Retrofitting solid wall buildings: carbon costs and savings

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Short Summary

Regulations and technological advances over the last decade have led to improved energy efficiency for new buildings. However much of the existing European building stock has poorly insulated fabric leading to low energy efficiency and high carbon emissions. In the UK we have a particular problem with homes built prior to 1930 with un-insulated solid walls. This paper briefly reviews the multiple barriers to retrofitting solid wall insulation in the UK. It then quantifies the whole life (operational and embodied) carbon of a solid-walled dwelling, first in its original state and then retrofitted with one of four solid wall insulation products. The results show that all of the products modelled repay their cradle to grave embodied energy and carbon costs within 13 months of installation through the operational savings achieved. The authors conclude that retrofitting with solid wall insulation can result in considerable whole life carbon reductions. While the barriers remain considerable, greater understanding of the issues will help contractors, home owners and developers to make informed design choices.

Keywords: retrofit, whole life energy and carbon, life cycle assessment, solid wall insulation

1. Introduction

According to the International Energy Agency [1], buildings account for close to 40% of the energy used in most countries, with space heating still the main factor. The IPCC have suggested that buildings have the highest potential for cost-effective reduction of energy among all sectors and in all countries [3]. Reducing heating demand through energy efficiency measures could reduce energy use in the domestic sector alone by 50% or more [1].

Regulation and technological advances over the last decade have led to increasing improvements in the energy efficiency of new buildings, with net zero energy due to become the norm in the UK by 2019. However much of the existing European building stock which will still be standing in 2050 has poorly insulated fabric leading to low energy efficiency and high carbon emissions. In the UK we have a particular problem with homes built prior to 1930 with un-insulated solid walls; 31% of existing dwellings fall into this category [2] and these are responsible for over 30Mt CO_2 emissions per year. The option of demolishing and rebuilding these homes with more energy efficient designs would not only lose our cultural and social heritage, it would also have a high embodied carbon cost.

The Climate Change Act of 2008 committed the UK to reducing carbon emissions by 80% by 2050. A number of policy instruments have been developed to achieve this target, including increasingly stringent Building Regulations for new buildings. In 2013 a financial instrument, the Green Deal, was launched to encourage the retrofit of existing homes. This is expected to increase the up-take of solid wall insulation in particular with the result of reducing carbon emissions, as well as energy use, from existing dwellings. However the process and materials involved in retrofit also have a carbon impact which needs to be included in any calculation of savings. The Government Low Carbon Innovation and Growth Report of 2010 recommended that embodied carbon should be assessed at the feasibility stage of construction projects to inform design decisions [4], and this also, necessarily, applies to retrofit projects.

The multiple reasons for the current slow uptake of external insulation installation are discussed in the following section. The paper then describes a theoretical model simulating the performance of a solid wall house with four options, each with a different insulation product as part of the building's wall construction. For each option, the operational energy and carbon saved during the building's lifetime is compared with the embodied energy and carbon of the product.

2. Barriers to solid wall insulation

Energy efficient technologies can be attractive investment opportunities, not only at governmental and industrial levels but also at household level; they can be net present value (NPV) positive, they have low time payback period, and are most likely to remain competitive in the future (Reddy 1990). Cavity wall insulation and loft insulation programmes have been encouraged by the UK Government for many years, with widespread uptake in both social and privately-owned housing. Solid wall insulation systems have also existed for many years – however, these systems have had very poor uptake, for a number of reasons.

Many of these reasons are technological. One important issue for traditional buildings is that they are "breathing" structures, made of permeable materials and without the vapour barriers and membranes which are standard in modern construction. This permeable fabric tends to absorb more moisture, which is then released by internal and external evaporation. Inappropriate application of impermeable solid wall insulation products can lead in some cases to problems with damp ingress [5]. Other technical challenges can be problems with thermal bridging and the creation of cold spots [6].

Further barriers arise from social and cultural considerations. External insulation systems can change the appearance of the building, while internal systems reduce room sizes. Both are disruptive to the daily activities of the occupants. Economic concerns are also considerable, with not only the cost of installing the insulation and applying finishes and redecoration, but often considerable further building work, such as extending window sills and eaves, needed as a secondary effect of adding the insulation.

