Global warming implications of construction work in Western Australia

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Abstract: **T**he Australian Green Infrastructure Council (AGIC) is currently leading a new approach to delivering and operating infrastructure through more careful examination of the carbon footprints of construction activities. In order to facilitate this situation, this paper examines the carbon footprints of Engineering Pavilion (hereafter referred to as Building 216) at Curtin University Western Australia, using a LCA analysis. The current LCA analysis used a ‘cradle to use’ approach, which means that it takes into account the lifecycle of theproduct up to the utilisation stage. The Life cycle GHG emissions and embodied energy of Building 216 were calculated to be 14,229 tonne CO2 –e and 172 TJ, respectively. This report identified the ‘hotspot(s)’ or the stages in production and operation of Building 216 that cause the most GHG emissions so that further environmental management improvements can be made.

1 Introduction

In 2007 the Intergovernmental Panel on Climate Change (IPCC) identified three areas for reducing emissions from buildings: reducing energy consumption and building embodied energy, switching to renewable energy, and controlling non CO2 emissions [1].

Almost a quarter (23%) of Australia's total GHG emissions are a result of energy demand in the building sector. The building sector, comprising both residential and commercial buildings, drives a large proportion of Australia's economic activity [2]. This sector's contribution to GHG emissions is mainly driven by its end use of, or demand for, electricity (operational energy). For example, there are approximately 21 million square metres of commercial office space in Australia, spread across 3,980 buildings. However, in the main, these offices have not been designed to consider energy efficiency or- solar passive design or their long-term environmental and social impacts [3].

Along with life cycle GHG emissions, energy use is often used to measure the environmental performance of buildings. Recent studies have highlighted the importance of both the embodied energy and operational energy use attributable to buildings over their lifetime. Embodied energy is the energy consumed by processes associated with the total production of a building, from the acquisition of natural resources including mining, manufacturing, transport and other functions, to the final consumption of building materials. On the other hand, operational energy involves the energy utilised by the buildings operation and use and includes air conditioning, heating and lighting energy use.

The infrastructure industry has now acknowledged this shortcoming and through the Australian Green Infrastructure Council (AGIC) will lead a new approach to delivering and operating infrastructure with more careful examination of the carbon footprints associated with construction activities.

Life Cycle Assessment (LCA) for green building design has recently been developed with the understanding that there is a shortage of holistic environmental assessment tools in the building industry. Life cycle assessment can benefit decision-making by reviewing the benefits of sustainability initiatives, throughout the entire building life cycle, including the design, detailing, delivery and deconstruction phases.

Using an LCA methodology, this report presents a life cycle GHG emissions and energy analysis of Stage 2 of Building 216. This report identifies the ‘hotspot(s)’ or the stages causing the most GHG emissions within the building construction and operational phases so that further environmental management improvements can be made.

2 Methodology

The LCA employed follows the ISO14040-43 guidelines [4] to calculate the life cycle GHG emissions and embodied energy of Stage 2 of Building 216. The LCA is divided into four steps: 1) goal and scope definition; 2) inventory analysis; 3) impact assessment; and 4) interpretation (as presented in the ‘Results’ section of this report).

2.1 Goal and scope definitions

The goal of this research is to assess the life cycle greenhouse gas emissions and embodied energy consumption involved in constructing and utilising Building 216.

The system boundary of the LCA consists of four stages: the production of construction materials, the transportation of these materials to the construction site, the construction stage and finally the usage stage [e.g. Fig 2].

The 'Supply of construction materials' stage includes the greenhouse gas emissions associated with the mining, processing and production of construction materials (e.g. concrete, steel, glass etc.) and its transportation to the construction site (i.e. Curtin University). The locations for different construction materials were advised by the Curtin University Project Management Department.

The 'Construction stage' includes the GHG emissions associated with the construction processes, including fencing, site clearing, excavation and filling, installation of a tower crane, concrete pouring, pre-casting, shuttering and mortar preparation.

The 'Usage stage' includes the GHG emissions associated with the energy consumption of end use appliances within the building, including lighting, computing, office and kitchen equipment, air conditioning, lifts, fans and heating.

