Abstract

Purpose - The sustainability and low carbon pressures facing construction are focused entirely on operational energy. This case study highlights the impact of embodied energy of materials, which is often neglected, and sets a basis for offsetting the carbon generation by identifying carbon hotspots. This gives more of a whole life cycle approach to assessing a building's carbon footprint, and promotes better adaption to the impacts of climate change.

Design/methodology approach - A low carbon building with simple fabric and structure was chosen prior to construction. An inventory of materials was obtained and embodied energy coefficients applied to assess the key building components. Their aggregate operational energy was identified using benchmarking to produce a carbon footprint for the building. The total carbon content was assessed. Current and future scenarios for offsetting carbon generated were applied to the building components.

Findings – The results indicate that while operational energy is far more significant over the long term, the embodied energy of key materials cannot be ignored, and is likely to be a bigger proportion of the total carbon in a low carbon building. Hot spots for carbon within the components have been identified.

Limitations/implications – It may be a challenge to create components inventories for whole buildings or for refurbishments. A potential future approach is to use a BIM model to simplify this process.

Originality value - This case study identifies the importance of considering carbon use during the whole life cycle of buildings, as well as highlighting the use of carbon offsetting.

Keywords:

Article Classification: Case study

Note: Articles should be a maximum of 5000 words in length. Authors must supply a structured abstract; maximum is 250 words in total (including keywords).

A title of not more than eight words should be provided.

1 Introduction and literature review

2

Since the early 1980s there has been growing interest in reducing global overall energy consumption in the built and natural environment and making adaptations to a changing climate. The focus has recently been directed on buildings, and for good reason. In EU countries, the building sector accounts for approximately 40-50% of total energy consumption (IEA, 2001).

A number of measures and targets have been introduced, including various fiscal and regulatory measures, to tackle climate change and move towards low and zero carbon buildings. In the UK these include binding targets for CO_2 reductions, such as the Climate Change Act (EPC, TSO, 2008), Low Carbon Buildings Programme (BERR, 2009), renewable energy obligations (SI, 2002), the Code for Sustainable Homes (HMSO, 2006) and Energy Performance of Buildings Directive (EPC, 2002). However, this approach has largely focused on buildings' operational carbon consumption (e.g. heating, lighting, services), where seasonal energy variations and reductions in use can be observed. Recent advances in modelling and Dynamic Simulation Modelling (DSM) of buildings has assisted measurement, through commercial packages such as Integrated Environmental Solutions (IES, 2010).

In the UK, operational carbon emissions in buildings are now being regulated by the government. In response to this, there are now standardised methods available in the industry for the operational carbon assessment of both new and existing buildings. Reporting on operational energy use is a statutory requirement, with the introduction of Display Energy Certificates (DECs) for public buildings and Energy Performance Certificates (EPCs) for domestic buildings (CLG, 2010). These certificates give carbon emissions ratings - from A-G - based on the ratio of real energy consumption data to benchmark emissions for typical buildings of that category. There are currently 30 building categories, representing different groups of buildings. These categories and benchmark values are subject to regular reviews and updates by the Chartered Institution of Building Services Engineers (CIBSE) (CIBSE, TM46). One flaw in the current legislation is the exclusion of current embodied carbon emissions in favour of operational energy targets. Mansfield (2011) suggests that one problem with ignoring embodied carbon is that the derived metric is based on partial measurement of a building's whole emissions profile.

As our understanding of buildings' energy efficiency increases with the shift towards low carbon design, more and more questions are being asked about life cycle assessments of buildings over their lifetimes. Hence, operational carbon is no longer the driving force in measuring sustainability in buildings. The embodied energy content of a building – i.e. that derived from materials extraction, manufacturing, transportation and construction - could form a substantial percentage of its total energy (Yung et al., 2013). Embodied carbon and operational carbon together form a building's carbon footprint.

Carbon counting refers to quantifying in units the carbon impact of a product, and is considered an important part of life cycle analysis outside the construction sector. Due to recent interest in reducing the impacts of climate change, some companies, e.g. Coca-cola and Walkers crisps, have released details of the carbon footprint of their products (CTC603, 2006). In addition, online carbon footprint calculators can be used to determine human footprints, such as Best Foot Forward, BP calculator and WWF footprint calculator. Some of these provide the option of buying back carbon to offset one's personal activities, such as air travel and car use (Pandey et al., 2011).

