How much do we spend to save?

Calculating the embodied carbon costs of retrofit

Daniela Sahagun[1] and Alice Moncaster[2]

[1]Department of Chemical Engineering,
[2]Centre for Sustainable Development,
University of Cambridge, Cambridge, CB2 1TN,
United Kingdom

Email: danielasahagun@gmail.com; amm24@cam.ac.uk

Abstract:
The drive to reduce carbon emissions from domestic housing has led to a recent shift of focus from new-build to retrofit. However there are two significant differences. Firstly more work is needed to retrofit existing housing to the same energy efficiency standards as new-build. Secondly the remaining length of service life is potentially shorter. This implies that the capital expenditure – both financial and carbon - of retrofit may be disproportionate to the savings gained over the remaining life. However the Government's definition of low and zero carbon continues to exclude the capital (embodied) carbon costs of construction, which has resulted in a lack of data for comparison. The paper addresses this gap by reporting the embodied carbon costs of retrofitting four individual pilot properties in Rampton Drift, part of an Eco-Town Demonstrator Project in Cambridgeshire. Through collecting details of the materials used and their journeys from manufacturer to site, the paper conducts a 'cradle-to-gate' life cycle carbon assessment for each property. The embodied carbon figures are calculated using a software tool being developed by the Centre for Sustainable Development at the University of Cambridge. The key aims are to assess the real embodied carbon costs of retrofit of domestic properties, and to test the new tool; it is hoped that the methodology, the tool and the specific findings will be transferable to other projects. Initial changes in operational energy as a result of the retrofit works will be reported and compared with the embodied carbon costs when presenting this paper.

Keywords:
Embodied carbon, modelling tool, retrofit, whole life costing

1 Introduction

In the Climate Change Act of 2008, the UK set a legally binding target to reduce its greenhouse gas (GHG) emissions by 80% below 1990 levels by 2050 (Climate Change Act, 2008). Recent UK and European policy have acknowledged the importance of both lowering the energy use in buildings and of switching to renewable or other low carbon fuels. In the UK, legislation has focused on the need to reduce the energy used in the operational stage of a building, requiring all new residential buildings to be 'zero carbon' by 2016 and non-domestic by 2019. A building can be considered zero carbon when it has no net carbon dioxide emissions arising from its operation including space and water heating, lighting and the use of appliances (DCLG, 2007 a).

However, this definition ignores the aspects of energy use related to the construction and delivery of the building and its components (Hernandez and Kenny, 2010); there are significant carbon and energy implications mainly due to the extraction, processing, manufacture and transportation of the materials that constitute the building. These are known as the embodied carbon emissions and energy.

Until recently, it was generally accepted that the energy used during the occupation of a building represented a much higher proportion than its embodied energy; thus, great efforts were put into reducing energy use in this phase. New and improved technologies have reduced the operational energy through a variety of solutions, including energy-efficient equipment and appliances, improved insulation levels, low energy lighting, heat recovery systems, the provision of solar hot water systems, photovoltaic panels for generation of electricity, and other renewable technologies (Gustavsson and Joelsson, 2010). However, these measures often imply an increase in materials use and energy demand for their production, which explains the growing importance of other phases in the total life cycle.

In meeting national targets, emission reductions are also needed in the existing building stock and thus there has been a recent shift of focus from new-build to the low carbon retrofit. Designing for retrofit has two main differences from new-build. Firstly, more work is needed to retrofit existing housing to the same energy efficiency standards, and secondly the remaining length of service life is shorter. These factors imply that the capital expenditure- both financial and carbon- of retrofit may be a higher proportion of the savings gained by the works. Environmental analysis of building retrofit is therefore necessary to assess the actual benefits of the process, but has been difficult since embodied carbon costs are not calculated for current definitions of low and zero carbon buildings.

