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Energy Retrofit Evaluation on Insulation and Glazing in a UK Case Study

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Abstract: In the present-day society, human beings spent 90% of their time indoors on average [1]. Thus, indoor thermal comfort should be considered more seriously to improve human health and productivity. In order to maintain the internal comfortable condition, heating, ventilation and air-conditioning (HVAC) systems was favoured to be controlled flexibly. However, heavily depending on these systems would bring a huge burden on energy bill. Households were the end-use sector that globally consumed nearly one-third energy and it accounted for over 20% total direct and indirect CO_2 emission worldwide [2]. In the UK, housing was the largest contributor to national CO_2 emission, responsible near 30% (DETR, 1998). Thus, according to the sustainable development concept, promoting energy efficiency and emission abatement in dwelling could be an alternative solution. Most research concerned about these issues in new buildings, but the benefits gained from the design would only have marginal effect in the short and medium terms under such situation where the housing demolition rate was quite low with new dwellings added to the housing stock, rather than replacing the existing ones [3]. Hence, increasing attention should be paid to existing dwellings retrofit to achieve the sustainability requirement without sacrifice of thermal comfort.
Keywords: Thermal comfort, energy retrofit, sustainable development.

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1. INTRODUCTION

This report attempts to provide a basic understanding of housing retrofit by using PHPP model for a selected house. The principal effects, including cost implications, thermal comfort implication, energy consumption, carbon emissions, maintenance aspects and usability, would be raised according to retrofit methods on insulation and glazing type. Finally, the project would give convictive evidence to show the possibility for the application of proposed changes.

2. BACKGROUND

Refurbishment for existing houses was fairly complicated, involving environmental, economic and social issues. The decision should be balanced among them. Renewable energy technologies, such as Photovoltaic generation and solar water heating systems, were preferred to have zero carbon during operation, but relatively high capital cost prohibited the widespread use of these sophisticated technologies. From Fig. 1, it revealed that the expenditure for per unit carbon emission reduction was often very high in renewable energy systems. The insulation measures seemed to be an appropriate and cost-effective choice. However, in reality, the external insulation could be hardly applied because of the local conservation policy while the internal insulation should be paid attention carefully in some narrow space (i.e. corridor with stairs) because of the building construction regulation for spacing requirement.