The availability of basic carbon estimators for educational and lifestyle purposes is in stark contrast to the limited use and availability of tools for more detailed and robust life cycle analysis of buildings, and for estimating both the embodied and operational impact of buildings, including carbon emissions associated with construction processes and building maintenance (Jones, 2009, Hammond and Jones, 2008). The development of the BREEAM rating system in recent years has helped address some sustainability issues in buildings; however, it relies on post-performance indicators and therefore does not inform early decision-making processes regarding materials or construction processes.

Sartori and Hestnes (2007) reviewed 60 cases in order to clarify the relative importance of operating and embodied energy, and the study showed a linear relation between operating and total energy valid through all the cases . In addition design of low-energy buildings induces both a net benefit in total life cycle of energy and an increase in the embodied energy.

As well as often ignoring the impact of embodied energy of construction materials, life cycle analysis of buildings is a complex process and methods for calculations can vary widely. Ramesh et al. (2010) conducted a review which concluded that buildings' life cycle energy can be significantly reduced by minimising its operational energy through the use of passive and active technologies. However, neither of these studies, which used information from a variety of databases, specified what constituted the beginning and end of the 'life cycle'. Furthermore, these studies focused exclusively on operational vs. embodied energy, and made no attempts to address issues such as how to calculate carbon hotspots in buildings, or whether and how carbon offsetting can be applied to buildings construction.

2.1 Building carbon assessment and climate change adaptation in buildings

It has been established thus far that a building's carbon footprint is made up of two components: embodied and operational carbon. Quantifying the carbon emissions of new buildings is fundamental to improving the quality of the built and natural environment by enabling effective carbon reduction and management, as discussed in the UK Government's Low Carbon Construction Innovation and Growth Team (IGT) Report (BIS, 2010). This report proposes the introduction of whole-life carbon appraisal in feasibility studies for the purposes of scheme appraisal and also as a design tool.

Carbon is becoming the new currency with regard to construction and its impacts on climate change. The EU Emissions Trading Scheme (ETS) was founded to regulate carbon emissions, and the UK power tariffs now include a carbon component (Voorspools, 2006). In other words, carbon emissions now have monetary implications, and this is changing the industry's culture towards environmental awareness and carbon accountability. While the cost of carbon is currently not a major part of a building's cost, projections suggest it will increase significantly in the future as a tradable commodity for offsetting and tackling climate change (UKERC).

Quantifying carbon, which is now seen as a major metric of environmental performance and energy efficiency, is fundamental to reducing the impact of buildings on the built and natural environments (Ürge-Vorsatz and Novikova, 2008). Thus measuring the impact of buildings in terms of carbon is a valuable tool for future adaptation to climate change.

3 Objectives of the work

The examples mentioned above indicate that researchers have been struggling with the challenge of life cycle energy analysis (LCA) of buildings. Any analysis of carbon emissions has to adhere to international standards, in this case ISO14040 (ISO, 2006), which defines LCA as *"A technique for assessing the environmental aspects and potential impacts associated with a product, by: compiling an inventory of relevant inputs and outputs of a product system*". In common with this definition, the research described in this paper uses the carbon footprint of the building as an analytical decision support tool.

The aim of this study was to take a specific aspect of the life cycle and analyse the carbon impact of the basic construction materials of a low energy building at an early design stage, in order to provide a valuable indication of the carbon impact, as well as long term implications for climate change and the sustainability of the building. Carbon counting is becoming increasingly important - which components of the building fabric contribute the most 'hotspots' - and its impact in the future will be even more significant. This case study attempts to quantify the cost of offsetting the building materials at the present time, and predict costs for future years. The outcome will provide design teams with valuable information beyond current best practice in terms of the impact of materials and options such as using alternative or recycled materials; such data is currently not considered at the design stage. Setting up study boundaries regarding what aspects can and cannot be analysed is very important. The materials covered will be basic structural building components, accounting for most of the weight. Unfortunately, recurring embodied energy for maintenance, upgrading to services, and demolition will be outside the scope of the objectives, as no data is available at this stage for them.

