Embodied energy - a ticking time bomb?

Reducing energy use in buildings is now well and truly on the national agenda; low-energy design of new buildings, low-energy refurbishment of existing ones and energy-use behaviour of the occupants are all being tackled across the scale, from the Department of Energy and Climate Change and its associated quangos, out to myriad initiatives up and down the country. But a so-called zero carbon building still has a significant energy and carbon footprint – caused by the energy used to manufacture the materials, build the building, and maintain and repair it throughout its life. As the operational energy is driven ever downward, the importance of this 'embodied' energy, and the associated carbon emissions, looms increasingly large. Kate de Selincourt reports ...

In a way this is an issue that has come full circle. 'Low embodied energy' has long been heard as the rationale behind, say, the use of natural materials such as timber, straw and rammed earth. More recently though the convention has been that in the overall life cycle of a building, the energy and carbon cost of even relatively high-impact materials, like cement and steel, was overwhelmed many times over by the lifetime energy use, and far more dramatic energy and carbon savings could be made by paying attention to the in-use efficiency of the buildings.

While so many of our buildings are still performing so poorly, this argument is still significant. A summary of the carbon impact of the construction sector in 2007 showed that around 16% of the total impact was down to manufacture of materials and components, transport and construction; 84% was down to operational emissions. The chief construction advisor's report is at: http://tiny.cc/7zkku

But because so much has been achieved in driving down building energy use through design in new-build and refurbishment, embodied energy is once more becoming visible as a concern. A recent study for the couldn't-be-more-mainstream, National House Building Council, predicted that as operational energy and emissions fall, embodied carbon could account for up to 40% of the total lifetime carbon emissions for a typical new-build house. The study also indicated that these embodied costs could be reduced by 5-10%, without compromising performance, or doing anything radical. http://tiny.cc/tnk6p

And there's an additional reason we should perhaps be taking embodied emissions more seriously. It is cumulative carbon dioxide emissions, over time, that drive climate change. If we can postpone an emission, we reduce the time the carbon dioxide is in the atmosphere, and therefore, reduce the harm done. If, as is widely believed, we are in the last desperate window of opportunity to fend off a climate 'tipping point', it is especially important to reduce emissions in the present time - which, of course, is where embodied emissions are concentrated.

A rough back–of-an-envelope calculations (see box – the time factor) suggest that a tonne of carbon dioxide emitted at the start of a building's life will have almost twice the climate impact of an average tonne emitted during the building's life, because of this cumulative effect.

At the very least, failing to account for embodied carbon and energy can be a wasted opportunity to cut carbon. At worst, it could end up being counter-productive, as a report written by Simon Sturgis and Gareth Roberts for the Royal Institute of Chartered Surveyors points out: "There is ... a danger that this pressure to cut operational emissions will have the unintended consequence of adversely affecting embodied emissions, by requiring the use of increasingly carbon-intensive solutions, the closer we get to zero operational carbon emissions. Current legislation and practice currently only calls for the partial inclusion of the sources of CO_2 generated by buildings, specifically, operational carbon use. The significant amounts of carbon used to make and maintain a building are ignored ...significant problems arise as a result of this, including the misallocation of environmental and financial resources ... much of this money may not achieve the environmental goals it was designed to ..." http://tiny.cc/vj4or

Change is coming!

Most 'green' designers will tell you they do, of course, consider embodied energy and carbon in their design process. But whilst there are more or less universally accepted methods for calculating fabric efficiency and building energy use, there is no equivalent to SAP or PHPP sitting in every office for all the designs routinely to be run through. There are no benchmarks, and few other obligations, other than the need to make vague statements about 'sustainable materials'.

