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Minimising the life cycle energy of buildings: Review and analysis

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ABSTRACT

The life cycle energy of a residential building consists of the embodied energy involved in the building materials and construction, and the operational energy of the building. Previous studies into the life cycle energy of buildings have concluded that embodied energy is a relatively small factor and can generally be ignored. A review and analysis of previous life cycle energy analysis studies was conducted re-examining this conclusion. This reevaluation has identified that this is not the case when considering climatic factors, and that in milder regions embodied energy can represent up to 25% of the total life cycle energy. The time value of carbon is generally ignored in life cycle energy analysis studies, however in a national emissions reduction regime, when the energy consumption is reduced, can become an important factor. Applying Net Present Value principles the impact of embodied and operational energy was analysed in the context of a future emissions target. It was demonstrated that embodied energy can represent 35% of the future emissions target of a building in a mild climate. The research highlights that a more wholistic approach is needed to achieve low life cycle energy buildings in the future.

1. Introduction

There has been considerable activity over the past few decades investigating the life cycle energy of buildings. To reduce the life cycle energy of buildings, the traditional focus has been on reducing the operational energy of buildings through improved building design or equipment efficiency. The majority of design changes which reduces the operational energy of buildings impacts on the embodied energy of the building. Current research concludes that operational energy remains the dominant parameter and when attempting to reduce the life cycle energy of buildings, the change in embodied energy can be generally ignored [1,2]. However, it can be argued that in a carbon constrained economy the importance of embodied energy in different regions around the world needs to be reconsidered.

This paper re-examines existing life cycle energy studies on buildings, focussing on residential buildings, and investigates how embodied energy is important in reducing the life cycle energy of buildings. A review into the minimising of the life cycle energy of buildings is presented showing that further work is needed. An analysis was completed into the impact climate has on the importance of embodied energy. Furthermore, as countries adopt greenhouse emissions targets the time value of emissions reductions becomes a factor, and its impact is analysed. Therefore, it can be argued that with future designs, minimising the life cycle energy of buildings will be more complex than currently understood.

2. Literature review of life cycle energy analysis (LCEA)

2.1. Life cycle assessment (LCA)

Life Cycle Assessment (LCA) is a technique to identify and evaluate the environmental impacts of a product, process or an activity during its life. Material and energy uses and releases by the system to the environment are assessed from “cradle to grave”. It includes extraction of raw materials, production, transportation, use and disposal [3]. Life cycle stages are shown in Fig. 1.

The International Organisation for Standardisation (ISO) published the first version of the standard – ISO 14040 – on life cycle assessment in 1997, which included principles and framework of LCA (Environmental Management – Life cycle Assessment – Principles and Framework). Between 1998 and 2000 other standards were released by ISO such as international standard 14041, 14042 and 14043 [4]. The first release was completed by adding some other concepts such as Goal and Scope Definition and Inventory Analysis, Life cycle Impact Assessment and Life cycle Interpretation. Finally in 2006 two standards – ISO 14040 2006 and ISO 14044

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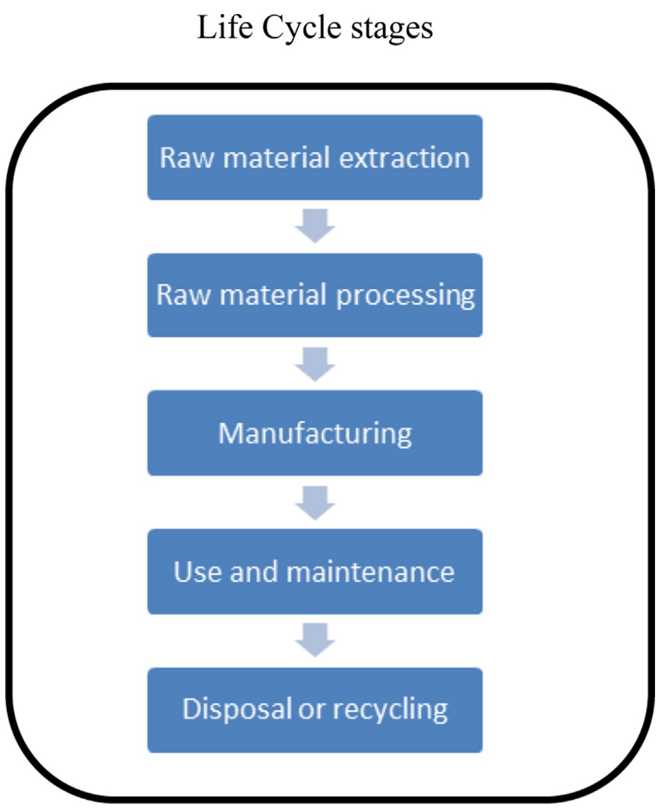

Fig. 1. Life cycle stages (Crawford 2011, p.39).

