OPTIMIZING EMBODIED ENERGY OF BUILDING CONSTRUCTION THROUGH BIOCLIMATIC PRINCIPLES

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Climate change and global warming are major issues in sustainable development, with the building sector being responsible for more than one third of global greenhouse gas emissions, and in many countries being the largest source of these emissions. It is believed today buildings are responsible for more than half of the energy consumption worldwide, significantly contributing with the carbon dioxide emissions they are responsible to the very cause of climate change. The knowledge gap that exists with respect to how emissions from built environments can be reduced and mitigated, how buildings and components can adapt to shifts in global and local climate must be filled (Altomonte 2008). A significant proportion of the energy consumed by the building over its life cycle is the embodied energy in building materials and construction processes. The intergovernmental panel on climate change estimated that around 30% of the base line carbon dioxide emissions in buildings projected for 2020 could be mitigated in a cost-effective way globally, at no or even negative costs, if bioclimatic principles were considered in material selection and construction stages of buildings, thus reducing their embodied energy. There are three major ways to reduce energy consumption: reducing building energy use, replacing fossil fuel with renewable energy, and increasing energy efficiency. Therefore, reducing embodied energy in buildings has come into focus as one of the issues in reduction of carbon dioxide emissions and global warming. Reducing embodied energy of buildings by using bioclimatic principles to achieve optimum embodied energy use can improve energy efficiency, and importantly reduce costs and lifecycle energy use. The paper discusses the use of bioclimatic design techniques to identify criteria that can be used to decrease the embodied energy used in building materials and construction processes. The criteria can assist with developing a model and checklist to apply for an optimum embodied energy of actual building which includes both pre-construction and construction stages.

Keywords: optimum, embodied energy, energy reduction, construction management, sustainability, environmental construction process.

INTRODUCTION

The construction process includes all the onsite work done in building or altering structure, from land clearance through completion. It includes all the activities of workshop and construction site to provide construction elements, transporting (raw material or other elements) to the site, and all the activities on the site during construction, moving the site people and using local facilities, services. The life cycle

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of buildings consists of four stages: pre-construction (Stage I); during construction (Stage II); post-construction (Stage III); after demolition (Stage IV). See Table 1.

Table 20: Life cycle model of building

Stage I	Stage II	Stage III		Stage IV
Before Operation Phase		Use Phase - Operation		After Use
-Extraction and production processes of Materials -Assembling of construction components and elements in manufacturing sections	Site preparation Construction processes of building on the Construction Site Cleaning and auditing services	Operation of building Incorporated services Operation of Other Appliances	Maintenance Repair and refurbishment	Demolition Reuse, Recycling Final Disposal

Source: Adapted from Lawson 1996; Sattary2007

EMBODIED ENERGY

"Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery". Transportation is a major element of embodied energy of construction materials (Edwards 1999; Technical Guide 2010).

Research in Australia and elsewhere has shown that the embodied energy of a building is a significant multiple of the annual operating energy consumed (Overbay 1999; Technical Guide 2010). It ranges from around 10 for typical dwellings to over 30 for office buildings (CSIRO 2000). Making buildings such as dwellings more energy efficient usually requires more embodied energy, thus increasing the ratio even further. In the construction sector, however, experience has shown that as the energy efficiency of buildings increases, the impacts of embodied energy on the overall building footprint become more conspicuous, because the ratio of embodied energy to total energy consumption increases. Not surprisingly, as more and more investors and tenants scan the property markets looking for verified indications of green performance, arguments for reducing the embodied energy in commercial buildings are becoming more compelling.