There is a substantial lack of data in the literature on embodied carbon in general, and in particular on the embodied carbon of buildings retrofit. This research addresses this gap by focusing on the calculation of the embodied energy and carbon costs of the retrofitting of four individual pilot properties in Rampton Drift, Cambridgeshire part of an Eco-Town Demonstrator Project (DCLG, 2007 b) to promote low-carbon lifestyles. This research conducts a ‘cradle-to-gate’ life cycle carbon assessment for each property through a detailed collection of the materials used and their journeys from manufacturer to site. The embodied carbon figures associated with the materials, including their production and transportation, and waste generated on site, are calculated using a software tool being developed by the Centre for Sustainable Development at the University of Cambridge. The paper seeks to assess the real embodied carbon costs of the refurbishment, with a secondary aim of testing the new tool.

2 Literature Review

2.1 Environmental performance of buildings

The energy consumption in a building’s life cycle can be split into two categories (Sustainable Homes, 1999):

- Operational Energy: energy required by the occupants of a building in maintaining the inside environment through space and water heating and cooling, lighting and the use of appliances.
- Embodied (or embedded) Energy: Energy involved in the acquisition of raw materials, processing and manufacture of the building materials and components, and their transportation to site.

The above definition of embodied energy encompasses the production stage of a building, or the 'cradle-to-gate' embodied energy. Different studies also take into account the energy used during the construction process itself, refurbishment and maintenance works, and the end-of life energy requirements of the building, which include further energy inputs associated to deconstruction or demolition activities, waste management, and recycling and disposal of building materials (Moncaster and Song, 2011). Current research shows that embodied energy constitutes a high proportion of the whole-life energy requirements and carbon emissions. The implications of this contribution are largely influenced by the selection of materials and construction technologies (Zabalza *et al.*, 2011). For low-energy buildings in particular embodied carbon and energy are important parameters, since although less energy is used during operation there is usually extra energy embedded in the systems they incorporate or the additional materials that are required (Treloar, 1998). Awareness of these parameters is essential to avoid shifting problems from one part of the life cycle to another.

2.2 Retrofit

Both building stock levels and population are projected to rise. The UK has a target of two million new homes by 2016, and three million by 2020 (DCLG, 2007 a). These imply a large increase in construction, which will impact the UK's carbon budget to an extent dependant on the type of construction and materials used (Monahan and Powell, 2010).

It has also been estimated that about 24 million homes that exist now or are built before 2016 will still exist in 2050. This means that in order to meet the low carbon agenda, it is not only important to reduce carbon emissions in new buildings, but to undertake a major renovation of the existing housing stock. In fact, this figure implies that some 600,000 homes will need to be refurbished to a high degree of thermal performance each year (Energy Saving Trust, 2010). The environmental benefits and burdens of retrofit schemes need to be assessed and considered in future legislation.

2.3 Standards and legislation

There is currently no legislation requiring the calculation of embodied energy and carbon in buildings. However, European standards (CEN TC 350 series of standards) considering the environmental, social and economic sustainability of construction works are being developed (Moncaster and Song, 2011). These include a set calculation method for embodied impacts of construction materials and a standard way of communicating results through Environmental Product Declarations (EPDs). The International Standards Organisation is currently developing the ISO/CD 14067, expected in 2012, which will represent the first internationally agreed carbon foot-printing calculation method (Jones, 2011). The PAS 2050 is a UK developed, non-regulatory standard co-sponsored by the Carbon Trust and DEFRA that uses a LCA approach for measuring GHG emissions embodied in products and services, and is expected to be the standard for assessment over the next few years (Cherruault, 2010).

In the UK at the end of 2010 the Low Carbon Construction Innovation and Growth Team (IGT) developed a series of recommendations to aid the government in its transition to a low carbon economy. Specifically on embodied carbon, the IGT (2010) stated:

- That … the Treasury should introduce into the Green Book a requirement to conduct a whole-life (embodied + operational) carbon appraisal and that this is factored into feasibility studies on the basis of a realistic price for carbon.
- That the industry should agree with Government a standard method of measuring embodied carbon for use as a design tool and for the purposes of scheme appraisal.