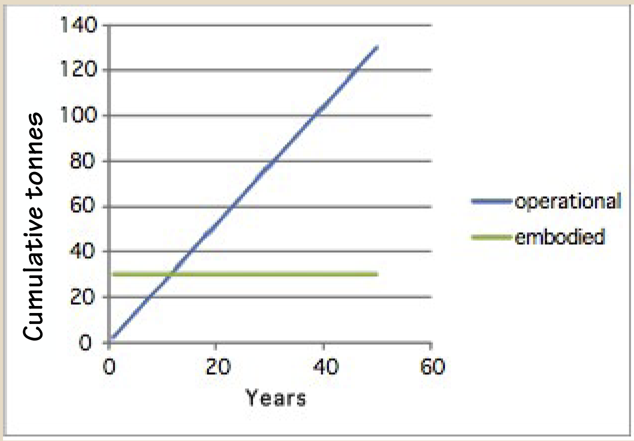
But this looks set to change. As BSRIA (Building Services Research and Information Association) puts it: "With a target of 80% reduction in carbon being brandished by the

Cumulative emissions from embodied and operational energy

Cumulative emissions, or tonne years, are identified by the IPCC (Intergovernmental Panel on Climate Change) as the metric which gives the closest measure of actual damage to the climate.

In a paper for the Oxford Institute for Energy Studies, senior research fellow, John Rhys, has pointed out that as CO_2 emissions are cumulative, a "significantly higher weight should be attached to current, as opposed to future emissions". The fact that they may well lead to more emissions via positive feedback loops, adds even more weight to this argument. http://tiny.cc/187pr

This makes perfect sense – the longer a tonne of CO_2 hangs around in the atmosphere, the more damage it can do. Thus even holding a tonne of CO_2 out of the atmosphere by temporary storage for 30 or 60 years, or putting off its emission for 30 or 60 years, will have a positive impact compared to emitting that tonne now.

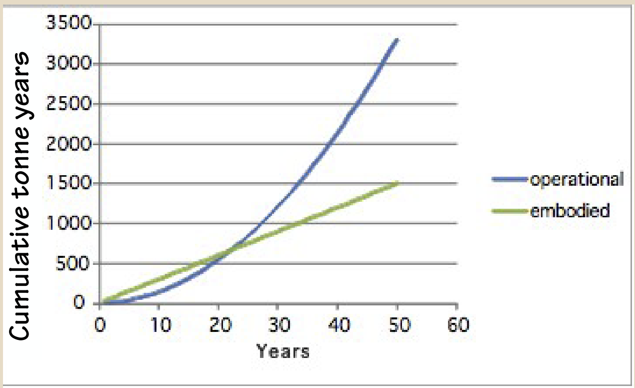


This makes a very big difference to the way you might count embodied and operational energy. While the embodied energy emissions generally form less than half the total emissions from the life cycle of a building, most of the embodied tonnes were released right up front, so tonne for tonne, they tot up the most tonne years' impact. This is most easily illustrated by the pair of graphs.

Life cycle analysis expert at PE International, Jane Anderson, who co-wrote the BRE's Green Guide, comments that consideration of accounting for the date of emissions is a valid question. The approach was allowed for in the more general UK life carbon footprinting standard (not particularly aimed towards construction), PAS 2050:2008. This standard did allow an option for discounting of emissions expected to happen in the future – thus weighing the initial emissions more heavily in a full life cycle carbon analysis.

As Jane Anderson put it: "There is a very big difference between the impact in this respect between a product with the same net emissions, that initially has a big carbon impact but may be recycled at end of life, so gets recycling credits, versus timber or other materials that have a low impact today. It does need to be thought about, but at the moment there is no scheme for buildings that can take this into account."

This may be about to change. There is one, at least, embodied carbon calculator in development that allows the user to account for the timing of emissions; the (provisionally named) RAPIER model being developed by a group of companies (BDSP, Sweett Group, Architype and Greenspace Live) – we hope to do a future article giving more information about this and other tools that are becoming available.



The graph on the left shows the standard way to express embodied emissions (green line) and operational emissions (blue line). If, however, the tonne years for the same building are plotted (above), the embodied emissions get off to a 'head start' and it takes almost twice as long for the operational emissions to 'catch up' in terms of impact. (The figures used are 30 tonnes of embodied energy with emissions equivalent to 2.6 tonnes/year, based on a reasonably modest low-energy dwelling). Analysis of the two plots shows that each tonne emitted at the start, continues to have this extra 'weight', compared to an average operational tonne, however far into the future you go.

