

Energy Briefing Sheet: Embodied Energy and Carbon

ICE's energy briefing sheets provide an informative guide to the various sub-sectors, issues and challenges within the energy industry. Authored by members of our Energy Expert Panel, our briefings are updated regularly and are intended to provide accurate information to a varied audience.

This briefing sheet focuses on embodied energy.

Definition

The dictionary of energy defines embodied energy as “the sum of the energy requirements associated, directly or indirectly, with the delivery of a good or service” ([Cleveland & Morris, 2009](#)). In practice however there are different ways of defining embodied energy depending on the chosen boundaries of the study. The three most common options are: cradle-to-gate, cradle-to-site, and cradle-to-grave ([Densley, Tingley & Davinson, 2011](#)). The two following definitions illustrate this more clearly:

Cradle-to-Site

A *cradle-to-site* study favours defining the embodied energy of individual building components as the energy required to extract the raw materials, process them, assemble them into usable products and transport them to site. This definition is useful when looking at the comparative scale of building components and relates more to the “good” in Cleveland & Morris’s definition as it neglects any maintenance or end of life costs. A *cradle-to-gate* model simply describes the energy required to produce the finished product without any further considerations.

Cradle-to-Grave

A *cradle-to-grave* approach defines embodied energy as that “consumed” by a building throughout its life. This definition is a far more useful one when looking at a building or project holistically, though admittedly much more complex to estimate. The energy consumption can be broken down further (Yohanis & Norton, 2002) into:

Initial embodied energy is the energy required to initially produce the building. It includes the energy used for the abstraction, often referred to as primary energy, the processing and the manufacture of the materials of the building as well as their transportation and assembly on site.

Recurring embodied energy is the energy needed to refurbish and maintain the building over its lifetime.

Demolition energy is the energy necessary to demolish and dispose of the building at the end of its life.

Note that the cradle-to-grave embodied energy, i.e. its *life-cycle embodied energy*, does not include the operational energy required to utilise the final product. In other terms it does not account for the heating, cooling, lighting and power of any appliances that allow the building to serve its intended function.

The above definitions are given for energy but are equally valid when considering embodied carbon (dioxide) emissions. Subtleties in correctly measuring embodied carbon include the sequestration of carbon within building materials such as timber, and the emission (or sequestration) of carbon dioxide through chemical reactions during the production of materials such as cement and the lifetime use of materials such as in the carbonation of concrete.

Importance of Embodied Energy

For the United Kingdom to reach its legal obligations of greenhouse gas emission reduction, a low carbon transition plan has been put into place. The plan covers the next 40 years, and it is understood that “the transition to low carbon can almost be read as a business plan for construction, bringing opportunities for growth” (IGT 2010.1, p.4). Still, the focus of the UK Building Regulations has been on operational energy use to date with embodied energy absent from legislative attention ([Densley, Tingley & Davinson, 2011](#)).

The continued tightening of the Building Regulations’ requirements for operational efficiency ([BRE 2006, p4](#)) may have the unintended consequence of increasing the embodied energy of the buildings they serve. This in turn offsets the carbon savings of the whole-life cost. It is therefore very important to standardise the industry’s reporting of embodied energy in order to prevent merely shifting the time at which energy is ‘spent’ and actually reducing the net carbon cost of any project.

The numbers resulting from studies analysing the proportion of embodied carbon against other energy costs continue to be widespread given the breadth of building usages. It is also worth noting that the proportion of initial embodied energy for residential and commercial buildings, which make an intensive use of operating energy, is very different to other forms of construction such as bridges or even stadia where the relative importance of embodied energy is likely to be even greater.

A study of the energy use of Swedish low-energy buildings found that the initial energy embodied in a one family home accounted for more than 40% of the whole-life energy requirements over a 50 years life span (Thormark 2002). Rawlinson and Weight (2007) suggest that in the UK the embodied energy in complex commercial buildings may be equivalent to 30 times annual operational energy use, whilst at the same time Sturgis and Roberts (2010) suggest that this accounts for 45% of the whole life-cycle carbon of its structure.