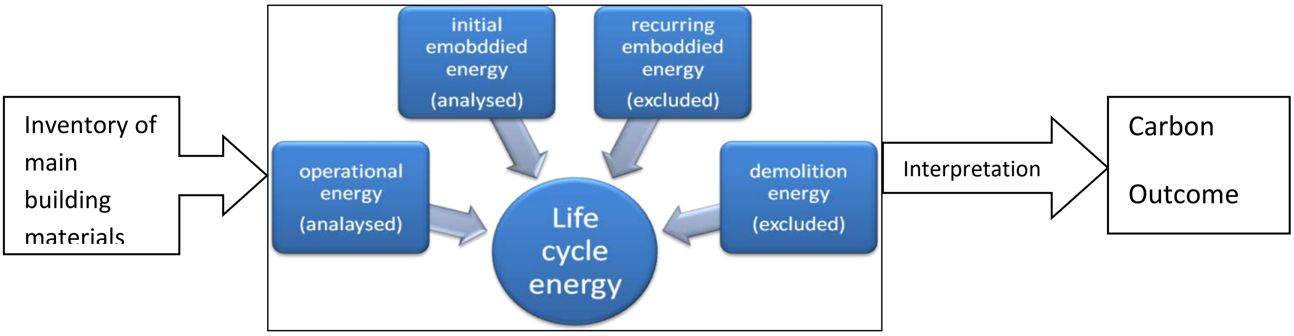


Figure 1: Boundaries of the study

For the purposes of this study the Inventory of Carbon and Energy (ICE) database was chosen for embodied energy and carbon calculations. This was considered by far the most suitable and comprehensive for the UK environment. The database contains 200 materials (embodied energy and carbon), and contains information about treatment of data boundaries for products and where the best data has been used from around the world for embodied energy. In addition, the database complies with approved methodologies and standards such as ISO 14040. According to the University of Bath, ICE has been used on a variety of analyses of projects and has had more than 7000 copies downloaded worldwide. The developers (Hammond and Jones, 2008) acknowledge that there is no methodology that fits all solutions, and for different buildings and products different approaches are needed.

4 Selection criteria for the case study

In the search for a suitable building with simple structure, use and built components for this case study, many buildings were reviewed but did not fulfil the requirement for analysis. The proposed example is the award-winning Huttoft Observatory and Visitor Centre. The structure is located between the dunes of an unspoilt stretch of beach near the village of Huttoft in Lincolnshire (see figure 2). The reasons for choosing this specific building were as follows:

- **Environmental commitments**: Due to its location, the building has to have a low carbon footprint during its operation and construction in order to have a minimal impact on the landscape, with planning guidance specified by BREEAM through third party environmental certifications which the developers have to adhere to.
- **Design stage material balance:** The design team are committed to a low carbon project, offsetting carbon emissions and adapting the building to future climate change. The findings of the work may influence selection of materials at the design stage.
- **Ability to replicate methodology**: While there is no guarantee that a building with low energy use will be efficient over its lifetime, it is hoped that this approach will be used by other developers and adapted to different building types.
- **Inventories of materials**: The building is simple in design and structure, thus aiding the development of a basic inventory of materials needed for the analysis of their embodied impacts.