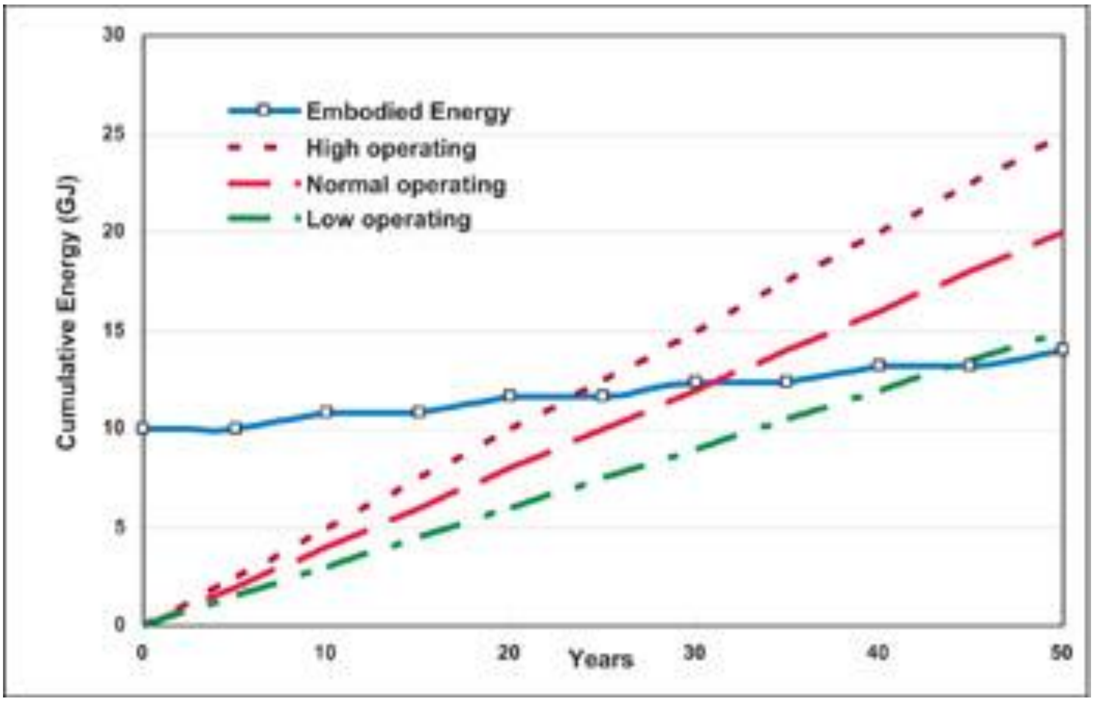
CSIRO research shows that the average house contains about 1,000 GJ of energy embodied in the materials used in its construction. This is equivalent to around 15 years of normal operational energy use. For a house that lasts 100 years, this is over 10 percent of the energy used in its lifetime (CSIRO 2000).

However use of the embodied energy figures in construction should be cautious, and must be considered in context. For example, transportation can affect embodied energy: thus a material manufactured and used in Melbourne has a different embodied energy if the same material is transported by road to Darwin. Recycling of some materials is also possible, and can decrease the impact over their lifecycle. For example, aluminium from a recycled source will contain less than ten per cent of the embodied energy of aluminium manufactured from raw materials; stainless steel can also be recycled many times (Your Home Technical guide 2010). Another consideration is definition. For example, in Canada architects only consider non-renewable energy sources in embodied energy. It can thus be seen that there are several factors to be taken into account when considering potential areas for reducing embodied energy levels of buildings (Canadian Architects 2010).

As buildings have become more energy efficient, the ratio of embodied energy to total energy consumption has increased. Clearly, for buildings designed to be 'zero-energy' or 'autonomous', the energy used for construction and disposal is significant (Canadian Architects 2010).

It can be seen then that as the energy efficiency of buildings and appliances increases, embodied energy is becoming increasingly important (CSIRO 2000). See Figure 1.