The duration of the 'usage stage' of the building has been assumed to be 50 years, and the end use energy consumption pattern has been considered to remain the same during this period. An increase in cooling load due to climatic change has also been taken into account in order to determine the future energy consumption of the air conditioning system [5].

This LCA analysis identified the stages causing the most significant greenhouse emissions, the inputs (energy or materials) creating the largest carbon footprints (measured as weight of CO2-e) and the production activities with the most embodied energy.

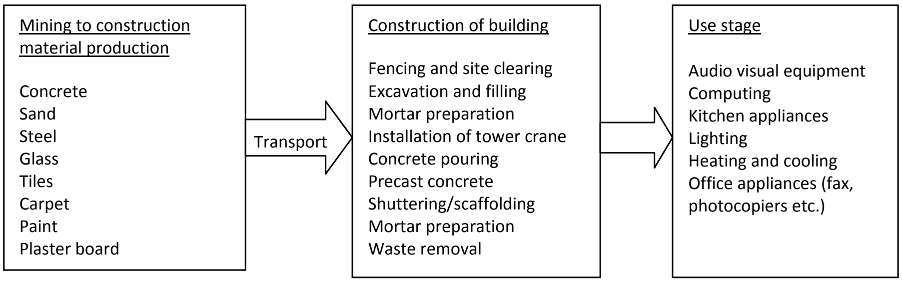

Fig 2: Life cycle inventory of a typical building

2.3 Inventory analysis

A life cycle inventory considers the amount of each input and output for processes which occur during the life cycle of a product. Undertaking a life cycle inventory is a necessary initial step in carrying out an LCA analysis. The inputs in terms of energy and material for Building 216 have been obtained from the Curtin University Project Management Department.

Figure 1 shows the simplified form of life cycle inventory of a building life cycle. The building materials inventory was conducted in accordance with given schematic design drawings. Every item was calculated discretely and classified according to its base material such as, concrete, steel, glass etc. In the case of insufficient data, standard material specifications were assumed after consulting with the project architect. Since the estimation was based on schematic design, the type and amount of final selected materials may vary to some extent.

Electrical energy is mainly used for construction purposes and end use applications. Diesel engines were used for transportation, crane and mortar operations during the construction stage. Along with greenhouse gas emissions from electricity generation and the combustion of diesel during the transportation, construction and usage stages, greenhouse gas emissions from other processes associated with the production of these inputs or construction materials (e.g. concrete, steel, glass, aluminium etc) have also been included.

All these inputs, including the energy and construction materials highlighted above were used to calculate the total GHG emissions associated with the life cycle of the production and use of Building 216.

2.4 Impact assessment

The greenhouse gas emissions assessment of the production and use of this building involves two steps. The first step calculates the total gases produced in each process, and the second step converts these gases to a CO2-equivalent (CO2 –e).

2.4.1 Step 1

The input and output data in the life cycle inventory were put into the Simapro 7 [6] software to ascertain the greenhouse emissions associated with the production and use of the new building. The recorded units of input and output data from the

life cycle inventory depends on the prescribed units of the relevant materials in Simapro or its libraries [6].
In order to make the LCA results more representative

of Australian conditions, local databases and libraries have been used. In the absence of Australian databases, European databases were included to carry out the analysis.
The library for construction materials is the Australian LCA database[7] was used to calculate greenhouse gas emissions from the production of construction materials, such as aluminium, steel, concrete, and glass. The emission factors for plaster board, paint and floor covers were obtained from the European database [8], as Australian databases or libraries were unavailable [7]. As the University's Project Management Department recommended the use of fly ash concrete (where fly ash by-products replace virgin materials in the ceement formulation), it was assumed that 30% of the cement in the concrete formulation was replaced with fly ash cement. The assumption regarding the replacement of cement with fly ash cement was made following the energy efficiency research of Nath [9].
The library for the supply chain of construction materials to the point of use, was incorporated in order to assess the greenhouse gas emissions arising from the transportation of materials to the site. The unit for the transport library is tonne-kilometre (tkm). For example, 1,863 tkm is required to carry 84.7 tonne kg of structural steel from Bibra Lake which is 22 km away from the construction site (84.7 tonne x 22 km).
The library for Western Australian electricity generation was used to calculate the greenhouse gas emissions associated with the electric power used in the construction process [7]. In addition, the Australian database for diesel combustion was used to calculate the GHG emissions from crane and mortar operations [7].