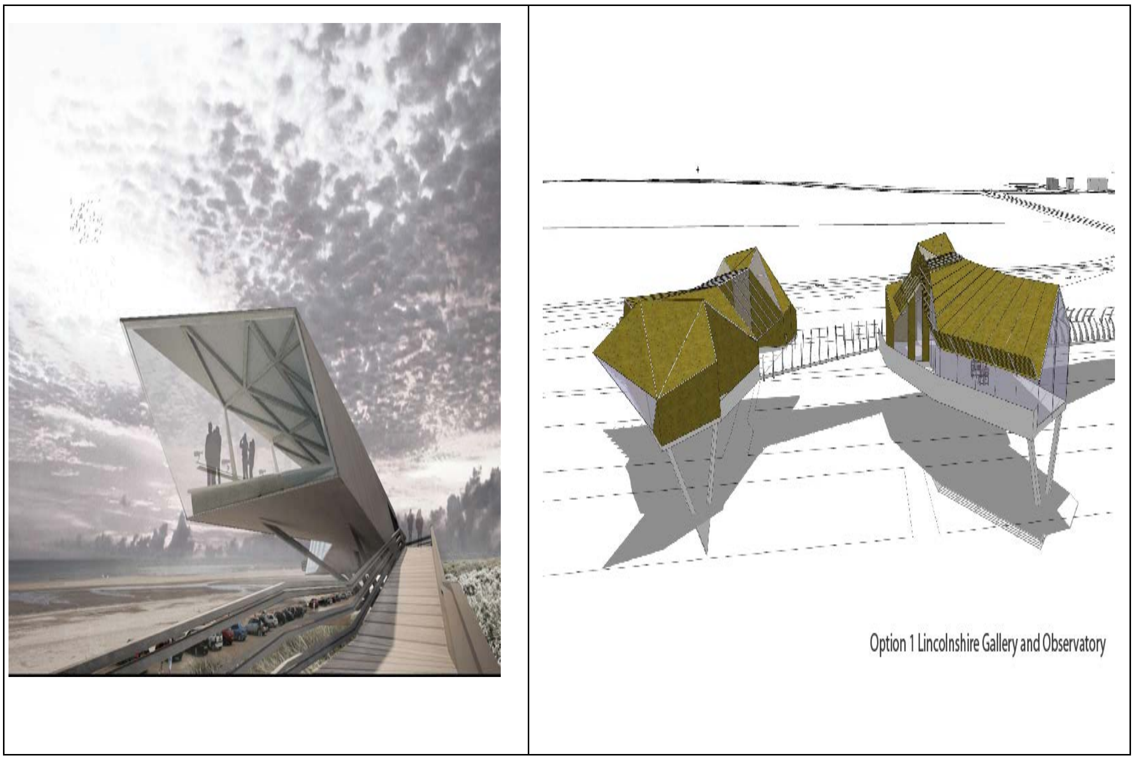


Figure 2: An early visualisation of Huttoft Observatory and Visitor Centre

1 Methodology and results

The methodology used in this study involved evaluating the total carbon footprint by following a series of steps which enabled separate calculations to be made for embodied and operational carbon. The approach was to develop an approach for calculating embodied and operational carbon separately and these will be explained below in detail

4.1 Embodied carbon assessment

In order to produce inventories of the basic building materials such as steel, concrete, timber and insulation, approximate volumes and densities were identified and measured. The process involved several steps as shown in the flow diagram in figure 3. This approach forms a basis for an evaluation tool which can be used at an early stage of design.