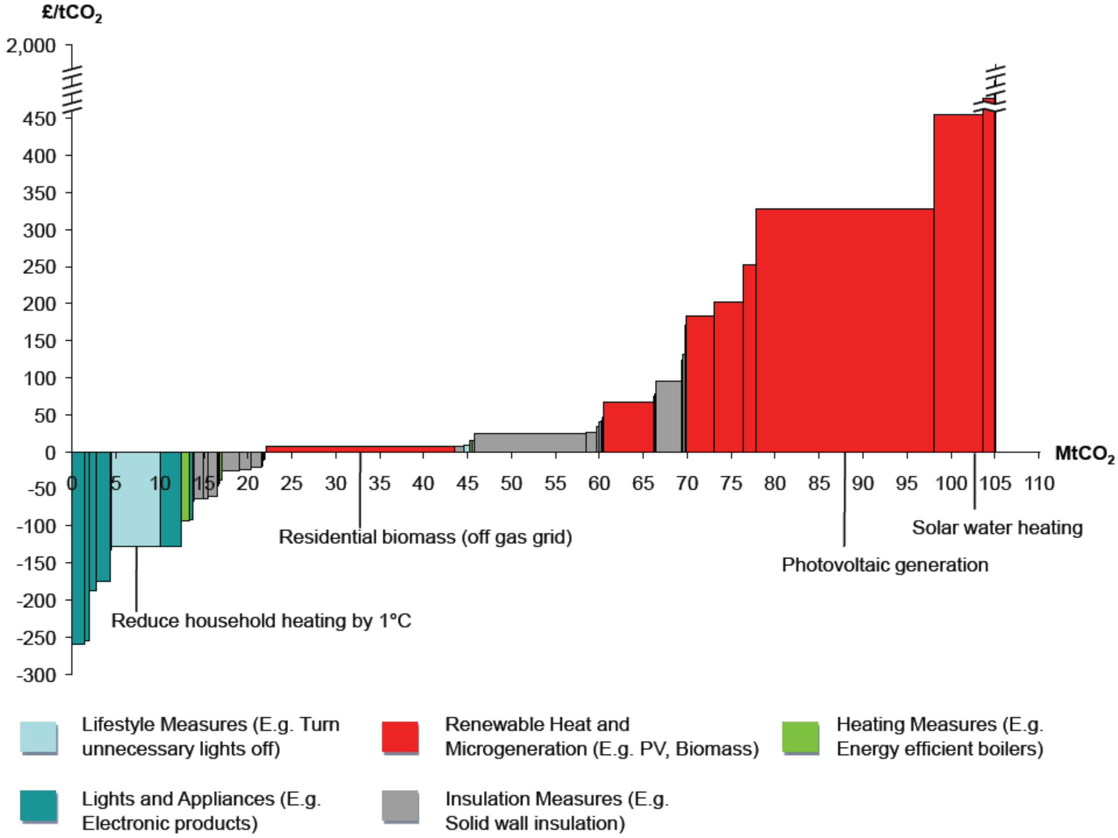

Fig. 1 residential sector Marginal Abatement Cost Curves

In recent years, the UK government and some organizations supported a series of funding for low energy housing retrofit projects as a form of competition or in the purpose of studying. Some simulations programs were used to assist for the choice of retrofit measures. The target houses were monitored both before and after the refurbishment to see the extent of energy saving. Due to the UK local climate, heating was always required massively during the year. In other words, measures, like insulation, on reducing heating load were usually given priority. Cheap and energy efficient device and equipment were also favored to replace the out-of-date ones. In the meantime, harnessing renewable energy resources by green technologies (some with feed in tariff) were still under consideration in order to achieve the carbon emission requirement.

SuperHomes campaign was famous for the low energy refurbishment in old residential houses as a pioneer to introduce the concept of eco-friendly, sustainable, low energy and low carbon retrofit to homeowners. By visiting two SuperHomes in London, refurbishment knowledge could be obtained from the owners' presentation tour. The measures and achievement was listed in Table 1.

Table 1 measures and achievement in SuperHomes

Aim	Measures	
	Camden Chester Road	Camden Bertram Street
Use insulation to reduce fabric heat loss	Double glazing with argon filled and low-e coating	Double glazing remade with Pilkington Vacuum glass
	Wall internally insulated with	Wall internally insulated with

	100mm or 50mm fiber board	100mm Knauf expanded polystyrene
	Whole roof insulated with rockwool and wood fiberboards	Loft insulation with 270mm mineral wool
	Underfloor insulation in living room	Limited insulation added at joist ends within floors
	-	External doors replaced with low U-value doors
Improve airtightness to reduce ventilation heat loss	Windows and doors draught stripped	Windows fully draught stripped
Lighting strategies to reduce lighting energy consumption	Low energy or LED lighting throughout	Megaman low energy lighting throughout house
	Sunpipe added to allow natural light into the hallway	-
Adding energy efficient units	Heat recovery units installed in the bathroom and shower room	Heat recovery units installed in the kitchen, bathroom and cloakroom
Replacing energy efficient device	Gas condensing boiler with full control system for heating and hot water	Condensing boiler with Thermostatic Radiators Valves and good control
	AAA washing machine, dishwasher and fridge freezer	AAA fridge freezer
	Wood burning stove in the living room	-
Renewable energy system installation	Flat plate solar thermal system	8 m2 flat plate solar thermal system
	1.8 kW peak PV system generating electricity	8 m2 PV system with 1.1 kW peak output
Water system improvement to reduce domestic water consumption	Using flow regulators, aerating taps and showers and ultra-low water usage WCs	Using low shower head
	Grey water and rainwater recycling for the garden use	-
Energy saving %	85%	77%

In terms of annual energy consumption in the unit of kWh/m2, BRE set the standards for Passivhaus (new-built houses) and EnerPHit (residential buildings after refurbishment), presented in Table 2 It was possible to achieve the Passivhaus standard for an existing building after renovations. However, it would require more work with high investment. To obtain the reduction percentage and the final energy consumption, the Passive House Planning Package (PHPP) was recommended to use to see the outcome after modification. Sometimes, even though the project could not reach the target, the spreadsheet showed the effectiveness of the retrofit strategies and provided the evidence on the application possibility.