2.4.2 Step 2

Simapro software calculated the greenhouse gas emissions once the inputs and outputs were linked to the relevant libraries. The program chose greenhouse gas emissions from the selected libraries, and then converted each selected greenhouse gas to CO2 equivalents. The Australian Greenhouse Gas method, developed by RMIT [7], was used to assess the GHG emissions. The Cumulative Energy

Demand Method was used to determine the embodied energy within the engineering building.

3 Limitations

Foreign databases for some construction materials have been used due to the absence of local libraries for these materials. Emission factors for plaster board, floor coverings and paint were obtained from the Eco-invent database, which is based on European production and energy sources, which may as a result, affect the accuracy of the LCA estimates provided. Also the LCA analysis does not consider the GHG emissions and mebodied energy associated with the production of end-used applicances used during the construction stage.

4 Results and discussions

4.1 Carbon footprint analsyis

The Life cycle GHG emissions and the embodied energy of Building 216 covered a total building weight of 5,633 tonnes and a gross area of 4,020 m2. The carbon footprint including GHG emissions from the mining, construction and usage stages of the new building is 14,229 tonne CO2-e. The 'usage stage' has a carbon footprint of 12,145 tonne CO2-e which represents about 85% of the total emissions and is approximately seven times more carbon intensive than the 'supply of construction materials stage' (1,778 tonne CO2-e and 13% of total emissions) and 40 times more carbon intensive than the 'construction stage' (2% of total emissions) of the new building.

Whilst the 'usage stage' will contribute to 0.06 tonne CO2 –e per m2 per year during the 50 year lifetime of the building, it is however 63% lower than the university building 'usage stage' average (i.e. 0.16 tonne CO2 –e) [10] due to the utilisation of an energy efficient Building Management System (BMS). The BMS has a computer based control system to monitor and control the automatic cooling of the air throughout the building to achieve the desired ambient temperature (i.e. 25º C). The BMS operates the air conditioning system only when the inside temperature exceeds 25º C.

4.2 Identification of hotspots

4.2.1 GHG emissions from end-use appliances in the ‘usage stage’

Figure 1 shows the GHG contributions of all end-use appliances during the ‘usage stage’. The cooling load (65.8%), lifts (15.7%) and fans (9.6%) are the major electricity consuming appliances and contribute more than 91% of the total emissions during the ‘usage stage’. Since the cooling load accounts for a significant proportion of the total energy consumption during the ‘usage stage’, a reduction in the cooling load will accordingly decrease the life cycle GHG emissions significantly. Amenity utilities like coffee machines, computers, printers, projectors, telephones and microwave-ovens contribute a fairly insignificant portion (> 1%) of the total GHG emissions. Although refrigerators are a base load appliance, they account for only 1.3% of the total GHG emissions.

4.2.2 GHG emissions from the ‘mining to building construction stage’

The ‘mining to building construction stage’, accounts for 14.5% of the total GHG emissions (2,083 kg CO2 e-) and consists of three sub-stages: mining to material production, transportation and construction.

The mining to material production, transportation and construction sub-stages contribute 1,767, 305 and 11 tonne of CO2 e-, of GHG emissions, respectively with the mining to material production stage generating 85% of the ‘mining to building construction' stage carbon footprint. Although concrete accounts for a significant proportion (42%) of total emissions from the mining to material production sub-stage (Figure 2), emissions from concrete on a per unit weight basis (0.14 tonne of CO2 e- per tonne of concrete) are significantly lower than for aluminium (19 tonne of CO2 e- per tonne of aluminium).