In addition, in the UK there is little previous experience of this type of work, either by builders or by home-owners. In a traditionally risk-averse industry this is a considerable barrier to implementation.

These barriers are summarised in Table 1 below.

Table 1: Barriers to growth of solid wall insulation sector

Classification	Barriers to implementation of solid wall insulation
Technological	i. Embodied energy and carbon emission savings in contrast with U-value.

	ii. U-value varies significantly between each type of insulation. The thickness of insulation plays a role in decision making iii. Technical challenges including thermal bridging, the creation of cold spots and potential damp inducement.
Economic/ Financial	i. The need for grants and other financial support as the cost of solid wall insulation can be a market inhibitor. ii. There is a lack of consistency and clarity on the direct and indirect costs of solid wall measures and payback times
Socio-cultural/ Behavioural	i. Change of appearance of the dwellings, especially when implementing external solid wall insulation ii. The reduction in the total area of the living space when using internal wall insulation, as well as the need for redecoration. iii. Both internal and external solid wall insulation disrupt the activities in the household.
Information/ Awareness	i. There is a lack of robust, detailed data on the size of the domestic solid wall insulation market in terms of value, number of installations, trends and forecasts. ii. A low public awareness especially on the options availability and the benefits each option introduces.

3. Whole life energy and carbon for five scenarios

The Energy Saving Trust states that ‘where products are very similar in terms of operational performance, then embodied energy aspects should also be taken into consideration’ ([6] p.32). The authors have calculated the whole life energy and carbon of a typical solid wall masonry UK domestic building, first in its original state and then retrofitted with one of four solid wall insulation products, in order to assess the carbon payback times for each product.

The tool used to model the building is a whole life cost, energy and carbon tool called ‘Butterfly’ [7], developed as part of an industrial-academic research consortium led by BLP Insurance and including the Centre for Sustainable Development (CfSD) at the University of Cambridge, the Energy Institute at UCL and UK major contractor, Wilmott Dixon.

The embodied energy (EE) and embodied carbon (EC) are calculated over the whole life of the building (‘cradle to grave’), following the methodology and boundary conditions set out in the recently published CEN TC 350 standards on Sustainability of Construction Works [8-10]. Figure 3 illustrates the modules of the Life Cycle Analysis framework as set out in these standards; those which are outlined in blue/bold form the embodied impacts. Only module B1, Use, incorporating B5 and B6, are currently the focus of regulation in the UK.

