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Lifecycle costing of low energy housing refurbishment: A case study of a 7 year retrofit in Chester Road, London

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ABSTRACT

The low energy retrofit of the UK existing building stock is an urgent matter after the government's commitment to reduce carbon emissions by 80% until 2050. This research addressed the question of whether it is preferable to refurbish in an extensive way or to choose a retrofit strategy with lower capital cost, embodied energy and CO_2, tackling issues of cost-effectiveness, embodied and operational energy throughout the lifecycle of an existing Victorian house in London. The indicator Cost per Ton carbon Saved (CTS) was used, which resulted in higher values for the EnerPHit retrofit model, rendering it a less viable alternative. It was also concluded that retrofitting, in general and especially the application of EnerPHit, is an appealing option only with rising gas prices, low discount rates and long lifespans. Those results were even more amplified when climate change was taken into account, a conclusion very important for the application of future legislation and the possible transfer of this study to other climates. It was deduced that a house's remaining lifetime is a very significant factor to be taken into account, as investments of higher capital cost give higher benefit in long term.

1. Introduction

Dwellings account for 60% of European Union building energy use, 40–60% of which is used for heating and with 80% of the existing building stock proven to exist in 2050 [52]. With the Climate Change Act [23] low carbon retrofitting of this stock becomes a necessity for the United Kingdom, as it sets targets of 80% reduction in net carbon account emissions by 2050 and 34% by 2020 with a baseline of 1990. This policy is mainly driven by two key driving forces: climate change and energy security.

The majority of energy consumed in the domestic sector is for space heating, producing in 2009 25% of the total CO2 emissions [25]. Water heating, lighting and appliances accounted for a further 18% and 19% respectively [3].

As resulting from the above, in the context of climate change, fossil fuel insecurity and the attribution of the second biggest percentage of energy consumption to domestic buildings, it is essential to prioritize the minimization of energy in the domestic stock in the way towards an 80% reduction in CO_2 emissions by 2050. With heating making up the biggest part of the consumption, increasing the insulation levels and the heating systems' efficiency in the existing building stock is expected to result in a big improvement.

The aim of this work is to address the topic of sustainable refurbishment of the existing building stock, by tackling the issues of cost – effectiveness, embodied and operational energy throughout the lifecycle of a residential building. This is researched by comparing a case study refurbishment complying with Part L1 B and a hypothetical refurbishment complying with Passive House[2] (PH) standards for refurbishments (EnerPHit), under the prism of Cost per Ton carbon Saved. The effect of individual measures was

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Abbreviations: CO2, carbon dioxide; CTS, cost per ton of carbon Saved; ECO2, embodied carbon; EE, embodied energy; EU, european union; IC, initial cost; LC, lifetime cost; LCC, Life Cycle Costing; LCS, lifetime carbon saved; LE, low energy; NPV, net present value; OC, operational cost; OCO2, operational carbon; OE, operational energy; PH, Passive House; PH PP, Passive House planning package; ppm, parts per million; PV, photovoltaic; r, discount rate; SAP, standard assessment procedure; SCC, social cost of carbon; TAS, thermal analysis simulation; TRY, test reference year; UK, United Kingdom; WLCC, Whole Life Cycle Costing; XPS, extruded polystyrene.

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[2] The building must be designed to have an annual heating and cooling demand of not more than 15 kWh/m2a in heating or cooling energy OR be designed with a peak heat load of 10 W/m2. The total primary energy consumption must not be more than 120 kWh/m2 a. The building must not leak more air than 0.6 times the house volume per hour ($n50 \leq 0.6/h$) at 50 Pa as tested by a blower door.

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assessed under the same perspective. Thus, this study addresses the debate of whether it is preferable to refurbish in an extensive way (insulating as much as possible), in order to achieve the minimum operational energy or to choose a retrofit strategy with lower capital cost, embodied energy and CO2, which will, hypothetically, be paid back earlier.

2. Life Cycle Costing and low energy retrofit

In order to assess the optimum retrofit strategy for existing buildings, Life Cycle Costing (LCC) was used in numerous studies, underlying the importance of considering the building as an energy system throughout its lifetime. LCC is the total cost of a building or its parts throughout its life, including the costs of Acquisition (including pre-construction and construction), Operation, Maintenance, Replacement (or refurbishment) and Disposal (sale or demolition) [28]. It is a technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital and future operational costs. In particular, it is an economic assessment considering all projected relevant cost flows over a period of analysis expressed in monetary value [28].

Retrofitting aims to the minimization of operational energy, however, focusing solely on the operation phase may bring less overall benefits due to potential trade-offs in other life cycle phases. According to a study [12] comparing the cumulative primary energy input over a lifetime of 80 years of six construction standards, the total production energy input for the PH was 1391 kWh/m^2, with thermal insulation measures accounting for 14% (194 kWh/m^2). The study claims that thermal insulation and ventilation saved 123 kWh/(m2a) on primary energy, having, thus, less than two years payback time. In the Life-Cycle primary energy balance for the ‘reference,[3]’, low energy[4] (LE), PH and self-sufficient house[5] it was obvious that the latter was always above the PH, while the starting points for the five first types were very close, contradicting the argument that PH has a significantly bigger initial energy input compared to standard buildings.

