

REDUCING EMBODIED ENERGY IN AUSTRALIAN BUILDING CONSTRUCTION

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Climate change and global warming are well recognised as major issues in sustainable development, with the building sector being responsible for considerable global greenhouse gas emissions. Until fairly recently, it was generally considered that the embodied energy content of a building was small relative to the operating energy over the building's lifetime. However, recent research in Australia and elsewhere has shown that the embodied energy of construction processes for houses is equivalent to 10-15 years of operating energy. Therefore, reducing embodied energy in the construction process has now come into focus as a way of reducing carbon dioxide emissions and global warming. This paper makes the case for strongly considering the embodied energy of building materials in the building life cycle, and discusses methods that take into account selection and use of building materials to decrease the embodied energy used in construction processes. The methods and techniques are illustrated by a green star environmentally rated project in Australia, which achieves efficient embodied energy usage.

Keywords: energy, environmental impact, green buildings, material management, sustainability.

INTRODUCTION

Climate change and global warming are well recognised as major issues in sustainable development. Moreover they are major priority areas for the United Nations. According to a publication by the United Nations Environmental Programme, the building sector, on a worldwide basis, is considered to be responsible for up to 40 per cent of the world's energy consumption and a related one-third of global greenhouse gas (GHG) emissions (UNEP SBCI, n.d.). Along with transportation and industrial processes, this sector has a significant environmental impact of our society.

Most of the focus on energy consumption and the reduction in greenhouse gas emission has centred on reducing energy consumption and its associated GHG emissions from the building function and tenants' operation of the building. Construction processes, and in particular the embodied energy in construction materials, have not traditionally drawn as much attention in the building sector as have environmental issues in building operations, since their environmental impacts have been assumed to be fairly small compared with those from the operation of the building. The construction processes, however, contribute approximately 10 per cent to the global GDP (United Nations Environment Programme, 2006), and construction activities significantly impact on waste, energy use and greenhouse gas (GHG) emissions (Wallace, 2005). Impacts generated by construction processes include

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energy consumption and its associated air emissions, raw material use, waste generation, water use and land use; and are significant. Of these issues, energy consumption and its associated air emissions require addressing because they are directly related to the demanding issues of global warming and the depletion of non-renewable energy sources. The transformation of construction processes through efficient management towards environmentally sustainable practice in terms of energy reduction is at a relatively early stage. Government agencies also have a limited ability to develop effective environmental regulations and incentives to regulate and stimulate the creation of environmentally sustainable construction processes (Ahn *et al.*, 2010).

As a national strategy the Australian Government is currently developing initiatives to improve the energy efficiency of buildings. Mandatory Disclosure of Commercial Office Building Energy Efficiency is one of the initiatives on Energy Efficiency strategies. Overall, it has been estimated that 19 per cent of Australia's total energy use can be attributed to the building sector, behind transportation (40 per cent) and manufacturing (31 per cent) (Senate Economics Committee, 2010). It is noted that the usual practice of considering annual energy consumption is wholly inappropriate for construction businesses because every project is different, and projects run only for a short term period (Popovec, 2008). Attention therefore needs to be paid to the whole building life cycle if energy use, and consequent greenhouse gas emission, in the building sector is to be reduced.

This paper argues that the embodied energy in construction processes, and in particular in building materials, is a significant component of the overall energy reduction in the building life cycle, and proposes approaches to reducing this embodied energy as part of the construction cycle, using the Australian context as an example.

THE BUILDING LIFE CYCLE

Figure 1, which has been adapted from a model proposed by Lawson (1997), illustrates four main stages of the building life cycle - pre-construction, construction, post construction and demolition. Energy consumption and corresponding greenhouse gas emission can occur at any stage of this life cycle. Traditionally, the focus on reducing energy in buildings has been on reducing operating energy, which occurs in the post construction phase and has in the past tended to be considered far more important than reducing embodied energy (for example, replacing materials like steel, which require significant amounts of energy to produce with materials such as wood, which require relatively small amounts of energy to produce). However, it has increasingly become apparent that the embodied energy, which occurs in all phases of the building life cycle but is initially concentrated in the pre construction and construction phases can be significant. Therefore a holistic approach is needed to analyse the life cycle energy use of buildings (Intergovernmental Panel on Climate Change, 2007).