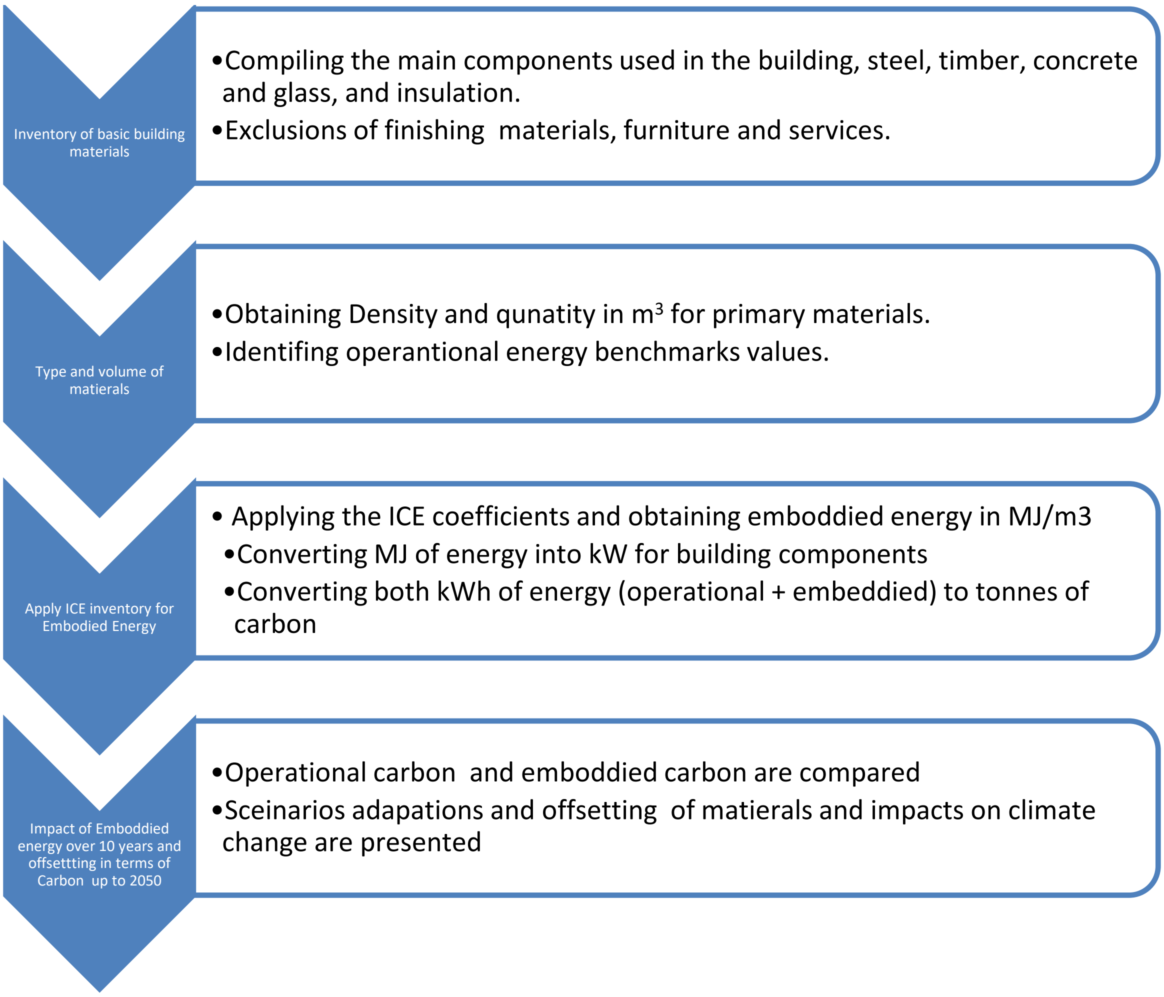
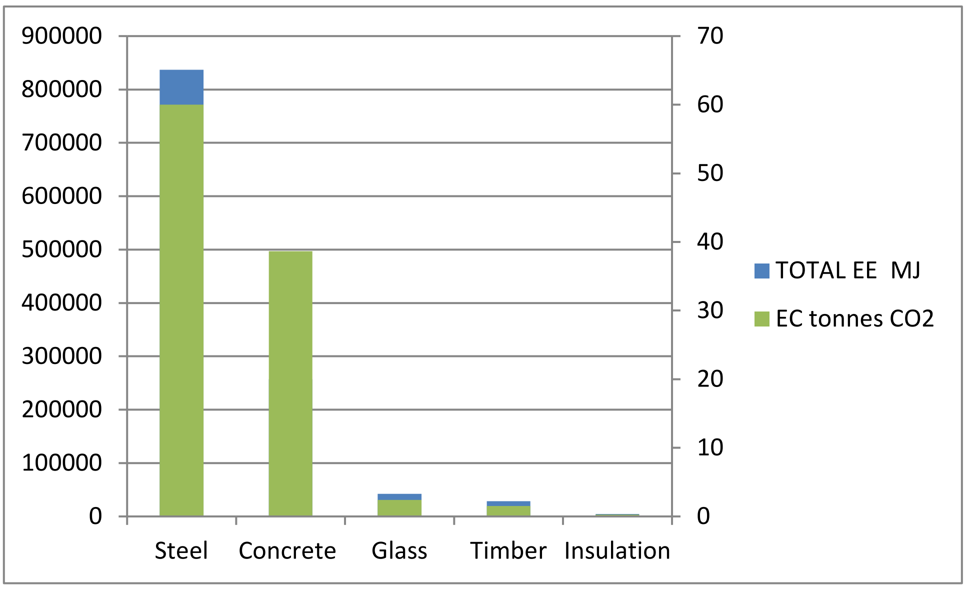


Figure 3: flow diagram of methodology used to assess embodied carbon

In this case for each of the building components different results were obtained, and a breakdown was provided for both embodied carbon and embodied energy. A detailed breakdown is given in Graph 1.



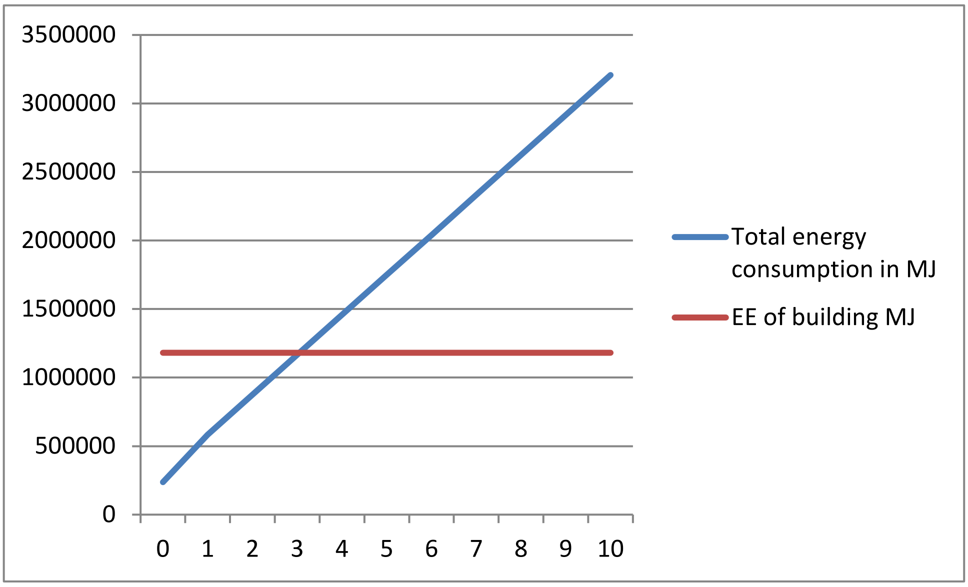
Graph 1: Embodied energy and carbon in building materials

