EMBODIED ENERGY AND THE PRESENT VALUE OF CARBON: TIME FOR LIFECYCLE THINKING*

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INTRODUCTION

Embodied energy is the energy required to make a product which includes 'raw material extraction and processing, energy production, transportation and product manufacture – aka cradle to gate' [1]. Buildings are material intensive creatures. The World Business Council for Sustainable Development reports that buildings consume a whopping 32% of all resources, 40% of all energy and are responsible for 40% of global landfill waste [8]. The energy embodied in these consumed and dumped building materials represents a significant mass of emitted carbon equivalent greenhouse gasses. Figure 1 below illustrates energy use in the building lifecycle.

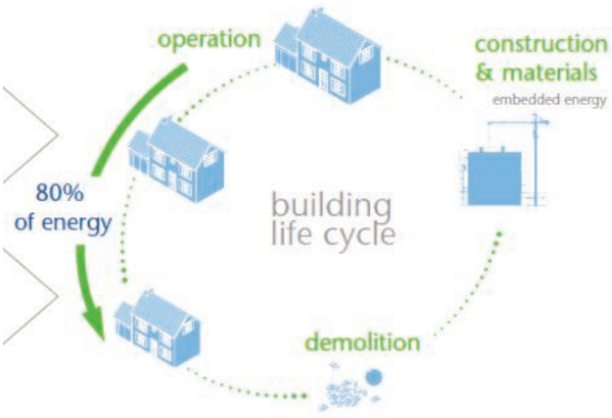

Figure 1. Energy Lifecycle in Buildings. WBCSD, 2009.

New Zealand's recently announced greenhouse gas emissions reduction target of 10-20% below 1990 levels by 2020 will require a major effort by the building industry given the significant and growing energy demands of the sector.

OPERATIONAL ENERGY

There is a possibility that the pursuit of reduced operational energy in buildings, with no regard for embodied energy, may be a driver of unintended outcomes when it comes to reducing lifecycle greenhouse gas emissions. The 2009 Green Star Office Design tool's most heavily weighted credit is based on the reduction of energy consumption in the building for the stated purpose of reducing greenhouse gas emissions. Accordingly, designers have aimed to maximise Green Star ratings by targeting reductions in operating energy consumption. This is often achieved through greater use of energy intensive building materials – one of which is glass.

Dematerialisation can be expressed as "the reduction of the throughput of materials in human societies" [2]. It refers the total production and use of materials and can be referred to in absolute terms (society as a whole) and in relative terms (an industry sector) [2]. In an age where the cell phone has reduced from a 1kg house brick to something more like the size and shape of a credit card, it is difficult to justify the reverse trend occurring in certain parts of the building sector.

Since 1973 the average New Zealand dwelling has increased from 110m^2 to 197m^2. Over the same period the average household size has decreased significantly meaning that the average New Zealander in 1973 had 32.5m^2 of living space compared with 73m^2 in 2008 – an increase of a staggering 125%. This has had a profound effect on both embodied and operational energy of New Zealand houses driving up the capital build cost to the point where the 2008 Government declared a housing affordability crisis [3]. Perhaps on a square meter for square meter basis (excluding land), houses today are actually relatively cheap. It seems our perception of adequacy may have been the true driver of diminished affordability.

Is the same growth in space demand true of the commercial building sector? At least for office space, it would seem not. A recent study of Auckland office space utilisations demonstrates reducing space per employee from 21m^2 in 1998, to 18.67m^2 in 2000, and just 15.6m^2 in 2008. This includes all reception areas, meeting and board rooms [4]. A reduction of over 25% in the past decade indicates the commercial market is more aware of spatial needs and has targeted value accordingly. This trend is likely driven by greater use of needs assessment tools and a better understanding of the 'functional unit' office space provides. Owners of offices are also less prone to the effects of having to keep pace with the Joneses.