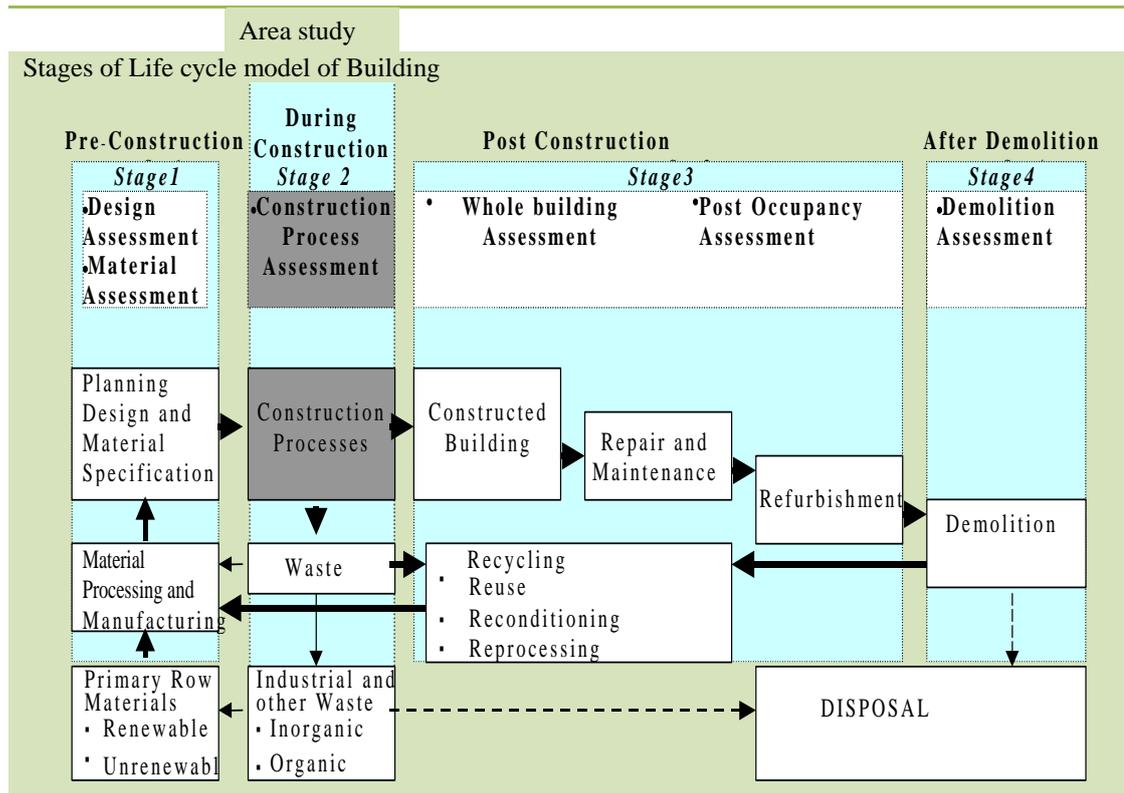


Figure 1: Life cycle model of building (Sattary, 2007), adapted from Lawson (1997).

CONSIDERATIONS IN EMBODIED ENERGY REDUCTION

Embodied Energy of Building Materials

Embodied energy can be defined as the energy consumed by all of the processes associated with the production of a building materials, from the mining and processing of natural resources to manufacturing, transport and product delivery (Milne and Reardon, 2008). Such embodied energy can be divided into initial embodied energy (the embodied energy that is consumed in the construction process) and recurring embodied energy, which can be considered as the non-renewable energy that is "consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building" (Canadian Architect, 2011).

Typical levels for embodied energy of some common building materials are shown in Table 1. The carbon dioxide emissions in the third column assume that 98kg of carbon dioxide are produced per gigajoule of embodied energy (Recovery Insulation, 2010).

Research by the Australian Commonwealth and Scientific Industrial Research Organisation (CSIRO) confirms that the embodied energy of typical construction materials is 1.9 megajoules per kilogram for in-situ concrete and 170 megajoules per kilogram for aluminium (CSIRO, 2000). Figures of a similar order are also given by other authorities. For example, the Canadian Architect publication (2011) gives respective figures of 1.3 megajoules per kilogram for precast concrete and 227 megajoules per kilogram for aluminium. Therefore, embodied energy by unit mass in building materials is significant, and also varies considerably with material.

Embodied energy in building materials has been studied for some time by researchers interested in relationships between building materials, construction processes, and their environmental impact. It was thought until recently that the embodied energy content of a building was small compared to the energy used in operating the building

over its lifetime. Most effort was thus put into reducing operating energy by improvement of the energy efficiency of the building envelope.