Figure 1: Cumulative life cycle energy of an office building



Source: (CSIRO 2000; Recovery Insulation 2010)

Assessments of embodied energy levels for common building materials have to also take into account other factors including the energy used in transporting materials from production point to construction site and, as energy savings with recycling can be significant, whether source materials are raw or recycled. Materials with the lowest embodied energy levels such as concrete, bricks and timber, are usually consumed in large quantities, whereas those with higher embodied energy content levels such as stainless steel are often used in much smaller amounts. Construction techniques crucially determine the mix of embodied energy from low or high embodied energy level materials (CSIRO 2000; Timber Building In Australia 2010). This means that if embodied energy in buildings is to be assessed, designed and managed it has to be calculated and accounted for within an 'assembled building element or system'. Besides materials and assembly inputs to embodied energy, there are also the recurring contributions made up by "the non-renewable energy" used in the maintenance, repair and refurbishment of the building over its entire life (Canadian Architects 2010).

Bio-climatic design characteristics also have to be considered. Such analysis should enable the identification of what can be done to achieve a reasonable reduction in energy use by retrofitting (Liu 2010; UNEP World Business Council for Sustainable Development 2010).

Government guides and industry experts point to the re-use of building materials commonly saving about 95 per cent of embodied energy that would otherwise be wasted (Milne and Reardon 2008; Technical Guide 2010). The embodied energy savings to be made by recycling of materials will vary according to materials (CSIRO 2000; Milne and Reardon 2008).

RE-USE AND RECYCLING OF BUILDING MATERIALS

Re-use of building materials commonly saves about 95 per cent of embodied energy that would otherwise be wasted (Commonwealth of Australia ; Geoff Milne 2008). There are significant energy savings to be made by recycling of materials, though this is variable – for example, as can be seen in Table 2, recycling of aluminium can save up to 95 per cent of energy used in full production, but only 5 per cent of energy can be saved in recycling glass due to the energy used in its reprocessing (CSIRO 2000). For example, lessons from research and experiences in USA shows for a typical building, an energy star window will save $126 to $465 per year when replacing single-pane windows and $27 to $111 per year when replacing double-pane windows. (Energy star 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: (Home Energy 2010)

BIOCLIMATIC PRINCIPLES

The design process brings together disciplines of human physiology, climatology and building physics (Olgyay 1963; Hyde 2008). Building on this 'bio mimetic' metaphor – where the flexible cooperation of several constituents contributes to the metabolism and well-being of living creatures – the proposal here is to develop a design method based on the integration of specialized and interconnected competences (Altomonte 2008). Bioclimatic issues in architecture were identified by Olgyay in the 1950's and developed into a process of design in the 1960's (Olgyay, 1963, Altomonte 2008). This design process brings together the disciplines of human physiology, climatology and building physics; it has been integrated within the building design professions in the context of regionalism in architecture, and in recent years has been seen as a cornerstone for achieving more sustainable buildings (Hyde 2008, Altomonte 2008).

Pereira (2002) believes that building design should be inspired by nature, and aim to minimize environmental impact. In order to do this, issues that must be considered in design include health and well-being, energy and sustainability.

Energy saving may be achieved through attention to such bioclimatic design principles. This has been shown in research which has found that appropriate bioclimatic design can reduce energy consumption in a building by five to six times as compared to a conventional building (Jones, 1998). As the energy efficiency of buildings increases, the relative contribution of embodied energy to total energy consumption becomes increasingly important, as does its reduction through bioclimatic principles or other method. The term 'bioclimatic' refers to a process where savings in energy are achieved through use of bioclimatic design principles in building.

Energy reduction in the Australian building sector is a priority both for the federal government and also the city councils of Australia (City of Melbourne 2008; Green building concil Australia 2010). However considerable progress in reducing the energy consumption of new buildings has been achieved through use of modern bioclimatic techniques. Attention has now turned to reducing the energy consumption of existing buildings. By use of appropriate technologies and techniques of bioclimatic retrofitting, it is possible to significantly reduce the energy consumption of buildings, perhaps by a factor of up to five times (Hyde 2008). Other benefits of such energy reduction include improved health and productivity of workers, and reduction in costs of building (Birkeland 2002). Australian cities are beginning to act in this area – for example, the Victorian Government and City of Melbourne aim to retrofit more than two-thirds of Melbourne's commercial buildings with the aim of improved sustainability and reduction in environmental impact (City of Melbourne 2008).