Occasionally I hear people rattle off energy consumption figures from something they read somewhere – many of which tend to imply that embodied energy is negligible compared with operational and therefore of little concern. With CO_2 emissions from cement production currently estimated at around 5% of the anthropogenic global total (more than all air travel combined), the lack of an embodied energy measure in Green Star rating tools must be difficult to comprehend for those preparing sustainable transport plans and installing

** Originally published by CAENZ, Constructingnz newsletter, Issue 13, August 2009*

video conferencing to reduce air travel – the sum of which may produce a fraction of the CO_2 savings on offer through the use of low energy cement for example.

An illustration of the importance of understanding lifecycle energy is found in low-e glass. Low emissivity glass has advanced coatings applied to it which can potentially double the insulation value of the glazing unit. What isn't commonly understood is that the manufacturing rejection rate for low-e glass is as high as 50% due to the difficulty of applying the advanced coatings. This causes huge quantities of glass to be ground and re-melted at the manufacturing plant resulting in very significant wasted energy ($3.8x10^{10}$ Btu's) in the low-e glass manufacturing process [5].

LIFECYCLE ENERGY AND CO_2

Engineers are very good at optimising a system for a given variable. We need to start optimising for whole life cycle energy and CO_2 emissions rather than operational alone. The building material manufacturers recognise the importance of embodied energy. Anyone travelling up Auckland's southern motorway over the past 12 months will have bypassed advertisements from both the Cement and Concrete Association and NZ Wood – advertisements which have concentrated on the embodied CO_2 of these important building materials.

The steel industry is very interested in CO_2 as well. In 2008 Steel Construction New Zealand Inc (SCNZ) published a report comparing the embodied energy of three competing 10 storey structural systems comprising mainly concrete, mainly steel and a combination of the two [6]. This research uses a dual lifecycle method of analysing the embodied energy in the structural system – a methodology which in this case favours the steel example due to the greater recycling rates applied to the steel case. A full lifecycle assessment of the competing systems which also assessed their respective effects on operational energy consumption would be a more robust and useful comparison. This study highlights the importance of the assumptions made in the calculation of embodied energy – one of the reasons why the New Zealand Green Building Council has steered clear of this issue to date [9].

Interestingly a mainly timber option was not considered in the SCNZ study. Until recently timber has not been considered a viable option for buildings above roughly 6 storeys in height. Recent work at the University of Canterbury has changed that for good.

In 2008 the Structural Timber Innovation Company (STIC) was founded promising to develop new and exciting uses for timber in buildings. One of these new uses is in multi-storey buildings. A recently constructed prototype building consisting of post-tensioned LVL (Laminated Veneer Lumber) beams, columns and walls has the potential to deliver timber buildings of 20 storeys or more according to Professor of Timber Design, Andy Buchanan.

An actual 6-storey, 4250m^2 building at the University of Canterbury was analysed in terms of whole of life (60 years) energy consumption assessing the contribution of embodied energy in competing structural systems – but this time the timber system described above was considered along with the incumbents – concrete and steel [7]. The outcome of this research showed that embodied energy is important. Using New Zealand-specific embodied energy figures from researcher Andrew Alcorn, the study demonstrates that the total embodied energy between the 4 structural options for this real building averaged 23% of the total (operating energy consumption was 77%). In terms of CO_2, the results using Alcorn's coefficients demonstrated that on average 7% of the entire lifecycle CO_2 equivalent emissions are embodied, while 93% are operational. The importance of embodied CO_2 is even greater if GaBi (world average) coefficients are used. GaBi coefficients place embodied CO_2 at a very significant 16% of total emissions over the 60 year lifecycle of the building.

This research example was taken a step further when Scion partnered with Victoria and Canterbury Universities in a report for MAF titled, Environmental Impacts of Multi-Storey Buildings Using Different Construction Materials [1]. This report is by far the most comprehensive and up to date study available on this particular subject in New Zealand. Scion has carried out the most recent Life Cycle Assessment (LCA) study on building materials. LCA is widely regarded as the most robust means of assessing competing systems.