The figures presented in the graph above for both embodied carbon and embodied energy show that certain materials are 'hot spots' in terms of carbon impact, while others have a minimal impact. Materials such as steel and concrete have by far the highest embodied carbon content, accounting approximately over 50% of all emissions. This could be attributed to the weight and density of the material, so that while insulation covers a large volume, its low density means its carbon footprint is much less. The embodied energy in the ICE database is usually measured in Mega joules (MJ) accounts for significantly less.

4.2 Operational carbon assessment

Methods used for calculating operational energy are well established, as mentioned in the introduction. The use of computer simulation packages has become the most customary way of evaluating summer and winter cooling loads, effects of overheating, and thermal performance. However, as a detailed dynamic building energy simulation model has not been developed for this building, operational base loads for it cannot be obtained in this manner. Base loads can be calculated for different building types in kWh/m^2. As the building is still at a design stage, it is impossible to evaluate the full range of operational energy, such as occupancy patterns, weather adjustments, and the specification of the heating unit. Therefore, CIBSE benchmarks were used and extrapolated over a future 10 year period to give operational values based on buildings of similar type and DEC rating. Benchmark values for both electrical and thermal need were used, and this is expressed in terms of delivered energy (kWh/m^2). To obtain operational carbon output data, the figures were converted to $kgCO_2/m^2$ using defined CO_2 intensity factors for both thermal and electrical energy. Finally, as the ICE database presents energy embodied energy in MJ/kg, for ease of comparison the units for operational energy were converted to MJ from kWh.

It is clear that embodied energy forms a significant part of the building's carbon footprint in the early stages of the building; however, over time the cumulative effect of operating energy becomes much more significant (see graph 2). Based on these findings, even with low carbon specifications the building will take approximately 3 years to pay off - or offset - its operational load.



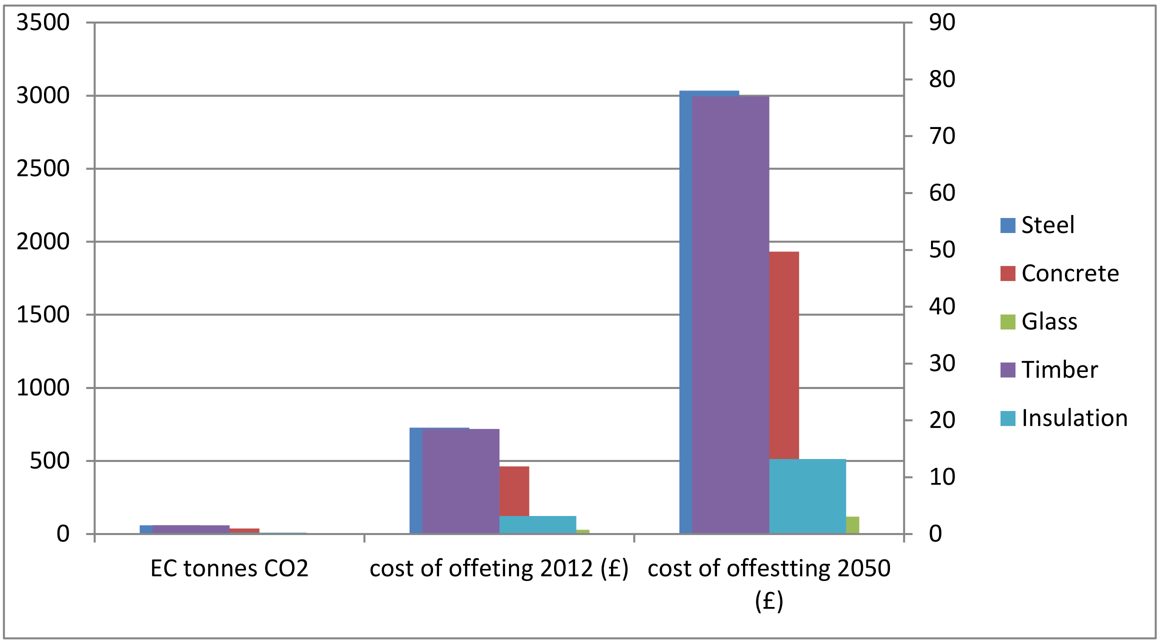
Graph 2: Embodied energy and operational energy over a 10 year cycle