There are two main aims in bioclimatic construction – first, to ensure that the constructed building is able to function satisfactorily within current and future climatic conditions; and second, that the environmental impact of existing building is reduced through reduction in its energy use and GHG emissions (AIBS 2008).

In summary, by using the proposed model through bioclimatic principles the following can be achieved:

- Minimize energy consumption in mining, processing, equipment, pre-assembling, assembly in manufacturing. Criteria measured are reduced energy in mining, processing, equipment and services of construction materials.
- Minimize Transportation in whole stages of the processes. Criteria measured are reduced energy in transportation for professional workers in preassembling, site workers and materials to the site and suppliers.
- Minimize using resources, achieving waste reduction by facilitating reuse and recycling possibility. Criteria measured are reduced energy by recycling and reusing of materials and elements.
- Minimize pollution by reducing carbon dioxide emissions.
- Maximize use of renewable energy. Criteria measured are replaced energy in mining and construction (preassembling, professional's transportation, site process, site worker transport, materials transportation).

There are numerous data and criteria to measure and consider for materials and construction processes to identify optimum embodied energy that needs lifecycle monitored energy consumption that time consumer and vary for each individual materials and elements therefore the proposed model is based on achievable, reliable and collectable data from the five aspects of quality data resources.

CRITERIA TO OPTIMIZE EMBODIED ENERGY OF BUILDING

The proposal is to develop a model based on integration of specialized method and construction processes to decrease embodied energy of all the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery, see Table 3.

Table 3: Life Cycle Stages (1, 2) of Building and Consumed Energy

Life Cycle Stage I	**Life Cycle Stage II**
Production and pre-assembling	**Construction processes on site**
- Energy consumed in extracting - Energy consumed in production processing - Energy input for transport of workers, site people and equipment - Energy consumed by equipment and support services - Energy consumed for transportation of raw materials to building site or supplier - Energy used for preassembling of building components, elements - Energy input for transport of workers - Energy consumed for transport of components and building elements to building site or supplier	- Site preparation and fencing - Energy input for transport of the workers and site people - Energy consumed by machineries and support services - Energy input to transport the equipment to building site - Energy consumed input in the construction processes of building - Energy consumed by equipment - Energy consumed for transportation of raw materials and elements from supplier, production or preassembling - Energy input to the workers and site people

Source: (Lawson 1996; Sattary 2007; UNEP SBCI Sustainable Buildings &2010)

Research by the Steel Construction Institute in the European Union suggests that the key to lifecycle assessment of environmental impact is in the relationship between manufacture, transportation, use of materials of construction and the transportation is a major element of embodied energy of construction (Edwards 1999). The following categories and criteria can be used to decrease embodied energy to identify optimum embodied energy through bioclimatic principles: Site & Climate Analysis, Flexible & Adaptive Structural Systems; Renewable & Environmental Building Materials; Modular Building Systems; Building Envelope Systems; Renewable & Non-conventional Energy Systems; Innovative Heating, Ventilation & Air Conditioning Systems (Altomonte 2008)

A proposed model to analyze the energy consumption in pre-construction and post-construction, in order to identify the optimum embodied energy of the construction is presented in the following two tables. The first table (Table 4) identifies reduced energy in the stages of the production and construction processes. In this table and the following table (Table 5), the length of the bars in each column represents the amount of energy relevant to the particular item discussed in that column.