This is due to the higher energy requirements in converting alumina to aluminium. Transport constitutes only 0.53% of the total GHG emissions in the ‘mining to building construction stage’. The construction sub-stage, using diesel fuel for crane and mortar operation purposes, produces around 6 times less GHG emissions than the mining to material production sub-stage.

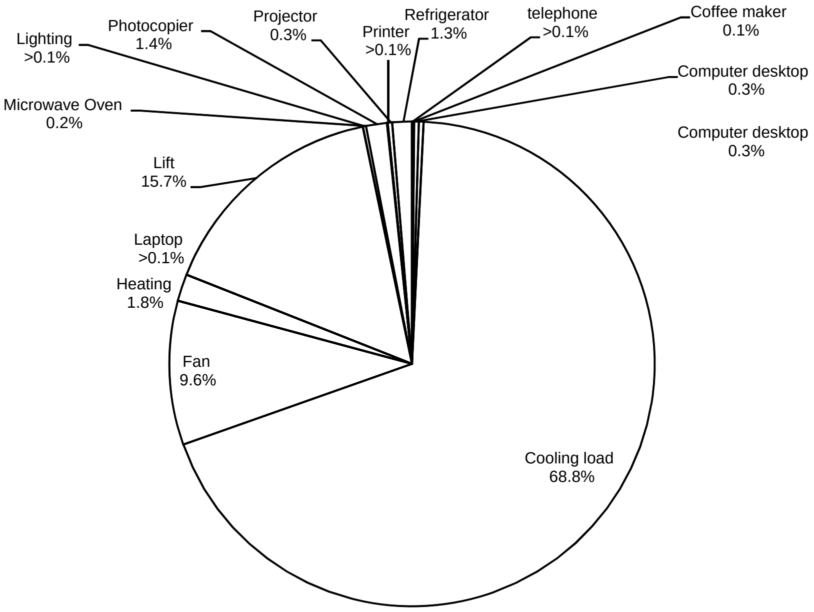

Fig 2: **Percentage contribution of inputs to GHG emissions during the 'Usage stage'**

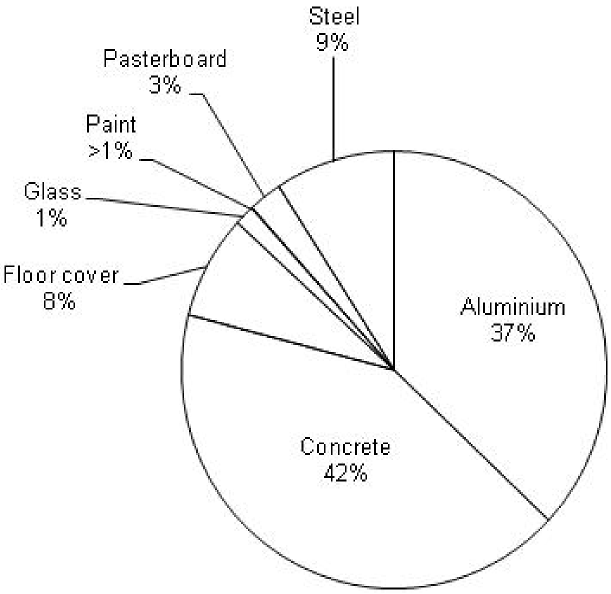

Fig 2: **GHG emissions from mining to production of construction materials**

4.3 Embodied energy analysis

The total life cycle embodied energy of the new building with a 50 years life cycle period is 172 TJ (terajoule). The ‘usage stage’ accounts for 87% of the embodied energy in Building 216 with the ‘supply of construction materials’ generating 11% and the ‘construction stage’ 2%. The energy consumption of the usage stage is 6.8 times higher than the energy consumption associated with actually constructing Building 216 (including the mining, processing, transportation and application of construction materials.).

According the National Greenhouse and Energy Report, the total energy consumption of Curtin University was 215. 4 TJ in 2009-2010. Using this information, it was derived that the specific energy consumption of the usage stage of the university with a gross floor area of 235,125 m2.is 0.92 GJ per m2 per year which is 18% higher than the specific energy consumption of the new engineering building (i.e. 0.74 GJ per m2 per year)[10]. This energy improvement also highlights the significant thermal performance improvement of Building 216 when compared to other University building average energy usage[11].