4.3 Offsetting and impact on climate change

In order for such a building to be truly low carbon from a material as well as operational viewpoint, and to reduce the impact of the embodied energy within the building materials over the lifetime of the building, which may be 40-50 years or more, there has to be either a sequestration of CO_2 within the materials, or a reliance on renewable energy generation, or both. This can be achieved through complete reliance on renewables, if the building has features such as natural ventilation and energy generation using biomass or photovoltaics, or through carbon offsetting.

At present capital costs are based on the latest projected value of carbon, which is currently circa £12/tCO2 and projected to rise to around £200/tCO2 by 2050 (UKERC, 2010). While the figures are not significant in terms of a building project's capital costs, the graph below demonstrates the pressures facing low or zero carbon projects. Graph 3 gives an indication of the potential cost of offsetting carbon, showing that the materials which have the biggest contribution to embodied energy are also the ones that cost the most to offset. It can be clearly said that such components are carbon 'hot spots'.

It has to be emphasised, however, that the figures used here relate purely to offsetting the embodied carbon of materials and not their carbon cost in use, i.e. operational costs. Adding this would lead to a much greater overall cost. At some point in the future it may well be cheaper to reduce use than to offset emissions. A combination of carbon reduction and offsetting may therefore be the most appropriate way forward in the future.



Graph 3: Cost of offsetting embodied carbon

4.3.1 Limitations of embodied carbon assessment

The results have demonstrated that the CO_2 impact of materials in addition to operational carbon can be calculated at an early design stage through a specified inventory of embodied carbon. Embodied energy, which is currently outside the regulatory framework, can be a significant component of the total carbon footprint used to assess environmental and sustainability performance over the long term. In addition, the costs of offsetting materials used may increase a lot over the coming decades.

Several limitations regarding the calculation of a building's embodied carbon emissions coefficient came to light during this case study, and further development of the methodology should involve consideration of the following elements:

Study boundaries of materials: It is very important to set up the correct boundaries for LCA analysis. An inventory of building materials can be very complex with a wide range of materials (often more than 100 different types); however, many of these may be used only in very small volumes or have very low density, meaning their contribution to the overall embodied carbon calculations is very small. While specific care was taken to compile an accurate inventory of materials, certain exclusions were made in relation to finishing materials such as plaster, paint (it which would be very challenging to measure the paint used), or carpets. At this stage most of the finishing materials, including furniture and services, have not been specified, so their impact, however small, cannot be quantified. Thus they were excluded from the study.

Waste and surplus building materials: The level of waste generated by the construction process should be considered. It was not possible to assess waste at this stage.

Lifetime of building: This study specified a 10 year period as a basis for the calculations of operational and embodied carbon. Realistically, specific materials are likely to last for different time periods. For example, timber cladding might need replaced after 10 years, whereas the steel frame of building might last for 80 years. In addition, at this stage the values for operational energy are doubling every year as the building uses the same amount of carbon to achieve thermal comfort. However, the normal energy mix can have less carbon in the future as more renewable sources of energy are incorporated into the national grid.

Services and maintenance: The study has focused on major building materials that are unlikely to change a great deal over the lifetime of the building. However, over their lifetime, buildings are likely to undergo refurbishments and upgrades to services, furniture and equipment. It is necessary to highlight that at this stage it is very hard to predict the level and detail of change, including what maintenance will be performed on the building over its lifetime.

4.4 Discussion and conclusions

This case study has highlighted the importance of identifying embodied energy at an early stage of the design process, in addition to the impacts and potential long term consequences of using different construction materials. Specific materials and components appear to be carbon ‘hotspots’. This early stage analysis can be used to assess which materials have the least environmental impact in order to make informed material substitutions. In terms of system boundaries and developing an inventory of materials, there are many challenges regarding the quantification of basic and finishing materials. One potential future solution to this could involve using a BIM library approach to extract all materials used and apply embodied energy values. Having a BIM model with carbon rates attached would greatly simplify the process.

