ENVIRONMENTAL SUSTAINABILITY IN THE CONSTRUCTION INDUSTRY IN DEVELOPING COUNTRIES: A STUDY OF EMBODIED ENERGY OF LOW-COST HOUSING

Effiness C Mpakati Gama[1], Sam C Wamuziri[2] Brian Sloan[3]

School of Engineering and the Built Environment, Edinburgh Napier University, 10 Colinton Road, Edinburgh, EH10 5DT, UK

The embodied energy (EE) of a residential building is estimated at 20-40% of operation energy over its total usable life. However, this varies from one context to the other due to the primary energy used, technological advancement of a particular context and the methods used for the inventory analysis. Despite the lack of monetary value, EE analysis (EEA) is recommended for the selection of building materials at the design stage in terms of environmental loads. However, little attention has been paid to this area in developing countries, particularly, the Sub-Saharan Africa. Due to the increasing demand of building materials deemed to rise with urbanisation in this region, the acceleration of environmental impacts is also inevitable. Therefore, data based tools are required to complement the existing policy and regulatory frameworks. In this study, EE of masonry and roof components of low-cost housing in Malawi will be assessed. The process based-hybrid energy analysis is employed to evaluate energy and the greenhouse gases related to the manufacturing, transportation of building materials and the assembling and maintenance of the entire residential building. This paper in particular, presents part of the conceptual framework of the study focusing on EE analysis especially the methods used and the associated problems based the literature review. So far, it is noted that the inventory analysis stage, which involves the evaluation of energy requirements, is the essential part of the EEA because of the various methods employed. Although the existing methods are sufficient relative to the available data, there is an urgency to increase the process data sets to enhance the reliability of the existing methods. Therefore, in addition to enhancing knowledge and understanding of life-cycle thinking to the construction stakeholders and decision makers in the selection of building materials, this study will also contribute to such data.

Keywords: embodied energy, environmental impact, housing, hybrid-analysis, sustainability.

INTRODUCTION

Buildings are associated with a number of environmental burdens which vary from one context to the other. These effects include the energy consumption, greenhouse gas emissions, land degradation, ecosystem destruction (Ahn & Oanh, 2009; Singh & Asgher, 2005). For the past few decades, there has been a dramatic increase in the

[1] E.Mpakatigama@napier.ac.uk
[2] S.Wamuziri@napier.ac.uk
[3] B.Sloan@napier.ac.uk

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interest in finding ways for minimising such effects. Among the several approaches are those promoting environmental awareness like the policies and the marketing tools such as the awards and labelling systems. The designers and decision makers' guidelines include the checklists, regulations and the bench marking systems. Further, the process based assessments such as the critical paths and the life-cycle assessments (Halliday, 2008) are also used to assess materials and services at multiple stages. In the developing countries in particular, frameworks such as the international Agenda 21 for Sustainable Construction in Developing Countries (A21 SCDC) are also proposed. The A21 SCDC framework recommended the technological, institutional and value related enablers which are deemed important for encouraging the effective use of the natural capital as well as promoting the social and economic development activities in the construction industry (Du Plessis et al, 2002). Likewise with policies and regulations, the framework aims at promoting awareness and knowledge on environmental effects related to the industry and suggest ways for minimise them.

In a number of developing countries, policies and regulations are the most commonly used tools though implementation is a major problem (Du Plessis, 2007; Halliday, 2008; Ebohon & Rwelamila, 2001). The implementation failure is deemed to be contributed by the institutional incapacity to enforce the proposed strategies (most of which are regarded to have been adopted from elsewhere) and the lack of precise targets and priorities in the policies and regulatory frameworks. Although restructuring could be one of the ways of solving the problems, Halliday, (2008) comments that such reviews appear to be ineffective even in well structured economies like the UK. In order to cater for the 67% of the 910 million people expected to be urbanised by 2050 in Africa (United Nations, 2008), more holistic approaches to complement the existing policy strategies are a prerequisite. However, these need to be based on appropriate information and data as suggested by previously by Ebohon & Rwelamila (2001). Therefore, one of the contributions of this study is to come up with such information and data for use in the construction sector in Malawi. Although the embodied energy (EE) analysis approach proposed in this study has some limitations highlighted later, it is a useful tool for the selection of building materials in terms of environmental costs.

Embodied energy of buildings

In recent years, the life-cycle thinking is being promoted when consideration of ways for minimising the environmental impacts of a service or a product over its usable life (ISO, 2006). In complex products such as buildings, several life-cycles are involved hence the assessment varies from one phase to the other depending on the purpose of the study. For the selection of building type for instance, the full life-cycle assessment is recommended (Mithraratne & Vale, 2004; Langston & Langston, 2008; ISO (2006). This comprises of the combination of energy requirements from the pre-use, operational and demolition phases. In contrast, the embodied energy (EE) is considered useful for the selection of building products (materials, components or the entire building structure) at design stage. EE constitutes the energy consumed in the process of extraction of raw materials, manufacturing, and assembling of a product.