It is important to recognise that there is no hard and fast rule in buildings and that in some buildings effective control of ventilation requirements through the use of massive building materials can more than outweigh the initial additional embodied energy in the building, demonstrating the importance of a full cradle to grave analysis in such cases.

Applications to Civil Engineering

Today the UK construction industry is the largest consumer of natural resources in the country with over 400 million tonnes of material consumed each year ([Davis Langdon LLP 2009](#)). It is estimated that this accounts for approximately 10% of total UK carbon emissions ([ENVEST, 2010](#)). Civil engineers specify a large proportion of all the materials used in construction (Symons, 2009) and thus have a great potential impact in this field. Note below the estimated proportion that the construction industry has the ability to influence (IGT, 2010.2), calculated by piecing together existing evidence on CO₂ emitted across the broad areas of a building's life cycle¹. Demanding better specifications from the supply chain can therefore have a major impact on the sector as it accounts for the largest amount of emissions within the process of construction.

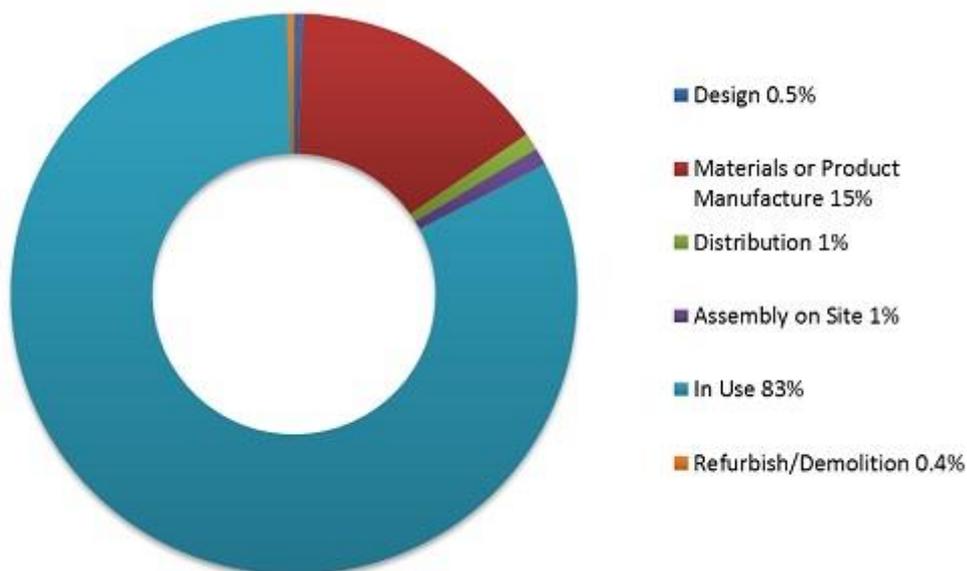


Figure 1: Broad areas of a building's life cycle, with the proportion of CO₂ emissions the construction industry has the ability to influence (IGT 2010.1, p.2)

Recommendations

The following are a series of commonly recommended steps towards reducing the embodied energy embodied of buildings (IStructE, 1999):

- Better specification of current mainstream material – steel and concrete are the main construction materials used in the UK today. Their energy and carbon content can be reduced by specifying them properly and sourcing them responsibly.
- Specification of alternative materials – timber, rammed earth, hempcrete etc. There are as many alternative materials that are appropriate for some design and construction situations in which full advantage can be taken of their low embodied energy content.

¹ See IGT (2010.2) for assumptions and caveats taken in calculations. Also, note the percentages do not add to 100% due to rounding.

- Design leaner structures and material optimisation – by minimising the quantity of materials we reduce the energy used to make the building in the first place.
- Design for deconstruction, reuse and recovery – buildings often have a service life that is far less than that of the materials they are made of. Building with deconstruction in mind will enhance the reuse of construction materials, effectively increasing their life-span and the energy efficiency of the buildings in which they are used.
- Design for future use, adaptability and flexibility – designing to make buildings suited to different uses will increase their life-span and reduce the need to use new construction materials.
- Minimise waste – the construction industry is responsible for some 120m tonnes of construction, demolition and excavation waste every year – around a third of all waste arising in the UK ([Davis Langdon LLP 2009](#)) – what accounts for 22% of all construction embodied energy and 19% of embodied carbon (Jones & Hammond 2008). The potential impact on energy efficiency is hence significant.