Table 2 criteria for Passivhaus and EnerPhit

Criteria	Passivhaus	EnerPHit
Specific heat demand	$\leq$15 kWh/m².yr	$\leq$25 kWh/m².yr
Primary energy demand	$\leq$120 kWh/m².yr	$\leq$120 kWh/m².yr

From the results shown above both house implemented various measures to reduce energy consumption. To decrease the heating requirement, heat loss was considered firstly to be lessened by modifying the external building envelope and improving airtightness. The lighting energy could be saved from high performance bulbs replacement and daylighting penetration through sunpipe. Mechanical ventilation with heat recovery (MVHR), solar hot water heating system, PV systems and other energy-saving appliance were introduced in the retrofit plan. Consequently, the total energy consumption was lowered by 85% and 77% in Chester Road and Bertram Street SuperHomes respectively.

3. METHOD

The target building was a solid brick inter-war semi-detached house, located in 42 Wolfe Crescent London. The 2-storey and east-facing dwelling was built in 1920's with typical cottage style. Before the retrofit project leaded by London Borough of Greenwich, the initial external walls were constructed with 215 mm solid brick while ground floors were all of solid concrete. Insulation was only implemented in loft using mineral wool. Thereafter, the building performance seemed terrible according to the current standard and the primary energy was huge, 603 kWh/m2 per year, when comparing to the Passivhaus criteria (120 kWh/m2 per year). Especially for the specific space heat demand value, 414 kWh/m2 per year accounted over two-thirds in the total energy consumption and far exceeded criteria of Passivhaus and EnerPHit.

Accordingly, the intention of the retrofit plan for this house was to bring down the energy demand by improving the efficiency of the external envelope of the buildings and using efficient appliances and device, and to provide the reduced energy required by introducing renewable energy sources. The energy consumption was estimated by PHPP after applying every measure. Achievements were demonstrated in Table 3. All of values decreased dramatically, over 80% when comparing to the original ones. The energy consumption reached the target. One point should be noticed that the space heating demand was lower than the criteria for EnerPHit but still higher than that for Passivhaus.

Table 3 achievement after retrofit

	Before retrofit	After retrofit	Percentage reduction
CO_2 emission	115 kg/m^2 yr	19.7 kg/m^2 yr	83%
Primary energy use	603 kWh/m^2 yr	84 kWh/m^2 yr	86%
Space heating	414 kWh/m^2 yr	20 kWh/m^2 yr	95%

Among them, the retrofit measures on insulation and glazing would be assessed in this report. Comparison between the present retrofit implementation and the other ways of application would be raised in terms of cost implications, thermal comfort implication, energy consumption, carbon emissions, maintenance aspects and usability. PHPP spreadsheet would be used for energy consumption analysis, especially for the heating demand value.

Table 4: wall construction details (top item faces inside while bottom item faces outside)

Assembly No. (name in PHPP)	Retrofit A (external insulation)	Retrofit B (internal insulation)
1 (exterior wall insulation)	Gypsum plastering 45mm	Gypsum plastering 45mm
	Brick leaf 225mm	Phenolic foam K5 200mm
	Phenolic foam K5 200mm	Brick leaf 225mm

	Render, cement and sand 15mm	Render, cement and sand 15mm
2 (NeW ext wall)	Gypsum plasterboard 10mm	Gypsum plasterboard 10mm
	Block durox psupablock 100mm	Phenolic foam K5 200mm
	Phenolic foam K5 200mm	Block durox psupablock 100mm
	Render, cement and sand 15mm	Render, cement and sand 15mm