Government responded stating their interest in working with industry to 'unify and further the use of various embodied and operational carbon calculation tools currently in use or under development', and emphasised the importance of developing policy focusing on carbon reductions from the built environment (HM Government, 2011).

Standards are therefore evolving, and Government has acknowledged the necessity of tackling embodied carbon costs as well as the potential of large-scale retrofit. It is essential that research in this area can provide the data to support and inform new legislation. The development of a tool to set a standard method of measuring embodied carbon is currently underway at the Centre for Sustainable Development at Cambridge, and is aiming at producing comparable data sets to inform decision-making. Once these data sets have been created it will be possible to assess the impact of design choices on whole life carbon emissions.

2.4 Published results

Currently available data is very diverse and there is no generally established LCA methodology. Published results are inconsistent and often non-comparable due to differences in calculation methods, lifetimes considered, and datasets included (Dixit *et al.*, 2010). Results also vary across countries due to the specific energy mix and transformation processes. Research studies conducted by Treloar (1998), Pullen (2000), and others show dissimilar results for embodied energy figures. For residential buildings, values span from 3.6 GJ/m^2 (Pullen, 2000), up to 8.76 GJ/m^2 in Treloar's research. The mean of various studies was found to be 5.506 GJ/m^2 with a standard deviation of 1.56 GJ/m^2 by Dixit *et al.* (2010). In the UK, Hammond and Jones reported an average of 5.3 GJ/m^2 embodied energy and 403 $kgCO_2/m^2$ embodied carbon for the 14 cases they studied (reported by Monahan and Powell, 2011).

As embodied carbon is not the subject of any current legislation, until recently there has been little coordinated research carried out in this area. There is a particular lack of studies referring specifically to building retrofit and refurbishment in the literature. While Ardente *et al.* (2011) carried out an analysis of the embodied energy of retrofit of public buildings, no work has considered residential retrofit.

3 Research Methodology

3.1 The Case Study- Rampton Drift Demonstrator Project

The Rampton Drift Demonstrator Project consists of the environmental refurbishment of 13 privately owned domestic properties built circa 1950's and 1970's. Individual dwellings vary in condition, with differing householder needs and different amounts of renovation work already carried out. For those reasons, each property had to be assessed and considered individually (PRP, 2011). Four properties were appointed as pilots and form the basis of this research, which takes advantage of the close collaboration and keen interest of the design team and the contractors to monitor and record minor details. This was essential for the compilation of an accurate inventory of materials and transportation information. A description of the measures implemented in the four pilot properties studied is given in Table 1.

Improvement Work	**68**	**69**	**1**	**13**
Monitoring Systems - Smart Meters	*	*	*	*
Real Time Energy Display	*	*	*	*
Cavity Wall Insulation	*		*	*
Insulation to Loft	*			*

Insulated Draught Stripped Loft Hatch	*		*	*
Draught proofing - Window / Door Overhaul	*	*	*	*
External wall insulation (behind vertical tiles)	*	*		
Radiator System Installation		*		*
Heat Recovery Fans	*	*	*	*
Socket outlet in roof space- for monitoring	*	*	*	*
Storage Boards	*			*
Flue Gas Heat Recovery Unit		*		*
High Efficiency Combi Boiler		*		*
Solar Hot Water System	*			
Insulated Plasterboard (under the stairs)	*	*		
Through wall vent- background ventilation to gas fire			*	
Replacement cylinder compatible with solar heating	*			
Property Specific Items	*	*	*	*

Table 1: Scope of works proposed in the four pilot properties.

3.2 Goal & Boundaries

The aim of this research is to calculate the embodied carbon and energy costs of the different retrofit scenarios of the four pilot properties of the Rampton Drift Demonstration Project, and to estimate the carbon payback period. The scope of the research concerns the embodied CO_2 emissions arising from:

- Materials and products used in the renovation
- Transportation of materials to the construction site
- Waste produced on site

3.3 Data collection

An inventory of the materials and components used in the retrofit was compiled from information provided by the design specifications, by the contractors through site visits, and through informal interviews with the site manager and manufacturing companies along the supply chain. Information about the materials and their quantities was given by the main contractors, and was verified by a detailed recording of delivery tickets consistent with the scope of works produced by the design team.