All these proposed solutions will be most effective when used in an integrated approach to design, construction, operation and maintenance as part of a global energy efficiency strategy.

Resources

Numerous private companies, both in the engineering and other built environment sectors, have developed in-house tools to measure the carbon and energy associated with a project. The Environment Agency (EA) and the Building Research Establishment (BRE) have produced carbon calculators all of which primarily reference figures from the Bath University Inventory of Carbon and Energy. This latter comparative list contains average absolute values for the embodied carbon associated with common construction materials in the UK, and explains the factors which have been taken into account when compiling the lists (Hammond & Jones, 2008). The database continues to be open and is updated regularly based on data extracted from peer-reviewed literature.

The CESMM4 Carbon & Price Book 2013 (Andrews, June 2013) includes the embodied carbon of every material, enabling users to calculate not just the economic impact of material specification but also the carbon cost.

Embodied energy plays an important role in the modelling of life-cycle assessments (LCA) of structures. European standards have been developed to specify the boundaries of these models, which should increase the reliability of analysis and allow for useful comparisons to be drawn across materials with respect to functionality.

Many companies are now producing Environmental Product Declarations (EPD) for their materials. Within the civil engineering domain, manufacturers of steel re-bar, glulam, and precast concrete for example produce certified documents which detail the environmental impact of their products (and this includes carbon impact). While not everyone is producing EPDs, the number is growing every year. The increase in projects taking part in environmental programs like LEED (Leadership in Energy & Environmental Design) in the

US and BREEAM (Building Research Establishment Environmental Assessment Methodology) “rewards” the usage of products with supporting EPDs.

Future Developments

Embodied carbon in particular will gain in relative importance more rapidly with the decoupling of energy generation and carbon emissions. In the UK, Zero Carbon buildings are to become a reality in 2016 for residential and 2019 for other buildings. Embodied carbon will then represent the majority of a project’s whole-life carbon emissions.

Measuring and reporting embodied carbon would put the savings made in operational carbon back in context. Some of those savings might be made through the use of high embodied energy components, negating the benefit. Also as improvements in operational energy have been achieved, further improvements become harder and more costly, reducing the embodied carbon content of the building might be significantly more cost effective.

It is important that designers and regulators begin to take embodied energy and carbon into account and move from a vision where zero-operational emissions is the ultimate aspiration to one where minimising whole-life carbon emissions is the norm. It also important to begin to appreciate the implications of embodied carbon beyond national boundaries. To truly mitigate any environmental impact, understanding the embodied (embedded) carbon relationship between imports and exports associated with UK trade flows is vital and needs continued development ([DEFRA, 2008](#)). Research on this is ongoing at the University of Leeds ([DEFRA, 2012](#)).

References

[BRE \(2006\) – Part L explained – The BRE Guide; Watford: BRE](#)

[Cleveland, C.J. & Morris, C.G. \(2009\) – Dictionary of Energy: Expanded Edition; Elsevier Science](#)

[Davis Langdon LLP \(2009\) – Designing out waste: a design team guide for buildings; Oxon: WRAP](#)

[Densley Tingley, D. & Davison, B. \(2011\) – Design for deconstruction and material reuse; Proceedings of the ICE – Energy, Vol 164, Issue 4, p195-204; Institution of Civil Engineers](#)

[DEFRA \(2008\) – Development of an embedded carbon emissions indicator; Department for Environment, Food and Rural Affairs](#)

[DEFRA \(2012\) – Embedded Carbon Emissions Indicator; Department for Environment, Food and Rural Affairs](#)

[ENVEST \(2010\) – Environmental Impact and Whole Life Costs Analysis for Buildings](#)