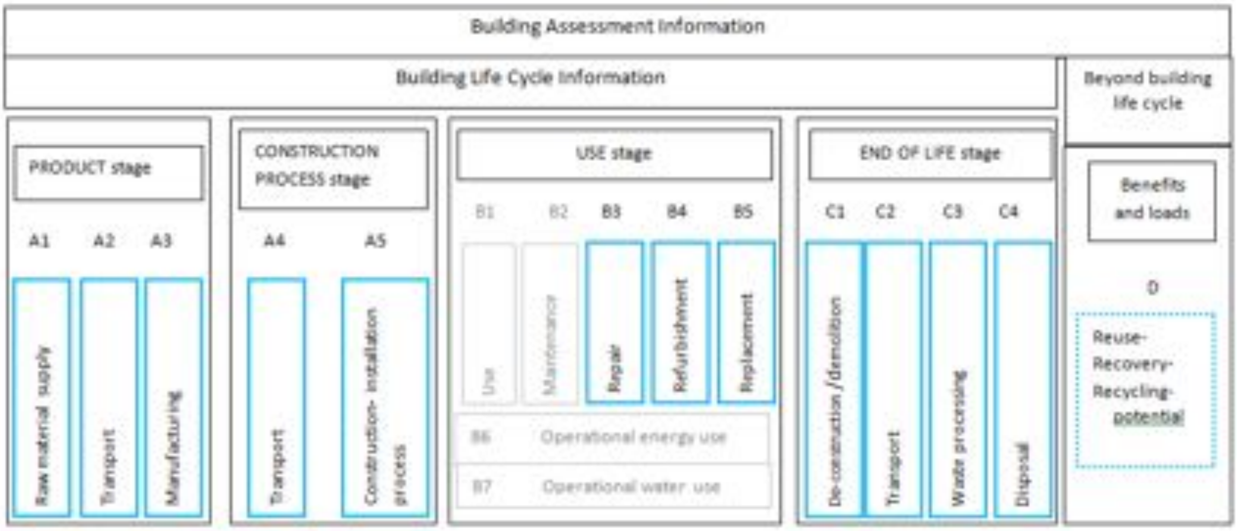

Fig. 1: Life cycle stages from BS EN 15978:2011 Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method [8]

The model considers the building broken down into assemblies (external wall, for example), each with their constituent components (plasterboard lining, for example) and the quantities of these are calculated using assumptions of typical construction methods and systems. These can be overruled by the user when actual figures are known. The embodied energy and carbon of each component is calculated for modules A-C and aggregated to give the total 'cradle to grave' embodied energy and carbon for the building. The construction phase is an exception to this method, since the energy and carbon is not easily attributed to each individual component, and so benchmarking data from construction projects has been used [11].

The operational energy and carbon is calculated using a SAP model, which considers the U values of the building fabric, heating systems and other energy use parameters of the building.

The baseline building used in this experiment is a traditional solid wall masonry semi-detached 2 storey house of $76m^2$ internal area. The model was run for five different external wall insulation conditions, the first base case with no insulation and the other four cases retrofitted with different products, including two which are used externally and two internally, with one mineral and one oil-derived product in each category. These are labelled options 1-4 and each is described in more detail below [12].

Option 1: ThermoShell rock mineral wool (External use)

> This product incorporates a rock mineral wool slab with thermal conductivity of 0.038W/mK, containing a water repellent additive to ensure that no water is able to pass through the slab and reach the substrate during installation and construction. However mineral renders and rock mineral wool insulation are breathable, allowing moisture to permeate through the system in use.

Option 2: OPTIMA system with ISOVER glass wool product (Internal use)

> The OPTIMA System consists of a metal frame, ISOVER glass wool insulation with a thermal conductivity of 0.035W/mK, a vapour retarder and air tightness layer. To avoid condensation damage in the structure, the vapour retarder and air tightness layer are installed on the inner facing surface of the insulation layer (i.e. the warm side).

Option 3: ThermoShell EPS Board (External use)

ThermoShell EPS Board is a graphite impregnated expanded polystyrene bead board with a thermal conductivity of 0.032W/mK. The boards can be either adhered and mechanically fixed or just mechanically fixed to the substrate and then overlaid with a mesh and a render system.

Option 4: Speedline Thermal Laminate Plasterboard (Internal use)

This is a composite product of 12.5mm tapered edge gypsum plasterboard factory bonded to polyisocyanurate foam (PIR) insulant with a thermal conductivity of 0.022W/mK. The PIR foam is faced on both sides by a multi-layer kraft paper and aluminium foil to create a vapour resistant product which can be either adhered or mechanically fixed to the wall.

The wall build-up modelled for each of the 4 options includes an external cement render layer and an internal plasterboard layer, and all options have a total thickness of 350mm; the difference between the options is therefore only in their thermal performance. Each of the four solid wall insulation options produce a u-value similar to that of a standard insulated cavity wall as shown in Table 2. The full external wall assembly is modelled in the programme under the ID code for each option, with only the external walls changed.

The additional embodied energy and carbon ‘cost’ of the solid wall insulation was then measured against the operational energy and carbon ‘saving’ due to the decreased u-values of the building envelope. In each case the carbon payback time was calculated, defined as the length of time from when the building starts operating to the point at which the operational carbon savings surpass the additional embodied energy and carbon.