Operational carbon is the most significant component of a building’s carbon footprint over its lifetime, and tackling embodied carbon is of secondary importance. However, in a low energy building such as this case study, operational energy reductions are limited, especially if the building is extremely energy efficient. Placing more emphasis on embodied carbon, and making the correct choices in terms of material at the design stage, can therefore be very important. Operational energy benchmarks alone may not be the most accurate method of identifying long term energy demand. Some technical work needs to be done underpinning benchmarks of all building types to make sure they are representative over the long term.

It has been shown that there is a linear relationship between total and operational carbon. In this example, almost a third of the energy produced over the first 3 years is due to materials used. Low energy buildings tend to show higher figures for embodied carbon, which needs to be offset. From a climate change perspective it is much more important to tackle carbon at an early stage. Although the contribution of embodied carbon is almost completely ignored in the current zero carbon buildings debate, our results indicate that they can make a contribution to the overall carbon footprint of a building, and the cost of offsetting is likely to increase as carbon costs increase.

While the study aimed to use the most appropriate and applicable methodology to quantify the impact of materials, applying different embodied databases, other than the ICE, might produce different results, as the definitions of system boundaries for materials might vary.

The aim of carrying out such footprinting of carbon use to make much more radical use of it at the design stage, giving real time readings of energy figures associated with embodied energy will be vital for making early decisions and material substitutions. BIM design platforms can potentially simplify the process by linking the embodied energy and operational energy. The adaptation of an integrated design tool such as BIM may also be the optimum way to share information at the design stage and enable greater transparency across the design team.

References

BERR. 2009. *Low Carbon Buildings* [Online]. Available: http://www.lowcarbonbuildings.org.uk/.

BIS 2010. Low carbon construction: innovation and growth team. *In:* DEPARTMENT FOR BUSINESS, I. A. S. B. (ed.). London: HM Government, Department for Business, Innovation and Skills (BIS).

CIBSE TM46. DEC benchmarks Energy Benchmarks. CIBSE Publications.

CLG 2010. Display Energy Certificates. London, Great Britain: Department for Communities and Local Government (CLG), HMSO.

CTC603 2006. The carbon emissions generated in all that we consume using the UK Carbon Attribution Model. Centre for Environmental Strategy.

EPC 2002. *European Parliament and the Council, Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings,* Belgium, Official Journal of the European Communities.

HAMMOND, G. P. & JONES, C. I. 2008. *Inventory of carbon and energy (ICE) Version 1.6a,* UK, University of Bath.

HMSO 2006. Code for Sustainable Homes. London, Great Britain: Department for Communities and Local Government.

IEA 2001. *LCA methods for buildings,* International Energy Agency.

IES. 2010. Model Building, Integrated Environmental Solutions Limited. Available: http://www.iesve.com/Software/Model-Building [Accessed 20 May 2010].

ISO 2006. ISO 14040 Environmental Management Life Cycle Assessment Principles and Framework. Brussels, Belgium: International Standards Organization.

JONES, C. I. 2009. Embodied Impact Assessment: The Methodological Challenge of Recycling at the End of Building Lifetime. *Construction Information Quarterly,* 11**,** 140-146.

MANSFIELD, J. R. 2011. Sustainable refurbishment: some practical regulatory hurdles. *Structural Survey,* 29**,** 120-132.

PANDEY, D., AGRAWAL, M. & PANDEY, J. 2011. Carbon footprint: current methods of estimation. *Environmental Monitoring and Assessment,* 178**,** 135-160.

RAMESH, T., PRAKASH, R. & SHUKLA, K. K. 2010. Life cycle energy analysis of buildings: An overview. *Energy and Buildings,* 42**,** 1592-1600.

SARTORI, I. & HESTNES, A. G. 2007. Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings,* 39**,** 249-257.

SI 2002. Renewable Obligation Order

TSO 2008. Climate Change Act 2008: Elizabeth II. Great Britain: The Stationary Office.

UKERC A secure and low carbon future study report. The UK Energy Research Centre (www.ukerc.ac.uk).

UKERC 2010. A secure and Low carbon future; Study report. The UK Energy Research Centre.

ÜRGE-VORSATZ, D. & NOVIKOVA, A. 2008. Potentials and costs of carbon dioxide mitigation in the world's buildings. *Energy Policy,* 36**,** 642-661.

VOORSPOOLS, K. 2006. The CARBON Component of the U.K. Power Price. *Environmental Science & Technology,* 40**,** 4543-4546.

YUNG, P., LAM, K. C. & YU, C. 2013. An audit of life cycle energy analyses of buildings. *Habitat International,* 39**,** 43-54.