Table 5: material properties

Material	Thermal resistance (m2 K/W)	Vapor resistivity (MN s/g m)
Gypsum plastering	0.079	50
Gypsum plasterboard	0.048	50
Brick	0.292	50
Block	0.637	150
Phenolic foam	9.524	250
Render, cement and sand	0.015	100

Table 6: glazing information

	Retrofit C (double glazing)	Retrofit D (triple glazing)
Name	EcoContract double unit argon fill 24mm	EcoPlus triple unit krypton fill 36mm
g-value	0.640	0.520
U-value W/m^2 K	1.100	0.500

As for the insulation aspect, evaluation would be given between the internal insulation and external insulation for all walls. The construction details listed in Table 4. It should be noted that there were two types of external walls. The only different point for the change was the location of the insulation (internally or externally), which meant the material and thickness of each component were not changed. The material properties of each element were illustrated in Table 5.

As for the glazing aspect, double glazing and triple glazing were required to be compared in this case. However, the retrofit project in Wolfe Crescent House used both types of windows. To make it simple, all windows in Retrofit C would be installed with double glazing while Retrofit D was with triple glazing. The information on different windows was in Table 6.

4. RESULTS AND ANALYSIS

The two retrofit measures selected to be evaluated mainly aimed at reducing heat loss therefore less space heating demand. The results and analysis would be presented one after another, considering all the principal effects.

4.1 Internal insulation vs. external insulation

Building insulation allowed much smaller fluctuation in temperature during day and night when comparing to the external condition, also leading to lower heating demand. In other words, the comfort temperature was easier to be maintained in a building with appropriate amount of insulation. The key parameter U-value determined the building thermal performance. Theoretically, if the wall construction had the same material with identical thickness, U-value would be exactly same regardless of the layer order from inside to outside. Hence, in PHPP, Retrofit A and Retrofit B had same result in energy consumption and carbon emission. In real life, the insulation layer, placed closer to the inside surface than the heavyweight brick layer, allowed to raise the surface temperature more quickly when the room was heated (McMullan, 2007). In other words, the thermal comfort would be reached faster under this condition. It seemed that the building thermal performance could benefit from the wall with internal insulation at the starting stage of air conditioning.

In fact, the scenario would be different because of the condensation risk in construction. Condensation could cause several problems, such as mould growth on surfaces, rot in wooden material, corrosion in metal material, frost damage, and wetting of insulation. It would affect the human living condition and safety issues in buildings. Take Wall 1 as a case in point. After inputting proper parameters (obtained from Table 5) in Dewpoint Tool, the results noted that there was no surface condensation in both retrofit plans throughout the year. Unfortunately, the interstitial condensation happened during the cold period in internal insulation case. Transparently, the interstitial condensation could be a threat to the internal insulation and brick layer. The dampness in walls could damage important structural materials (e.g. steelwork) to cause safety problem and also could make insulating materials (i.e. phenolic foam) less effective therefore to lower the inside thermal comfort level. Future maintenance and examination would be required more frequently in walls with internal insulation.

In order to prevent the interstitial condensation, a vapor barrier was needed, which would bring in extra capital investment in Retrofit B. Suppose to apply vapor barrier in Retrofit B, the building could have similar thermal performance in these two proposed strategies. The internal surface area was calculated to be 20 m2 less than the external surface area. Thus the initial costs were listed in Table 7. The financial cost for both cases was very similar, only £ 900 difference. So the benefit for investing internal insulation was marginal. Once the insulation was added, it seldom required maintenance. But in case the vapor barrier was broken or damaged, the interstitial condensation would probably take place. According to the local regulation, there was no mandatory requirement on land conservation. Furthermore, external insulation had no influence on the internal space and the labor work could be done easier and had less harm to the stuff in buildings. As a result, even though Retrofit A had no advantage on the cost over Retrofit B, external insulation was preferred in this case.