Figure 4 shows the contribution of energy consumption for different end use appliances as a percentage of the total embodied energy for the use stage. Electricity for thermal applications including heating and cooling, alone account for 80% of the total embodied energy, followed by lifts (16%). Central lighting only accounted for only 1 percent of the total energy as the building has been solar-passive designed to access more sunlight to avoid the need for lighting during day time and all lamps used in this building are equipped with energy saving globes (i.e. compact fluorescent lamps -CFL). The embodied energy associated with class room (i.e. computer, overhead projector), office (telephone, photocopier, fax, printers) and kitchen (i.e. micro-wave, photocopier) appliances accounted for around 5% of the total energy consumption during the use stage.

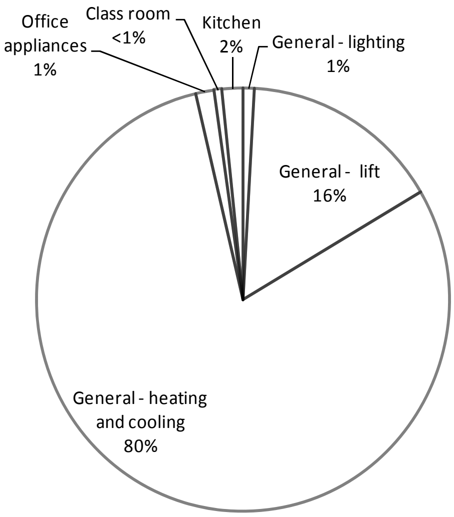

Fig 4: **Energy consumption for different end use appliances**

4.4 GHG emissions mitigation using cleaner production strategies

Other research has have also highlighted the benefits of cleaner production strategies in reducing the carbon footprint of a new building like Building 216 including:

1) The replacement of 30% by weight of cement with fly ash in concrete formulations [9].
2) The substitution of new aluminium with recycled aluminium reducing GHG emissions by around 70% [12].
3) The substitution of new steel with recycled steel reducing GHG emissions by around 60% [12].

Assuming the above substitutions can be made with functional equivalence between the alternative materials, it was estimated that 47% of the total GHG emissions in the mining to material production stage of Building 216 can potentially be avoided by replacing 30% of cement with fly ash, new aluminium with recycled aluminium and new steel with recycled steel. These material substitutions reduced the total GHG's emitted during the 'cradle to use' life cycle of Building 216 by a further 7% (i.e. 13, 241 kg CO2 e-).

5 Conclusions

Life cycle assessment is increasingly being used to determine the environmental impacts of building and construction projects. The initial impact of a building on the environment results from the energy and other resources consumed in its construction. However, the building continues to affect the environment directly and indirectly through its life including the operation, maintenance, refurbishment and finally its demolition, which can also include the potential for material recycling and reuse at the end of the buildings life.

The Life cycle GHG emissions and embodied energy of Stage 2 of Building 216 are 14,229 tonne CO2 –e and 172 TJ, respectively. The 'usage stage' of this building produces 63% less GHG emissions than the university building average due to the implementation of an energy efficient Building Management System. As a result, specific energy consumption of the usage stage is 17% less than the university average.

However, there still exists opportunities for GHG mitigation in the construction and material life cycle of a new building with the use of revised cement formulations and recycled aluminium and steel where possible. Applying these more energy efficient cleaner production strategies could further reduce the total life cycle GHG emissions of Building 216 by a further 7%.

6 Acknowledgements

Engineer Pradip Nath for inventory development. Dr Odile Pouliquen-Young and Architect Charles Boyle for providing useful information on university buildings and the building plan for the life cycle assessment analysis. Mr John Chapman, who was involved in the electrical system design of the building for Engineering Pavilion Stage 2, for providing information on electrical loadings and the building management system. Finally, thank you to the Environment and Sustainability Office, Curtin University, Western Australia for funding this project.

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