The ‘Arbeitskreis Kostengünstige Passivhäuser, 1997’ [56] (Research Group on Cost Efficient Passive Houses) (Passipedia) concluded that the condition of the building prior refurbishment strongly determines whether an energy saving measure can be considered economical or not. It was also claimed that the implied extra investment of a PH retrofit leads to an overall gain during the lifetime of the components, with careful planning and implementation processes. Most importantly, it was inferred that the highest levels of thermal protection measures available were also the optimum ones, in terms of cost effectiveness, based on the ‘do it as good as possible’ principle.

A study comparing the retrofit of a 1950 Belgian dwelling to common practice, LE and PH standard (not EnerPHit standard) concluded that, although the PH retrofit saves on 87% on heating demand, in contrast to 63% of the LE one, its initial cost’s payback period is highly dependent on fuel price increase. With 2% increase the PH is not paid back not even in 40 years, making LE more cost effective, while with the improbable 10% fuel price increase, the payback time is 18.4 years Versele, 2008.

On the other hand, Hermelink [21] compared an existing PH development to a fictitious LE alternative based on environmental life cycle assessment, assuming constant gas prices. He found that construction and maintenance/repair have a relatively high environmental impact, exceeding the impact of space heating. Moreover, it was concluded that the slightly higher environmental impact of PH building stemming from construction and maintenance/repair is clearly over-compensated by its significantly lower operational energy consumption. While assessing the CO$_2$ emissions of the two LE building types, it was found that the LE would fail the 2050 target and the PH hardly reaches it, mainly due to the carbon intensity of electricity generation. From the cost point of view, as well, PH appears to be the most attractive solution, especially with increased gas and electricity prices.

Table 1
Refurbishment of building envelope.

Element	Refurbishment description
Walls	Double brickwork 220 mm Internal insulation with 100 mm Diffutherm woodfibre boards (U = 0.043W/m^{2}K) 50 mm insulation installed in the kitchen, the bathroom and around the fireplace
Party wall	Kitchen: partly insulated (130 cm from the junction with the external wall) Bathroom: insulated for the whole length Hall: above the height of 7m
Side wall	Re-pointed with a cement mortar with moisture resistance
Roof	100 mm rockwool installed between the rafters, two layers of Diffutherm (40 mm) and 22 mm of Isolair (U = 0.047 W/m^{2}K) above
Floors	Living room: Suspended floor retained, floor boards replaced and the old ones used in the attic. Intermediate space between the joists filled with rockwool (150 mm) and 20 mm of Diffutherm added below them. Junctions with walls foamed Hall: tiled Victorian floor not altered Kitchen: solid floor insulated with 50 mm XPS Attic floor: insulated mainly for noise proof issues with 100 mm rockwool between the joists, Regupol acoustic isolating strips on joists and chipboard on top
Windows and doors	Original sash windows at the front: now argon-filled double glazing manufactured by Vogrum Rear living room French door: triple glazed Ecocontract (U = 0.9 W/m^{2}K). Kitchen, bathroom and attic: Rationel double (U = 2.1 W/m^{2}K) First floor windows: double glazed Skylights: Velux Conservation (U = 1.7 W/m^{2}K) Windows and doors: draught – sealed Second door added to the entrance space, creating a draught lobby

Dodoo [7] and Gustafsson and Karlsson [17] highlighted the importance of the type of energy supply system which is substituted by the retrofit, concluding that the un insulated building with district heating has a lower life cycle primary energy use than if the same building was retrofitted to the PH standard and heated electrically. Similarly to Feist [12], a 4 year payback period of the primary energy for building construction through the operational energy savings was assessed.

The payback period of an energy retrofit is highly dependent on fuel prices and weather data and, as resulted from the Whole Life Cycle Costing study of Mohammadpourkarbasi [40] of a refurbished Victorian house under three gas prices and three weather scenarios, such an investment is only economically attractive with the rising gas prices scenario, although the additional costs of maintenance and replacement of the base case house were not taken into account, which is expected to alter the results. Interestingly, the cumulative cash flow of the refurbished near to PH standard building shows that the payback time from heating saved will be 27 years with upward prices and may never realistically pay back if prices fall or remain constant.

It is important to stress, however, the importance of the boundary condition of each study in the validity of the results. Fuel prices,

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[3] A mid-terrace house (156 m2) complying to the 1984 German Thermal Insulation Ordinance (WschVO 84) was taken as reference house.

[4] Annual heat requirement below 70 kWh/(m2a).

[5] Needs no end-use energy deliveries – apart from the incident energy flows from natural sources (solar radiation, wind).