Table 2: Comparison of external wall options

ID code	**U-value (W/m^2K)**	**Description**	**Operational carbon (regulated) (tCO_2e/yr)**	**Total embodied carbon (tCO_2e)**	**Relative embodied carbon (tCO_2e)**	**Payback (mths)**
2355	2.09	Solid wall, no insulation	3.93	33.23	-	-
2356	0.29	Option 1	2.36	34.41	1.18	9.0
2357	0.28	Option 2	2.35	34.65	1.42	10.8
2358	0.26	Option 3	2.33	34.56	1.33	10.0
300	0.20	Option 4	2.27	35.07	1.84	13.3
200	0.25	Cavity brick and block with 100mm cavity fill mineral wool insulation	2.32	32.31	-0.92	-

The percentage contribution of each life cycle stage to the total embodied carbon of a whole new-build dwelling is given in Table 3 below (from [11]). For the solid wall insulation products, stages B2-5, which include the replacement of components, will be zero for a retrofit design life extension of 60 years, since correctly installed this is also the design life of the insulation systems.

Table 3: Percentage contribution of each life cycle stage to the whole building embodied impacts

TC350 stage	**Embodied carbon (%)**	**Embodied energy (%)**

A1-3 Product	50	54
A4 Transport	9	10
A5 Construction	3	5
B3-5 Refurb and replace	17	26
C1-4 End of life	21	5
Total A-C	100	100

4. Discussion and conclusions

As can be seen from the results of the modelling in table 2, all four insulation products have very low payback periods, and are very similar to each other. In particular it is clear that the embodied carbon of external wall insulation is low compared to the operational carbon saved over its lifetime. This is an important finding for both designers and policy advisors interested in influencing retrofit of domestic buildings. While the addition of other energy technologies may appear more exciting and innovative, it is important to assess all options not just on the potential carbon saved but also on the initial carbon cost [13].

It is also important to consider, as the authors have here, the full life cycle impacts of a retrofit product. Here again solid wall insulation is a sensible choice for carbon reduction, since not only does it have relatively low initial embodied carbon, where correctly installed it is expected to last for at least 60 years, the standard extended design life of the building in which it is installed. This means that the repeat carbon costs of reinstallation over the life of the building are not an issue, unlike products which have a shorter design life such as most services components.

However, as discussed in section 2, a number of barriers still exist to the installation of these systems in the UK. The extra cost of installing external systems due to the additional work required, and the loss of space from installing internal systems in already small houses, are both considerable concerns. The lack of expertise and knowledge for both installers and home-owners is important, as are the valid fears of incorrect installation leading to damp problems. The Green Deal should go some way towards alleviating the economic barriers, leading to an increase in uptake and subsequently a greater experience of and confidence in the technology. As demand increases, the focus on manufacturers and specifiers will be to produce thinner systems, without huge increase in embodied carbon.

This paper concludes that the embodied carbon impact of retrofitting solid wall insulation to existing UK homes is very low compared with the carbon saved during the building's lifetime. The carbon payback time is calculated at around one year for each option, with only small variations between the four products studied. Even with the acknowledged variation between actual energy saved compared with that as modelled here by the Standard Assessment Procedure (SAP), the payback is likely to be very much shorter than the lifetime of the product. It is therefore clear that the take up of this insulation should be encouraged for the 31% of UK homes which currently have solid walls, in order to reduce whole life carbon emissions from the building stock. Since the embodied carbon of the four typical products chosen were similar, the choice of product used is likely to be dependent on other issues, such as whether the disruption and loss of space for internal insulation, or the expense and changes to dwelling appearance for external systems, are more acceptable.

This paper concludes that there are undeniable technical arguments for applying solid wall insulation. While the barriers remain considerable, the increase in uptake which is likely to result from the Green Deal will lead to greater understanding of the issues, which in turn will help contractors, home owners and developers to make informed design choices.

5. Acknowledgements

The authors would particularly like to thank Gary Sutton, SIG Energy Management and SIG plc for their input to and support of this research. The tool used to calculate the whole life carbon was funded by the Technology Strategy Board Low Impact Buildings Programme; the consortium was led by BLP Insurance and included the UCL Energy Institute and contractor Willmott Dixon.

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