrofitting measures arranged according to reduction of heating demand is established by the energy index method. The internal gains, (occupant, equipment and lighting gains) as calculated in TAS, are 5412 kWh and the same amount is also used for Energy Index.

Note: The influence of night shutters is approximate and is obtained by using the mean U-value of the window for 24 hrs.

There is fairly equivalent energy savings due to either insulating the cavity wall or replacing the glazed windows due to the high percentage of windows versus exposed wall in terraces. There seems to be a sizable improvement of 30 kWh/m^2 due to the addition of shutters to single glazing. The reduction of air infiltration (ACH) due to the implementation of the measures reduces the heating demand to a great extent. This reveals that a large portion of infiltration heat losses can be easily reduced just as a consequence of implementing some of the retrofitting measures. The energy index is 18 kWh/m^2 after all measures are implemented; illustrating that for a complete package of retrofit measures, there is a maximum possible reduction of 70 to 80% in heating requirement. (Table 1)

Table 1: Energy Index results (in kWh/m^2) for individual and combinations of retrofitting measures implemented on case study residence

Retrofit measure implemented	Energy Index (kWh/m^2)	ACH
Base case	105	1
Draught Proofing	97	0.9
Adding Insulated shutters	74	1
Cavity insulation	68	0.8
Replacement double glazing	64	0.8
Double glazing and night shutters	53	0.8
Cavity insulation and night shutters on single glazing	43	0.8
Cavity insulation, double glazing, improving air tightness	27	0.5
Cavity insulation, double glazing, night shutters, improving air tightness	18	0.5

Table 2: Retrofitting packages for the base case dwelling (Un-insulated single glazed house) illustrating most cost effective measures

Retrofit measure/package for Base Case dwelling	Energy Savings (kWh/m^2)	Pay back in years	Effectiveness vs Cost ranking
Cavity insulation and insulated night shutters	63	5.9	1
Cavity insulation, double glazing, insulated night shutters and air tightness to 0.5ach	92	13.5	2
Cavity insulation	35	5.2	3
Cavity insulation, replacement double glazing and insulated night shutters	83	12.9	4
Cavity insulation and replacement double glazing with low E	80	13.2	5
Cavity insulation and replacement double glazing	73	12.9	6
Night shutters on existing single glazing	32	5.7	7
Replacement double glazing with insulated night shutters	53	16	8
Replacement double glazing	45	17.5	9

Table 3: Retrofitting packages for the average UK dwelling (Un-insulated cavity walls with double glazed windows) illustrating most cost effective measures

Retrofit measure/package for the UK average dwelling	Energy Savings (kWh/m^2)	Pay back in years	Effectiveness vs Cost ranking
Cavity insulation	31	5.7	1
Cavity insulation and thermal zoning	41	6.4	2
Cavity insulation and insulated night shutters	42	8	3
Cavity insulation, insulated night shutters and thermal zoning	46	9.2	4
Insulated night shutters	14	12	5

5. EFFECTIVENESS VS AFFORDABILITY

The pay back time in years is calculated for different combinations of retrofitting packages in order to establish the most cost effective strategy. Best possible strategies are derived for the base case (Table 2) as well for the typical UK average dwelling (Table 3). The results of the costing analysis are arranged in a matrix that ranks the measures starting with the most effective and affordable package. (i.e. The package which has maximum reduction of heating load for the least pay back time)

Inferences:

As expected, a combination of measures implemented together is more effective than stand alone measures in terms of energy saved for the cost. A retrofit strategy where individual measures are implemented at different times would also be less effective, because a problem such as unfixed air leakage could waste the energy saved by replacement double glazing. Cavity insulation is seen as a must for any effective retrofit strategy, as it is very cost effective. It is therefore surprising that only 30% of its potential has been achieved in the UK. Insulated night shutters are very effective in the base case dwellings, but are completely absent from the building fabric in the UK and merits further research and design. Every retrofit measure should preferably be accompanied by post construction pressure testing for air leakages to improve its effectiveness.

5. CONCLUSION

This study focussed on arriving at strategies of retrofitting that would derive the most effectiveness out of each of the measures. The retrofit options in the UK have been studied in detail for a mid terraced residence and the extent of possible energy savings calculated. A matrix of measures based on effectiveness as well as cost clearly illustrates those that merit more attention and the important strategies to be followed while retrofitting. It has been observed from the software simulations that a total reduction of 70 to 80% in heating requirement for older base case dwellings can be achieved by using best practice retrofitting methods. On detail analysis, it is noted that a combination of cavity insulation and insulated night shutters is the most effective and affordable in base case dwellings. Affordable options such as night shutters, improving air tightness and thermal zoning could be implemented along with expensive options like replacement glazing to reduce pay back time.

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