Table 1: Embodied Energy. Source: Lawson 1997, Serious Materials, 2010

Material	Embodied energy MJ/kg (Megajoules per kilogram)	Carbon Dioxide Emission MJ/kg
Aggregate	0.10	150
Air dried sawn hardwood	0.5	49
Kiln dried sawn hardwood	2.0	196
Hardboard	24.2	2372
Plastics – general	90.0	8820
PVC	80.0	7840
Synthetic rubber	110.0	10780
Aluminium	170	16660
Copper	100	9800
Galvanised steel	38	3724
Steel	32.0	251200
Stainless Steel	54-72.10	5292- 7065. 8

Research has however shown that embodied energy can be the equivalent of a considerable number of years of operational energy (Canadian Architect, 2011). For example, research by the Commonwealth Scientific and Industrial Research Organisation shows that the average house contains about 1,000 gigajoules of energy embodied in the materials used in its construction. This is equivalent to around 15 years of normal operational energy use. For a house that lasts 100 years, this is over 10 percent of the energy used in its lifetime (Milne and Reardon, 2008). Another way of considering this point is that the initial embodied energy in an average Australian house is between 100 and 150 gigajoules.

The initial embodied energy of a building is therefore a significant multiple of the annual operating energy consumed, ranging from around 10 for typical dwellings to over 30 for office buildings (Recovery Insulation, 2010). As we make dwellings more energy efficient, this ratio is expected to decrease (CSIRO, 2000; Milne and Reardon, 2008).

For buildings designed to be ‘zero-energy’ or ‘autonomous’ the energy used for construction and disposal can become significant (Canadian Architect, 2011). Thus, as buildings become more efficient, the proportion of total building lifecycle energy included in construction processes has accordingly assumed greater importance. Therefore, in the construction of buildings, the study and reduction of the embodied energy of materials, which are an important component of construction processes, is now a key consideration in decreasing energy use in the building lifecycle.

Cole and Kernan (1996) argue that a further consideration is recurring embodied energy, which is likely to be equivalent to the initial embodied energy of the building when it is 50 years of age. This proportion of recurring embodied energy, which is mainly concentrated in the building services and interior finishes, rises rapidly as the building ages. The building structure, on the other hand, tends to last the lifetime of the building. Cole and Kernan (1996) conclude that reducing embodied energy therefore involves much more comprehensive design approaches than material substitution, and that attention should be focused on material longevity and the ability to replace elements in the building assembly.

Quantities of building materials used in Australian houses

The total quantity of each type of material used in the building is also an important consideration.

Research on the total embodied energy used in an average Australian house, which that has been undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO, 2000), shows that the use of large quantities of materials with a low unit mass embodied energy (such as concrete) can be more significant with respect to total embodied energy than the use of small quantities of materials with a high unit mass embodied energy (such as aluminium). Figure 2, in which the embodied energy scale represents total embodied energy in the house rather than the embodied energy per kilogram shown in Table 1, illustrates this point for a range of building materials.

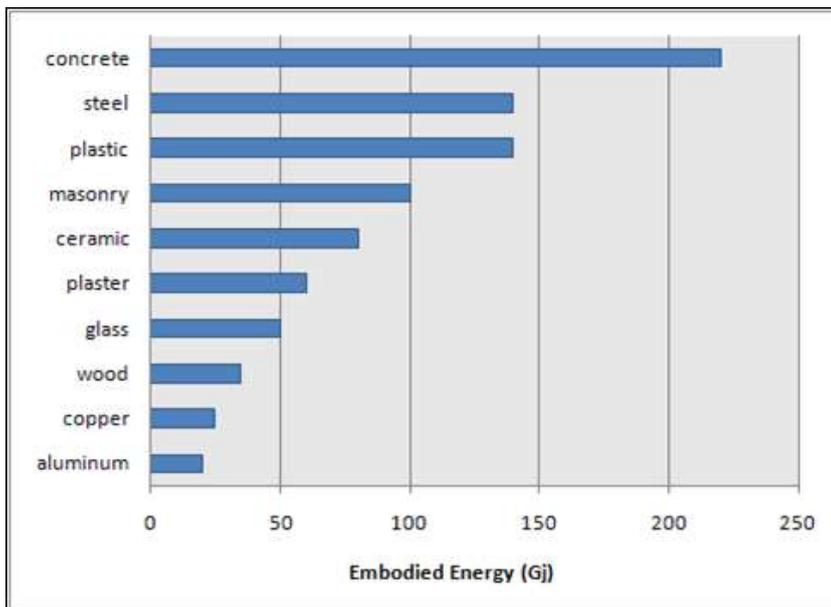


Figure 2: Total Embodied energy by material group, Source: (Nishimura1996; CSIRO, 2000)

For example, aluminium window coverings and double-glazing in buildings are used to achieve significant energy savings (Greener Homes, 2009). Although aluminium has a high embodied energy per unit mass (refer Table 1), increasing its quantity in the whole building to improve building window insulation and thereby significantly decrease overall building life cycle energy use is unlikely to materially add to total embodied energy.