Table 4: Energy Consumed from the mining and processing to manufacturing, transport and product delivery

MINING	ENERGY USED	Reduced ENERGY by bioclimatic principles
Mining Energy		Mining
Processing Energy		Processing
Equipment & services		Equipment and Support services
CONSTRUCTION		
Manufacturing (Preassembling)		Manufacturing (Preassembling)
Professional workers' Transportation		Professional workers' Transportations
Equipment and Processing services		equipment and Processing services
Transport of materials to the site or supplier		Transport of materials to the site or supplier
Professional site workers' Transportation		Professional site workers' Transportation
Environmental Quality		

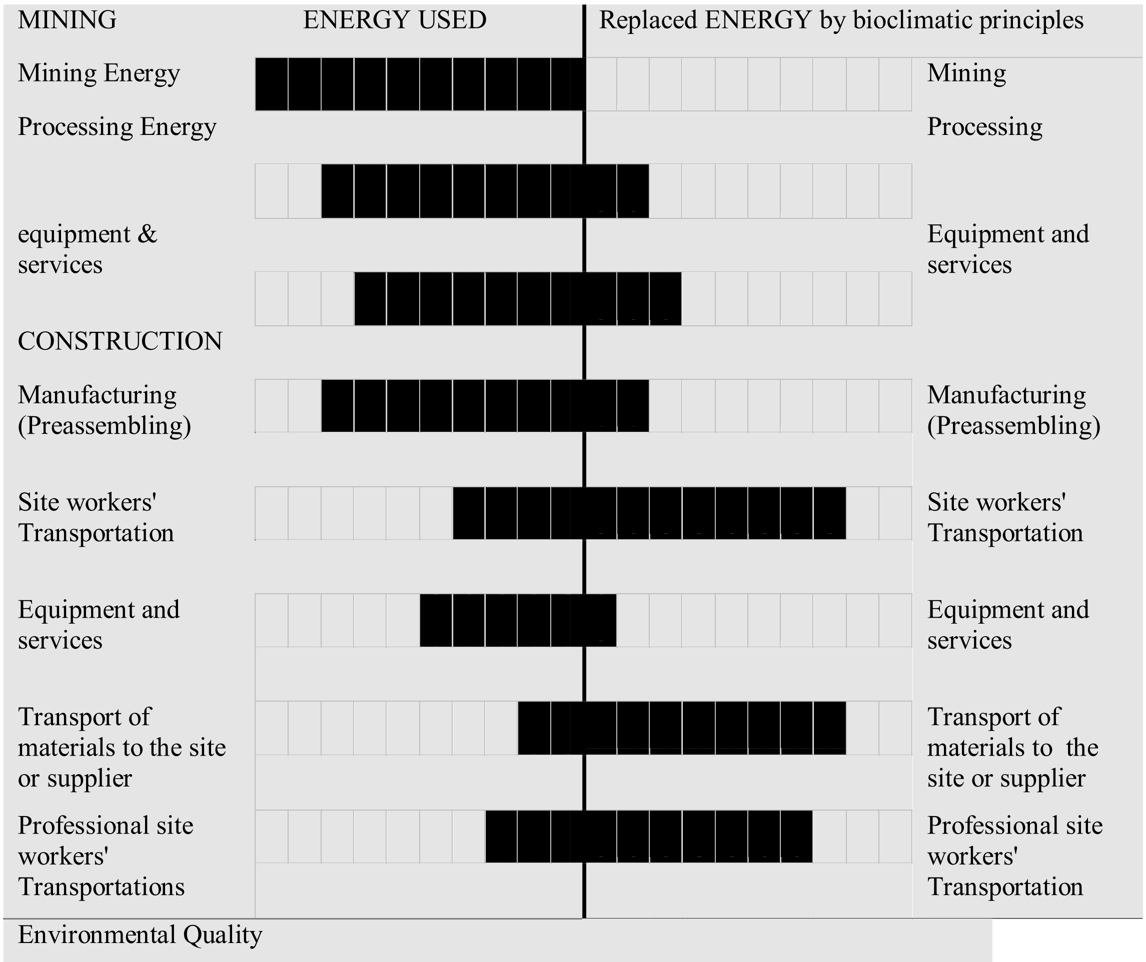
In the second step, the saved energy replaced renewable energy or produced renewable energy in whole stages of the production and construction processes are identified. Table 5 shows what can be replaced and reviewed in selected actual sustainable building projects in pre-construction and construction stages in Australia.