3.4 Calculation method

The calculation method used corresponds to a simplification of the PAS2050 approach. Embodied carbon can be calculated as the sum of the contributions of each of these stages:

$$Embodied\_Carbon = EC_{mat} + EC_{trans} + EC_{waste} \quad (1)$$

Where EC_{mat}: cradle-to-gate embodied carbon dioxide emissions;
EE_{mat}: cradle-to-gate embodied energy;
EC_{trans}: gate-to-site embodied carbon dioxide emissions;

In this case, due to the fact that renovation activities generate only a small amount of waste relative to other construction projects, there were no waste management plans and skips were not segregated on site. For this reason and in accordance with the method, it was assumed that the totality of waste generated was sent to landfill.

(Note: additional carbon emissions arise from use of landfill, due to change in land use and further GHGs from the waste as it breaks down; however these are outside the stated boundaries of this LCA.)

3.5 Data processing

One of the key concerns when choosing software is that the selection of a database should suit the context of the analysed buildings. For that reason, the software tool developed at the Centre for Sustainable Development at Cambridge University and which is based on the Inventory of Carbon & Energy (ICE) database from Hammond and Jones (2011) at the University of Bath (Bath ICE V2.0), was selected. This Excel-based tool is currently being developed by the ECEB Group as part of the Project Butterfly, which aims at the development of a whole life financial and carbon-costing tool for housing (ECEB, 2011).

4 Findings and Discussion

4.1 Data accuracy

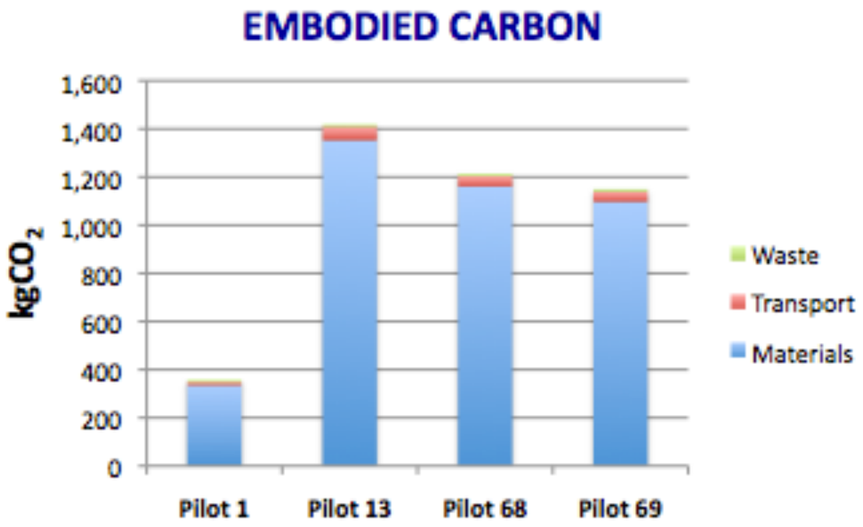
The tool used to obtain the materials' cradle-to-gate embodied carbon coefficients is specific to the UK building sector (Hammond and Jones, 2011) and thus, the figures are considered accurate and suitable to the construction context. The sources and amount of materials used were obtained from delivery tickets and design specifications, keeping uncertainty in these parameters at a minimum and yielding a nearly complete inventory of building materials.

The gate-to-site distances were calculated for each material using the software tool. For products and components where the manufacturer was known, this corresponds to the distance from the production plant to site. For other materials, assumptions were made in collaboration with the contractor and the supervisor, a civil engineer with many years of experience in the construction industry. Additionally, the tool uses a default distance of 50 km for materials that are generally manufactured locally. Although these approximations are still open to error, the proportion of transport to material embodied costs is less than 5%; therefore the induced error will be minimal.