Therefore, the use of a particular material to reduce embodied energy is a function of the energy properties of the material, its durability, its ability to be easily replaced, its role in the building construction and its ability to reduced operating energy use. For example, a reduction in the embodied energy of concrete can result in considerable energy reduction (Nishimura, Hondo *et al.* 1996; CSIRO, 2000). However, a decision with respect to the amount of concrete used requires to be considered in conjunction with the role of concrete in the building.

Managing Embodied Energy

The transformation of construction processes towards environmentally sustainable practices, in terms of energy consumption and associated energy reduction, is at a relatively early stage. One reason for this is that the significance of environmental

impacts from construction processes has not been well understood because the decentralised nature of construction processes employing a number of subcontractors has hindered accurate quantification of their environmental impacts. Secondly, the characteristics of construction processes, the uniqueness of each project (Popovec, 2008) and the high degree of fragmentation make it difficult for firms to pursue continuous improvement of their processes, and also limit the ability of governmental agencies to develop effective environmental regulations and incentives to regulate and stimulate the creation of environmentally sustainable construction process (Ahn *et al.*, 2010). These issues are gradually being addressed.

As a national strategy the Australian Government is currently developing initiatives to improve the energy efficiency of buildings. Mandatory Disclosure of Building Energy Efficiency is one of the initiatives on Energy Efficiency strategies (Senate Economics Committee, 2010). Although considerable progress has been achieved in the efficient design of buildings (as illustrated by recently constructed buildings in Australia that have been designed to be more energy efficient), embodied energy requires further attention in order for there to be significant reductions in building life cycle energy consumption.

Techniques for achieving these results commence with the selection of materials that have low embodied energy in manufacturing and operation and which exhibit the principles of eco-efficiency in their performance, including durability, disassembly, recyclability and reuse (see for example, the conclusions of Cole and Kernan 1996). These considerations extend across initiatives like zero net operation, carbon neutral operation, green buildings and efficient material transportation.

REDUCING BUILDING LIFE CYCLE EMBODIED ENERGY

Selection and use of materials are potential for re-use and recycling

One approach to reducing embodied energy in the building life cycle is to select and reuse building materials suitable for recycling, as discussed above. It is claimed that doing so can save up to 95 per cent of the embodied energy that would otherwise be wasted (Milne and Reardon, 2008).

There are significant energy savings to be made by recycling of materials. At the same time, such energy savings can be variable. For example, as can be seen in Table 2, which shows potential energy savings of some recycled materials, recycling of aluminium can save up to 95 per cent of the energy used in full production, but only five per cent of energy can be saved in recycling glass, as a result of the energy used in its reprocessing (Milne and Reardon, 2008). If long transport distances are involved, this can also increase the energy used in reprocessing materials (Technical Guide, 2010).

Table 2: Potential energy savings of some recycled materials

Material	Energy required to produce from virgin material (million btu/ton)	Energy saved by using recycled materials (percentage)
Aluminium	250	95
Plastics	98	88
Newsprint	29.8	34
Corrugated Cardboard	26.5	24
Glass	15.6	5

Source: (Mumma 1995)

There is also caution required in this process. For example, there can be environmental risks with some sustainable materials, such as potential leaching of contaminants from residual Portland cement binder in recycled concrete aggregate in road construction (Apul *et al.*, 2003; Petkovic *et al.*, 2004). However, provided the materials for recycling are selected with care and knowledge about their advantages and disadvantages, judicious reuse and repair of some building materials and elements can lead to substantial energy savings and decrease waste.

Use of materials that significantly help to carbon dioxide emission reduction

A significant proportion of carbon dioxide emissions relate to the energy consumed in manufacturing building materials. In this respect, aluminium manufacture produces significantly more carbon dioxide than glass manufacture. The challenge for the construction industry is to more closely consider buildings can be carbon neutral by, 2020. Doing so requires balancing embodied energy and other energy used over the building lifecycle.

Reducing embodied energy by localising the use of materials

Using low embodied energy material aims to achieve functional efficiencies in existing buildings by delivering a building product that is optimally performing in the prevailing low embodied energy and locally available materials (see for example the BedZED Beddington Zero Energy Development in London) (Bioregional Solutions for Sustainability, 2011).