Table 7 initial cost

		Retrofit A (external insulation)	Retrofit B (internal insulation)
Insulation and render to wall	Unit	145 m^2	125 m^2
	Rate	£ 145.00/m^2	£ 145.00/m^2
	Cost	£ 21,025.00	£ 18,125.00
Additional fee		-	Vapor barrier (material and implementation)* £ 2,000.00
Total initial cost		£ 21,025.00	£ 20,125.00

4.2 Double glazing vs. triple glazin

The comparison between double glazing and triple glazing was based on the house which already applied other retrofit measures. From PHPP, the output was summarized in Table 8. The real retrofit project planned to have both double glazing and triple glazing, leading to the resultant values were between Retrofit C and Retrofit D. It made sense since the triple glazing had a better performance allowing less heat loss. Although g-value was lower in triple glazing, leading to less heat gain by solar radiation, the better U-value allowing less heat loss played a predominate role in overall result. Triple glazing installation saved 3 kWh/ (m2a) in specific space heating energy (or total primary energy) and resulted in less 1 kg/ (m²a) in total equivalent CO_2 emission. If the wall thickness was sufficient and local regulation was allowed, there was no huge difference on the thermal comfort, maintenance frequency, and usability between double glazing and triple glazing. In realistic, the only thing that inhibited the widespread utilization of triple glazing was the large amount of window price. Information of window price quotes from Green Building Store via email provided the general fees (Table 9).

Table 8: output in PHPP for double glazing and triple glazing

	Retrofit C (double glazing)	Retrofit D (triple glazing)
Specific Space Heat Demand kWh/(m^2a)	21	18
Total Primary Energy Value kWh/(m^2a)	85	82
Total Emissions CO_2-Equivalent kg/(m^2a)	20	19

Table 9: window price quotes

Window type	Price for openable window	Price for fixed window
EcoContract (double)	£225/m^2	£180/m^2
EcoPlus (triple)	£540/m^2	£300/m^2

In order to estimate the cost and saving, some assumptions were raised as follows.

The house would be assumed to have all openable windows and the window area was 19.4 m2 in total.

The treated floor area was 108.4 m2 for energy saving calculation.

The electricity cost was 14.5p/kWh (Biomass Energy Centre, 2011).

The expenditure on labor was assumed to be same for both cases, which meant it would not affect the cost difference between them.

Thus, the window cost was £ 4,365 and £ 10,476 for double and triple glazing respectively. The energy saving on electricity for double glazing when comparing to triple one was £ 16 annually. Suppose there was no fluctuation on fuel price in future, the payback time for triple glazing was around 382 years, an impressively long period of time. Since the energy saving was extremely marginal, the initial cost became the vital issue on selection. In this case, double glazing was more cost-effective and the overall performance was great.

However, the techniques to produce triple glazing would be improved rapidly and the price would probably climb down. It could still be a choice in some special cases. And in future, it might be the best choice in ordinary dwellings when its price became adequately competitive.

5. CONCLUSION

In recent time, the low energy retrofit in existing houses would offer a great amount of energy saving and carbon emission in the UK. According to the different house situation, applicable and acceptable measures should be carefully applied in the balance among the sustainable concept, client requirement and local regulation, since the best building performance would usually accompany highest refurbishment expense.

The primary energy consumption in the case study house was reduced considerably by 86% after retrofit. Various measures, especially for reducing heat loss, were introduced. Insulation locations in walls and types of glazing were emphasized. As for insulation, the energy issues were same owing to the same U-value according to PHPP. However, the internal insulation would have interstitial condensation sometime during the year, which seriously affected the insulation effectiveness. With the vapor barrier applied, the costs for both cases were very close. However, because of the risk of broken barrier, external insulation seemed to be more suitable in this particular house which was located out of conservation area. When turn to glazing type, the cost benefit for double glazing overweighed triple one substantially while other advantages on triple glazing over double one, such as annual energy saving, seemed fairly tiny.

Thereafter, for this house, external insulation in walls and double glazing application would be sufficient in retrofit plan. However, depending on different circumstances, measures might be different according to the special requirements. It was reasonable to have more triple glazing for retrofit due to the updating production technologies and decreasing price. But triple glazing still had its potential usage in buildings in some special cases or in future retrofit houses when the price decreased.

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