The study [1] has the following key findings:

- Concrete, steel and timber buildings can all be designed to have low operational energy consumption of 85 kWh/m^2/year and within 3% of each other;
- The contribution of embodied energy to lifecycle energy ranged from 6% for the 'timber plus' design to 13% for the steel design;
- The end of life assumption for the materials has a significant impact on the energy and global warming potential (GWP);
- Assuming limited end of life carbon storage, the 'timber plus' design has the lowest GWP with 11% of the lifecycle emissions versus steel at 23%;
- Replacing energy intensive aluminium architectural finishes and claddings with timber gives very significant whole of life GWP and embodied energy reductions.

TIME VALUE OF CARBON

I am very interested to understand how Present Value analysis, as used in calculating the whole of life return on an investment, could equally be applied to the lifecycle emissions of CO_2. Consider one tonne of CO_2 emitted in year one versus one tonne of CO_2 emitted in year 60 of the project lifecycle. I hypothesise that it is significantly more important to mitigate the tonne of CO_2 today than the 60th year tonne. The tonne in the 60th year is still very important, but less so than the tonne today. If this is indeed the case, then the importance of carbon emitted in year zero (pre construction in the manufacture of materials), must be relatively more significant than the same carbon emitted during the operation of the structure. This weighting, if quantified, could give rise to the Net Present Value of CO_2 in the whole lifecycle of a structure. I hate to think how difficult it might be to work out a discount rate! If we take a monetary example for the purposes of illustration, using a discount rate of 5%, $1 in 60 years time is worth just 5 cents today. My very limited understanding of climate change theory is that the rate of warming increases exponentially with increases in CO_2 – hence the hypothesis that the 'time value of carbon' is important. This theory could drastically change the way we look at the importance of embodied energy. If year zero emissions (currently approximately 16% of lifecycle total), are weighted at 5-10 times greater than average operational emissions, the lifecycle emissions picture looks vastly different indeed. Google 'time value of carbon' for some ideas which may seriously alter your impression of the importance time in relation to emissions.

CUTTING OUT THE CARB'S

Concrete, the world's second most consumed resource after water and the most consumed man-made material, has significant potential to reduce its environmental footprint. Mainzeal recently used 5000 tonnes of waste glass aggregate in the construction of the new Lion Nathan brewery – much of which was used in the concrete. We are currently using concrete with 20% recycled aggregates and 20% replacement of cement with New Zealand flyash. Recent New Zealand research suggests that the recarbonation of concrete at end of life has the ability to reverse much of the CO_2 emissions resulting from calcination [10].

The steel industry is investigating ways to reduce the total steel required in buildings through a better understanding of material properties and through the use of high performance steel. A group was recently established to investigate ways that the metals industry can further reduce its carbon footprint in the light of Government and industry driven CO_2 reduction targets.

SUMMARY

The embodied energy in building materials such as glass, concrete, aluminium and steel is significant in the context of the whole lifecycle energy used in buildings. In certain structural systems it represents more than 20% of the lifecycle energy. If the time value of CO_2 is considered, this embodied energy is even more important than currently calculated. Environmentally conscious designers can no longer ignore this important fact.

Furthermore, the building industry has the ability to significantly cut these embodied energy and CO_2 emissions through far greater use of timber, low energy cement, recycling of metals and aggregates – and those are just ideas from recent Mainzeal projects. There are hundreds more innovations with the ability to drastically cut embodied energy and emissions.

The industry needs strong incentives to implement these technologies more widely. The Green Star Design tools are a great example of where these incentives could begin. If New Zealand is to meet its emissions reduction targets, the incentives for low-carbon construction need to be implemented immediately. We have proven we can construct low-carbon, energy efficient, cost effective buildings. It's time we got on with it.

Figure 2: High Performance Timber - World First:

Paul Blackler (Mainzeal, Southern Region GM), Mike Newcombe (PhD researcher, UoC), Ross Copland (Mainzeal, Sustainability Manager) and Andy Buchannan (Prof. Timber Design, UoC) with the recently constructed post-tensioned LVL test building at the University of Canterbury. Mainzeal, CHH, NPI, Hunters, McIntosh, STIC and others made contributions to ensure the success of this exciting research project which has proven the technology for the use of timber as the primary structural system in tall multi-storey buildings.

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