To minimise the embodied energy of materials used in the building, materials that are lightweight, renewable, durable, and local would be chosen where possible. This means that locally grown plantation timber can be used extensively, along with recycled bricks, recycled feature timberwork and, and window frames (Hyde, 2008).

Reduce energy used for transport of building materials

A similar consideration is reducing the energy in material transportation. This energy, while small compared to the energy used in the manufacture of the product, can be reduced by initiatives such as:

- Changing the mode of transportation, e.g. using train or ship freight in place of road transport
- Using a fuel source with less environmental impact for transporting materials (for example, liquefied petroleum gas)
- Smart route planning, where trips to several destinations in close proximity of each other are combined.

Achieving Carbon Neutral Buildings, Including Embodied Energy

It is now possible for buildings to achieve zero net operating emissions. There are already a number of projects worldwide that achieve this. New and existing buildings are taking steps towards becoming carbon neutral now by including a range of initiatives and technologies:

- On-site generation of energy from renewable sources
- Efficient appliances and light fittings
- Purchasing green power in the construction site (GBCA, 2008).

Reducing energy consumption and carbon dioxide emissions is an indispensable part of any sustainability strategy. The BedZED zero energy development in London,

mentioned previously, is an example (Bioregional Solutions for Sustainability, 2011). In such a strategy, a full review of the environmental impacts beyond energy should also be considered (GBCA, 2008).

As part of this process, total embodied energy, which includes both initial and recurring embodied energy, requires to be considered with respect to the whole building life cycle. Achieving carbon neutral buildings through balancing all the energy used by the building during its life cycle is a challenging task. Some approaches in achieving this goal, with respect to materials and their use, include the following:

- Measuring the embodied energy
- Re-using and reducing materials on the construction site
- Re-using and refurbishing existing facilities not new onsite facilities
- Considering how the building material is transported to the construction site.

ILLUSTRATION - REDUCING EMBODIED ENERGY

Two Australian projects that have utilised the contribution of sustainable management and the principles of sustainable material selection are the six star green rated buildings of Darling Island - Stage 3 in Sydney (GBCA, 2009a) and The Gauge in Melbourne (GBCA, 2009b). Some of the embodied energy initiatives in Darling Island Stage 3 are as follows:

- Appropriately sized recycling waste storage is specified in the base building, including collection space for paper, plastic, glass, metal, organic materials.
- 20 per cent of all aggregate specified is recycled aggregate, and 40 per cent of cement for in-situ concrete and 30 per cent of cement for precast concrete is replaced with industrial waste product.
- 90 per cent of all steel specified contains a post-consumer recycled content of greater than 50 per cent.
- Alternative materials are specified to replace 60 per cent (by cost) of total PVC costs.
- 95 per cent of specified timber and composite timber products (by cost) to be used in the building and construction works were sourced from more sustainable means or are reused/recycled (GBCA, 2009a).

This project illustrates the principles discussed in this paper, and in particular has examples of recycled materials, alternative materials, and sourcing of materials from sustainable means. The Gauge similarly makes use of recycled materials, alternative materials and sourcing sustainable materials. Both projects illustrate the careful consideration of embodied energy principles in the selection of building materials.

CONCLUSION

Embodied energy and energy saving is recognised as one of the main issues in sustainable construction and development. One of the significant issues in reducing this energy use and saving greenhouse gas emissions is the reduction in energy use and corresponding greenhouse gas emissions through building development and operation. While the ongoing energy used in the post construction (operations) phase of the building life cycle continues to be significant, the increasing trend to reduced or zero emissions means that reducing energy use in the pre-construction and construction phases of the building life cycle takes on increased significance. A

significant component of energy use in this phase is the embodied energy associated with the manufacture and use of building materials.

This paper has discussed a number of options for reducing embodied energy in building construction, with a particular focus on building materials, and has discussed a number of options including selecting and use of materials that are suitable for recycling, use of materials that assist to reduce carbon dioxide emission, localising the use of materials, reducing material transportation costs, and holistically considering the reduction in embodied energy of building materials in the context of achieving carbon neutral buildings. The paper has not indicated any priority in using these techniques, but has presented them as a set of options to consider in the process of reducing the environmental footprint of building construction and the building life cycle, with particular application to Australian conditions.

Further study and research in this area is required further to develop the ideal of the building that has zero net life cycle energy consumption, which includes consideration of embodied energy, and to develop a suitable prioritisation tool for applying the approaches for reducing embodied energy that have been discussed in this paper.

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