UK government, attention is now being focused on the total environmental penalties of buildings. This means counting everything, from cradle to grave." http://tiny.cc/nhnlf

In 2010 Paul Morrell, the government's chief construction advisor reported to the government on his enquiry into low carbon construction, and recommended that all government construction projects should include a whole life carbon appraisal "as soon as a sufficiently rigorous assessment system is in place". He also called on the Innovation and Growth Team to establish some targets. http://tiny.cc/r9yeq

But first, the "sufficiently rigorous system" has to be developed. In fact a number of systems and tools are under development and some will be explored in the next article; the government itself has commissioned one too, now being developed by RICS .

Implications for status of refurbishment

One area in which there is obvious potential for drastic reductions in embodied carbon from construction is by reducing the amount of construction – by refurbishing instead. Although demolition may seem a relatively minor issue for those practitioners concerned mainly with residential projects, in the non-residential sector this is a much bigger issue. Office buildings, in particular, are often left standing for only 20 or 30 years before another, shinier, new building takes their place.

The chief construction advisor is blunt on this subject. Talking at a construction industry event a couple of years ago he said he saw no signs that the industry was gearing up for the task of retrofitting existing buildings to make them more energy efficient. He said: "Most of us are involved in a conspiracy to rebuild rather than retrofit, because that's what we do for a living." He added that if embodied energy became part of construction methodologies, as it should, all the environmental benefits of retrofit could be taken on board. http://tiny.cc/29bnk

In fact there has also been a spate of home demolition in recent years. For example, Private Eye's building columnist reported in January 2012 that the last government's Pathfinder scheme allowed the demolition of 'decent terraced houses in the north of England' and that councils in Merseyside were currently planning to 'bulldoze' 2000 more.

BSRIA agrees this has to change: "Although there is little incentive, apart from public criticism, for companies to consider the environmental costs of demolishing and constructing buildings, this is bound to change." http://tiny.cc/h5u2d

This is not just an environmental issue, it is a social one as well. A reader of Building Design, commenting on the requirement for new school buildings to achieve a BREEAM rating, said the requirement had the perverse consequence 'of rendering historic school building stock as factually redundant'. As a result 'walls came tumbling down, and cheap buildings... sprang up. BREEAM did not seem to take into consideration the ... energy used in demolition, construction, excavation, manufacture and logistics. How can any new building that required the demolition of a fully functional existing building, claim to be BREEAM Excellent?' the comment continued, concluding: 'The result has been a significant cultural loss.'

Definitions (energy and carbon; embodied and sequestered)

So how is embodied energy and carbon defined and measured? This is not entirely straightforward – which is one reason why there is, as yet, no universally accepted way for accounting for it. (There are nationally and internationally agreed standards – but not everyone accepts them!)

Simply, embodied energy is taken to be the energy used to win the raw materials and then manufacture all the components of a building, and embodied carbon taken to represent the carbon given off as a result of this energy use – by mining machinery, factory gas burners, power stations, etc – and also, sometimes, by chemical processes. The two are not exactly analogous, owing for example to differing energy sources, and to the chemical effects (eg the extra CO_2 given off as a chemical reaction in cement manufacture).

The embodied emissions and the operational emissions for the building over its whole life – including the embodied energy in 'replacement parts' – can be added together to create a carbon footprint for the building, perhaps the most comprehensive way to look at the energy and carbon impact associated with our buildings. (This article more often refers to embodied carbon and carbon footprints, as being more directly relevant to climate change).

If the footprint is to be 'cradle to grave' it will also include impacts from transport and construction, and from demolition and the disposal of materials (including for example methane given off by natural materials when they are buried in landfill at the end of their life, converted to CO_2 equivalents) and sometimes more besides ... as quickly becomes clear, this issue is far from simple!