2006 – were released which covered all previous standards and helped to make the standard readable and accessible for a wider audience. ISO 14040 encompasses the Principles and Framework and 14044 covers the requirements and Guidelines [4].

ISO 14040 2006 defines four phases for any LCA which are; goal and scope definition, inventory analysis, impact assessment and interpretation. The first step is to define the purpose and boundaries of the study. In the next step, to calculate the material and energy input and outputs of a system, where data collection is required. Subsequently, the impact assessment evaluates the potential environmental impacts based on the LCI [1]. Finally, the results are summarised for conclusions, recommendations and decision making [5].

2.2. Life cycle energy analysis (LCEA)

All energy requirements associated with the building during its life time from the first step of manufacturing to demolition is called the life cycle energy. Life cycle energy of a building includes embodied energy and operational energy [6]. Operational energy is the energy used for space cooling and heating, ventilation, lighting, hot water, and running electrical equipment in the dwelling [6]. Embodied energy is the energy used to extract raw materials, transport and refine them, then use them for manufacturing and assembling new products, transportation of the products and construction at the building site. Also, energy used for renovation and demolition of building is included in embodied energy. Fig. 2 shows the system boundaries for whole life cycle energy analysis. It is understood that in a complete system energy is required for all phases of manufacturing, use and demolish in a form of embodied or operational energy.

One of the advantages of life cycle energy analysis is that high energy demand stages will be identified. Therefore, the process can be improved by reducing the energy consumption for those phases. Consequently, greenhouse gas emissions will be reduced as well [1].

2.3. Primary and secondary energy

To obtain accurate results from life cycle energy analysis it is important to clarify the form of energy. Delivered energy is the energy that is used by the householder [6]. Primary energy is used to produce the delivered energy and this depends on the source of energy that is consumed in this process (for example, coal or hydro). It is suggested in the literature that measurements in LCEA should be in form of primary energy [6]. For example, for studies in Australia, Fay et al. [6]specified the ratio of 3.4 units of primary energy to 1 for electricity. It means 3.4 units of primary energy in form of coal are used to produce 1-unit of electricity.

2.4. Operational energy

Since operational energy is generally larger than embodied energy in life cycle energy analysis, it has been studied widely in the literature. Different passive and active technologies have been suggested to reduce this energy [7–11]. Passive technologies such as using higher insulation in external walls and roofs, finding the best orientation for the house, using shading and glazing and improving the performance of windows, using thermal mass and applying passive solar heating technologies have been explained and studied. Different types of insulation in different regions and amount of insulation have been studied as well. For example, in the study by Mithraratne& Vale [12] a standard house–timber frame-according to the Building Industry Advisory Council (BIAC) in New Zealand was selected and adding higher insulation to it was studied. Authors concluded that it decreased the operational energy significantly. Another study [13] evaluated the thermal performance of a house in the harsh climate of Dubai with increasing the levels of insulation. Although an increase in embodied energy occurred, the energy payback period was 9 months. A study of heritage buildings in Victoria, Australia, showed that operational energy dominated and that measures such as insulation dramatically reduce life cycle energy [14].

Considerable research showing reductions in operational energy rely on building thermal modelling [9,12,14–16]. However, the real performance of passive options may not correspond to that determined by building models. For example, Belusko et al. [17] measured the actual thermal resistance of insulated roofing systems, and found the actual level of insulation to perform half that expected. It was explained that with increasing of insulation levels in buildings, it is more likely the gap between expected and assumed thermal resistance will increase. Another example is infiltration which is movement of air into building through cracks or leaks or other building openings. Infiltration causes variation in air conditioning load, temperature and moisture levels of indoor air in buildings [18]. These factors will increase operational energy for a given value of embodied energy. Therefore to achieve the expected reduction in operational energy additional materials are needed. These additional materials will increase the embodied energy of the building. Consequently the importance of embodied energy as a proportion of the total life cycle energy increases when considering the actual operational energy used in a building.

The total operational energy of building encompasses appliances, hot water, heating and cooling and lighting. However in the context of a building design it can be argued that only the operational energy of the heating and cooling equipment should be considered as it is strongly affected by the building. All other operational energy is generally independent Many of the life cycle energy studies have been conducted with this approach [6,12,18–20].