Since no detailed records on waste were kept during the retrofit process, average amounts were estimated for each property from information provided by the contractor on the total weight of waste generated on site. It was assumed that the totality of this was sent to landfill and in accordance with the method, a default distance from site to landfill of 30 km was used.
It was assumed that all materials and waste were transported by road, on diesel-fuelled heavy-goods rigid vehicles, with transport weights of 3.5-7.5 tonnes.

4.2 Contribution of materials, transport and waste

Figure 1 shows the breakdown of embodied carbon for all properties studied. It is observed that in all cases the majority of the embodied costs arise from the materials, which account for approximately 95% of the total. The embodied carbon in transportation activities from manufacturing facilities to the renovation site accounts for 4% of the overall CO_2 emissions, whilst contributions from waste are negligible. It can be seen that the property with the highest embodied loads is the pilot 13, with approximately 1.5 tonnes of embodied carbon whereas property 1 shows the lowest embodied burdens with around 0.4 tonCO_2.



	Pilot 1	Pilot 13	Pilot 68	Pilot 69
Materials	93%	95%	96%	95%
Transport	4%	4%	4%	4%
Waste	2%	1%	1%	1%
	100%	100%	100%	100%

Figure 1: Embodied Carbon by stage.

4.3 Payback times of the retrofit

One of the key aims of this research was to estimate the carbon payback times of the retrofit. The embodied parameters calculated for each property were therefore compared with the expected changes in operational energy as a result of the retrofit. The current and expected performance of the different properties is shown in Table 2, which is based on the estimates provided by the design team following a thermographic imaging carried out and SAP modelling.

Figure 2 shows the graph of the projections of cumulative carbon emissions for the four houses. Year 0 represents the year of the refurbishment and the point at which they start on the y-axis corresponds to the amount of embodied CO_2. The angle at which the lines incline depends on the amount of annual operational carbon and the point at which they intersect represents the payback period, that is, the point in time when the additional carbon costs that arose from the retrofit have been recovered. Thereby, embodied carbon can be considered a good carbon investment.

	CO_2 EMISSIONS		**ENERGY USE**	
	Current kgCO$_2$/year	Potential kgCO$_2$/year	Current kWh/year	Potential kWh/year
PILOT 68	5,188.76	4,189.91	25,388.51	20,401.19
PILOT 69	4,970.30	3,905.27	24,239.34	18,913.88
PILOT 13	5,188.76	4,189.91	25,388.51	20,401.19
PILOT 1	8,583.75	7,100.92	42,448.57	35,024.84

Table 2: Expected and current performance of pilot properties.