Here are just some of the parameters that vary between 'accounting systems':

- Some give generic figures for materials, some specify products, many use a mixture.
- Some use manufacturers' own data, others insist on third party certification.
- Some give a rating in quantities of CO_2, some blend the carbon impact in with other criteria, for example toxicity.
- Some discount renewable energy input, some count it or include it as a separate item.
- Some 'carry forward' a fraction of the energy used in primary manufacture (eg smelting metal ore) to be "shared" by future use & recycling cycles; some do not.
- Some subtract the carbon stored in timber and other natural materials, some do not.

And so on...

One of the trickiest aspects to follow is how each model sets its time boundaries, and whether it allows the present to 'borrow' credits from the future (perhaps because a material is likely to be recycled or a tree might regrow), or 'penalises' the present for future emissions when a building is demolished; there are so many different models.

The aspect that few of the construction industry models seem to allow for at all, however, is the cumulative impact of emissions over time. Almost all give equal weight to all emissions whenever in the 'index period' (100 years, or alternatively a supposed building lifetime of say 60, 80 or 120 years) they occur.

But as Nicholas Stern has pointed out: "It is cumulative emissions that are important." http://tiny.cc/43qm1

As mentioned at the beginning, taking this into account would lead us to give considerably more weight to the early emissions – the bulk of the embodied emissions, in other words – because they do considerably more harm to us.

Timber- a temporary carbon store?

One of the arguments for using natural materials is that they are a store of carbon, taken up when the timber, hemp or other material was part of a living organism, and 'locked away' safely in the building, where it cannot harm the climate. This is a very attractive argument – but the counter argument is that it could give false comfort to those supplying or purchasing timber from unsustainable – even destructive – timber sources. This is very much disputed territory – the different approaches, and the justifications behind them, will also be examined in the next article.

Embodied greenwash

Phrases like 'low embodied energy' are meaningless without a context, and without transparently derived data. Unfortunately it's still an unregulated wild west out there. As the Construction Emissions Community of Practice has warned :"Beware of marketing and claims of carbon neutral and zero carbon from the supply chain; their data sources should be checked."

With so many measuring systems to choose from, everyone can show their product is 'lower' in embodied energy, through the careful choice of figures or, if that's too much bother, just leaving out figures altogether. So we read on a steel industry website, http://tiny.cc/usw13 "It is standard practice to express the carbon dioxide emissions associated with material production on a per tonne basis ... This may give the impression that steel has higher impacts than other construction products. However, steel has a higher strength-to-weight ratio than most other structural materials, meaning that one tonne of steel goes much further. As a result, the CO_2 emissions associated with any steel building will be lower." Lower than what, though? Concrete? Timber? Or just lower than you thought? It doesn't say.

You are likely to find similar claims about brick, concrete, even timber. Clearly any claims direct from a manufacturer or anyone with a particular axe to grind, need to be taken with a generous helping of salt.

So where to go for more objective information? There are some good sources, though none have come to notice here that are currently free. One that is regularly recommended is the so-called ICE database, developed at the University of Bath and now published by BSRIA. While it does cost £60, it is one of the most comprehensive resources of its kind, most recently updated in 2011, and perhaps most useful, is that it is very thorough and transparent about the assumptions it makes and the sources for its data (also available second hand with a lower carbon content!), http://tiny.cc/wibgw

The disadvantage of this database from the point of view of day-to-day decision making, is that most of the values are given in relation to 1kg of the material in question, meaning the designer still has work to do, to translate into terms relevant to a building. In fact a number of third parties are engaged in doing exactly that, as we will see in the next article. But in the meantime, this database is a good resource for someone wanting to answer questions for themselves, now.

Don't compromise performance

Even without access to a detailed database, there are some principles that can guide a designer towards a lower embodied energy and carbon design.