PRODUCT ASSESSMENT AND GREEN SPECIFICATIONS

Green materials rating systems and specifications are broad guides to the environmental performance of the materials and systems used. Attention is now turning to more product-specific assessment to form the basis of green specification systems for construction. One problem with the proposed model is validating the environmental performance of the products and systems. Five aspects of quality data, which are used to develop the criteria for the proposed model, have been identified:

1. Eco-label (Australia and international);
2. Life-cycle assessment;
3. Independent verification;
4. Manufacture's declaration, certified by the company under trade practice legislation
5. Expert assessment Ecospecifier 2003 (Hyde 2008)

Table 5: Renewable Energy Consumed from mining and processing to manufacturing, transport and product delivery



The proposed model, with the collected data from the five resources described above, will be used to identify "Optimum Embodied Energy" of the construction systems and building elements will make possible to identify and complete a table similar to that shown in Tables 6, 7.

Table 6: Assembly embodied energy of some construction systems

MATERIAL	Original Embodied Energy MJ/kg	Reduced Embodied Energy in Mining and Construction per MJ/kg	Renewable Energy Used in Mining and Construction per MJ/kg	OPTIMUM EMBODIED ENERGY MJ/kg
Single skin AAC block wall	440	a- Percentage of reduced energy	b- Percentage of replaced energy	440 - (a +b)
Steel frame, compressed fibre cement clad wall	385	a- Percentage ...	b- Percentage ...	385 - (a +b)
Cavity clay brick wall	*860*	*a- Percentage ...*	*b- Percentage ...*	*860 - (a +b)*

Source: Buildings, materials, energy and the environment (Lawson 1996), the figures for the amount of embodied energy come from Lawson, and table created for model

Table 7: Assembly embodied energy of some building elements

MATERIAL	Original Embodied Energy MJ/kg	Reduced Embodied Energy in Mining and Construction per MJ/kg	Renewable Energy Used in Mining and Construction per MJ/kg	OPTIMUM EMBODIED ENERGY MJ/kg
Elevated timber floor	293	a- Percentage of reduced energy	b- Percentage of replaced energy	293 - (a +b)
110 mm concrete slab on ground	645	a- Percentage ...	b- Percentage...	654 - (a +b)
Roofs				
Timber frame, concrete tiles, plasterboard ceiling	251	a- Percentage ...	b- Percentage ...	251 - (a +b)
Timber frame, steel sheets, plasterboard ceiling	330	a- Percentage ...	b- Percentage ...	330 - (a +b)

Source: Buildings, materials, energy and the environment (Lawson 1996), the figures for the amount of embodied energy come from Lawson, and table created for model

CONCLUSIONS

Energy reduction in the Australian building sector is a priority for all levels of government in Australia. Embodied energy and achieving optimum energy is recognized as one of the main issues in sustainable construction and development. Key areas in reducing this energy use and saving greenhouse gas emissions are building development, construction processes and management. While the on-going 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 major component of energy use in this phase is the embodied energy of building materials and relevant energies, such as transport, equipment, processing and replacing renewable energy.

A model has been proposed to identify optimized embodied energy in pre-construction and construction phases of buildings that take into account decreased and replaced renewable energy in preconstruction and during construction processes, saved energy in transportation by localizing of whole two phases and reduced energy from reusing and recycling of the materials that can be significant.

Therefore, reducing embodied energy in building materials through processes like selecting suitable materials, recycling materials, balancing the use of materials, selecting materials for durability, localizing the manufacturing process, and similar measures is expected to make a considerable improvement in the efficient lifecycle energy use of buildings, There is considerable potential to achieve very low lifecycle energy use over the coming decades.

Further study and research in this area can facilitate achieving benchmark and criteria to achieve 'optimum embodied energy' and 'optimum embodied energy construction' in the building that is not far from belief for the building through bioclimatic principles to reducing embodied energy of the construction process.

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