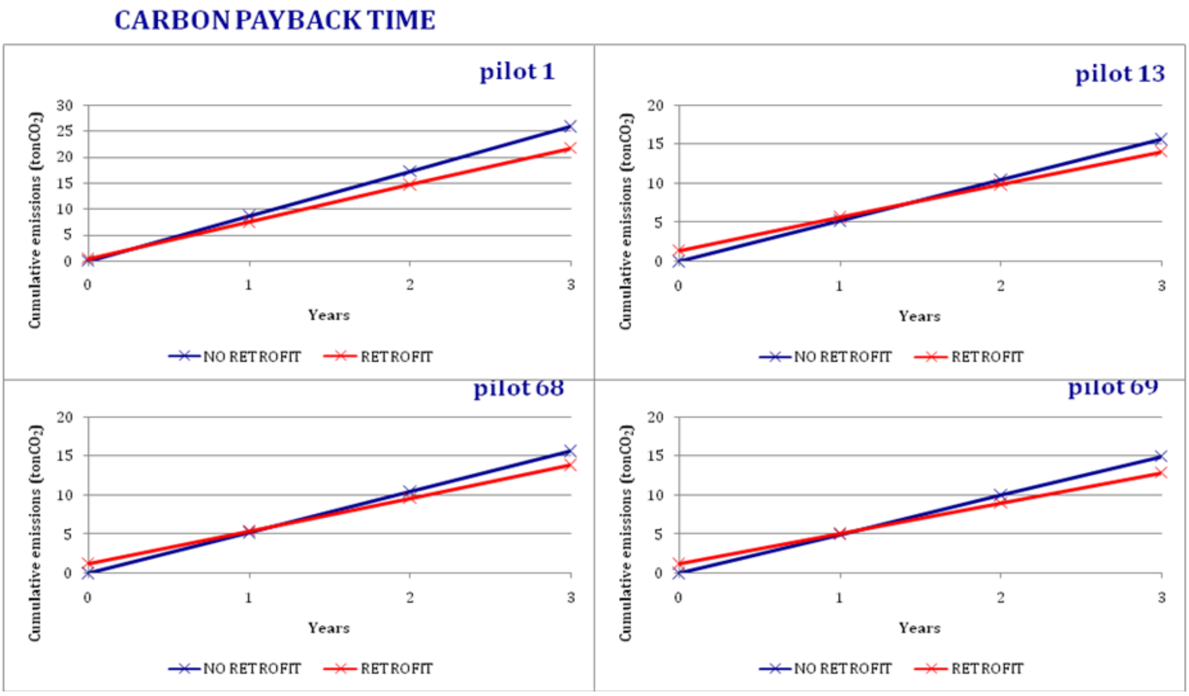


Figure 2: Payback time of the retrofit in terms of CO_2 emissions.

The graph in Fig 2 shows that by the second year, the carbon costs have been recovered in all cases. These graphs have been calculated using estimates of operating performance rather than actual figures. The SAP models could have overestimated the current energy use or potential reductions and thus might show greater carbon and energy savings than actually achieved. This would greatly affect the payback periods. The graphs will be reviewed once the monitoring equipment has been installed the model figures compared with the actual data. The expansion of the system boundaries in the case study to include the energy used by the construction works and the team on site would also increase the embodied energy of the retrofit, which would also result in longer payback times; this is a consideration for future work.

4.4 Limitations

The main limitation in this research was the difficulty of finding accurate data to use in the calculations, especially concerning complex materials and products due to two main reasons:

- Lack of information through the supply chain concerning the product, making it unfeasible to obtain its materials' breakdown
- Embodied carbon and energy data was unavailable for some products. For these, the embodied carbon/energy is approximated as the sum of their constituent materials; this excludes energy inputs from manufacturing or transport processes.

Ideally the cradle-to-gate embodied energy and carbon emission factors should be obtained from manufacturers to accurately represent the embodied costs of the specific products. However, although data was requested from a number of manufacturers, only one insulation manufacturing company possessed this information, and they were unwilling to share it.

5 Conclusion and Further Research

As thermal efficiency standards improve embodied carbon is gaining importance in the whole life environmental burdens of a building. However, there is a substantial lack of data on embodied carbon and energy. It is essential to extend the existing inventory databases of construction materials and urge manufacturers to produce accurate information on the impact of products. The results of this paper show that retrofit has great potential in lowering the whole life energy use and carbon emissions of buildings. The restricted budget and the individual requirements of each homeowner in this Demonstrator Project are determinant factors that make it a realistic prototype for future refurbishment schemes.

This study reiterates the need for a comprehensive carbon-accounting tool, which incorporates embodied carbon costs, and which will be useful to assess the real value of design decisions that reduce energy use in buildings. The omission of embodied carbon in current definitions of zero-energy buildings is misleading since it overestimates the CO_2 savings that domestic housing can achieve and does not accurately reflect the true environmental impacts of buildings. Embodied carbon costs should be taken into consideration in this definition and should be included in future retrofit schemes. Given the novelty of this research and the lack of data currently available, the results should be interpreted as an introduction to the environmental analysis of building retrofit. It is hoped that further research in this area will support the development of the ECEB tool and stimulate both academia and industry to study and declare the embodied carbon costs of building materials and components in general.

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