The first thing to say is that embodied energy and operational energy should not usually be in competition. Studies by organisations such as the Passivhaus Institute (PHI) and the Royal Institute of Chartered Surveyors have concluded that improving the energy performance of a building's fabric does not mean the embodied energy needs to be significantly higher than for a 'standard' build with more conventional operational energy targets. For example: "The energy expenditure for the production of a (otherwise identical) Passivhaus is not necessarily greater than that of an ordinary new construction; it can even be less. The 'primary energy investment' amortises very quickly, in less than a year as a rule." See Passipedia 'Primary energy – quantifying sustainability' http://tiny.cc/s2i2d

A study by the NHBC showed that, for instance, reducing the modelled operational emissions from a timber-framed detached house design from 108 to 72 tonnes, a cut of 36 tonnes, required the 'investment' of only another 0.9 tonnes of embodied emissions. Even if you were to double the impact of the extra embodied emissions to take account of the time factor, it is still a good trade. The general advice seems to be that working to optimise the fabric efficiency of a building should not make major differences to the embodied energy and carbon.

There is however a caveat when it comes to services and to renewables. As these can be relatively high in embodied energy, and/or have a relatively low life expectancy, they can take a building into the realm of diminishing returns. The point is not to set hard and fast rules, but to begin to include considerations of embodied energy in decision making, to ensure the energy and carbon saved over the lifetime comfortably outweighs the energy and carbon investment up front.

Outside questions of operational energy performance, other basic design decisions – such as the size and shape of a building, and what it is built from – certainly can affect the embodied emissions and, thereby, the life cycle impact as a whole.

While not wanting to suggest 'rules of thumb' are ever enough, there are a few simple principles – which won't necessarily surprise readers of Green Building – which could help keep a lid on embodied emissions.

The very first principles are simple: keep it small, and keep it compact. Then lower embodied energy, lower cost and lower operational energy demand will go hand in hand.

A bigger building than is needed uses more materials, and uses more energy. Obvious enough you'd think, but we've all seen those gigantic 'eco' mansions. A compact form minimises the surfaces, this minimises heat loss and materials at the same time. And of course it costs less, as practising architect and senior lecturer in construction at Northumbria University, Mark Siddall, points out: "An embodied energy target would encourage a compact building form to minimise material use, and keep down site waste and lifecycle maintenance. It could lead to cost savings too, which could be re-invested in more demand reduction, and, where possible, more eco-friendly materials."

Other things to think about include:

- Trading highly processed materials for less processed; processing materials (steel, cement, bricks, glass) means energy consumption, often a lot when high temperatures and/or high tech are involved. These materials may also be heavier, with transport implications and knock-on impacts on the rest of the structure. Use of highly processed materials is often justified of course (What? No windows?) but use them all judiciously.
- Local sourcing can reduce transport costs, but perhaps just as importantly, if you or your local colleagues visit the supplier's own premises, it enables you to get closer to verifying how something is produced.
- Less 'bling' : fabric first. With a limited carbon and cash budget, ensure everything pays its way in all respects.
- A timeless, durable building that won't need to be fiddled with, repaired or replaced will save on later bursts of emissions to make replacement parts. But if the building is likely to be short-life by its nature, then the elements can be chosen for ease of re-use.

In the NHBC study mentioned earlier, the same basic house shape built in conventional timber frame, as opposed to brick and block, saved the emission of 5.5 tonnes embodied CO_2 equivalent. Modelling of 'super-light' structures without a poured slab foundation (see photo) suggest even larger savings may be realised. The embodied energy savings offered by a lighter structure can be significant but, of course, must always be weighed against other factors such as performance, transport and durability. Some case studies will be looked at in the next article.

Trying to assess the relative merits of alternative approaches, all of which might have different 'knock on' implications, soon gets complicated, but it is important to account for it if you don't want, unwittingly, to lead to higher, not lower, emissions. How some pioneering practices have begun to go about this, and some examples of what the calculations reveal, will be discussed in more detail in the next article.

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Super-light timber building with no poured slab, southwest London, by Facit Homes

Picture courtesy of Facit Homes