The use of EE in the selection of either of the products is demonstrated in various studies in the literature. For instance, Venkatarama Reddy & Jagadish (2003) assessed the embodied energy of 41 buildings built of common and alternative building materials in India. The results demonstrated that energy requirements for soil cement stabilised blocks and concrete blocks ranged between 30-40% and 40-45%

respectively, relative to the EE for a house built of burnt bricks (2141 Mega Joules per cubic metre). It was therefore concluded that soil-cement blocks are energy efficient compared to the alternative masonry materials in India in accordance with this study. In separate studies, Suzuki et al (1995) and Dias and Pooliyadda (2004) included emissions in their assessments, carried out in Japan and Sri-Lanka respectively. Differences in results are obvious due to the variation in the inputs and the methods employed. In the former, where the assessment was based on building types, the national I-O tables were employed. The results showed that energy and greenhouse gases (ghgs) in steel reinforced concrete ranged from 8-10 Gigajoules and 850 kilogram per square metre respectively. The lightweight structure and the wooden house were estimated to be a half and a third of the values for steel reinforced concrete, respectively. In the latter study, timber was found to be the best option followed by concrete and steel respectively in terms of EE and carbon. These findings are based on a computerised relational database management system which was employed for the assessment of three different types of materials mentioned before. In all these and similar studies, EE was used for selection of different products related to the local materials and the available data for analysis which eventually, directing the type of method. Therefore, energy values vary from one context to the other due to several factor such as those highlighted in the literature. For instance the primary energy used, building materials (influenced by climatic conditions), the form or grade of the material and the analysis method employed (Menzies et al, 2007; Dixit et al, 2010); Baird & Chan, 1983). This is why, locally based analyses are recommended for the selection of building materials or components.

Interestingly, EE analysis is often considered least among the approaches used for environmental assessment in developing countries (Spence and Mulligan, 1995) particularly the sub Saharan Africa (sSA) despite the increasing problems related to building materials. Ibid highlighted that, the increasing distance between the sources of raw and manufactured materials and the construction sites can potentially contribute to transport related emissions. Similarly, the alternative building materials like cement due to their being located away from the urban areas tend to suffer similar transport emission problems. Although seldom considered, importation of materials also contributes significantly according to a study conducted in Hong Kong (Chen et al, 2001). So far, there is little evidence on studies to explore the extent of contribution of the construction sector to the EE and greenhouse (ghg) effects over the life-cycle of the construction phase in most countries in the sSA. This is, therefore, what forms the impetus of the current research which aims to answer the following broad question: To what extent can the building industry contribute to minimise the energy consumption and ghg emissions in developing countries? The following objectives are formulated as operational statements of the study.

Study aim and objectives

This study aims to explore alternative ways for attaining the environmental sustainability in the construction industry in Malawi. To answer the research question, the following objectives are formulated as operational statements:

- to review the embodied energy analysis approach and the methods used for assessing environmental impacts of buildings
- to assess and compare energy requirements of conventional and alternative building materials for urban residential buildings in Malawi

- to assess the ghg emissions associated with the construction of conventional and alternative building materials
- to identify potential areas for intervention for mitigating the energy consumed and the ghg ascribed to the use of the building materials under study
- to investigate the techniques for involving the construction stakeholders' participation in environmental sustainability in the construction industry
- to propose a usable tool for the selection of urban housing materials in Malawi

Scope

For the purpose of this study, the materials commonly used in Malawi for urban residential construction are classified into conventional and alternative materials. In Table 1, it is shown that the conventional materials include the burnt bricks and metal sheets for wall and roof respectively. The rest are different alternative masonry materials namely stabilised soil-cement blocks, cement hollow blocks, solid cement blocks and roofing cement tiles). The materials highlighted also form part of the wall and roof components as demonstrated in the Table.

Table 1: Building materials and components classification

Type of building materials	Wall component	Roof component
Conventional materials	Burnt clay bricks: plastered and painted internally	Inverted box rib (IBR) sheets on timber frames.
Alternative 1	Cement hollow blocks: plastered and painted internally	Cement tiles, on timber frames and painted on top
Alternative 2	Concrete blocks: plastered and painted internally	Cement tiles on timber frames and painted on top
Alternative 3	Stabilised soil-cement blocks: plastered and painted both sides	Corrugated iron sheets, on timber frames

The components are estimated at a total usable life of 40 years according to the Malawi urban houses' average life-span. The process-based hybrid (P-bH) analysis method proposed for inventory analysis is discussed in the next section where the summary of the EEA is presented.

EMBODIED ENERGY ANALYSIS

The idea of energy assessment as a means of identifying environmental impacts of a goods or services is not a new phenomenon in the literature. Energy analysis involves the evaluation of direct and indirect energy flows within certain system boundaries over a given timeframe (IFIAS, 1974; Odum, 1971). Due to the complexity of certain products such as buildings, energy is assessed at different phases namely; the pre-use (EE), operational (use) or demolition depending on the purpose of the study and the system boundary employed.

EE refers to all the direct or indirect energy accumulated in the manufacturing of a product. Therefore in buildings, the product refers to the building material, component or the entire structure. Therefore, the direct energy constitutes all energy requirements for the assembling of the building and transportation of the materials. While as the indirect energy, is that for the production and transportation of equipment (Milnes, 2005). With the available resources for this study, the energy assessment will be limited to the processes of manufacturing of the building materials and elements; transportation of building products to the construction sites; site activities (erection of the building) and the maintenance of walls and roofs. The EEA is one of the approaches recommended for the selection of building materials though criticised for the exclusion of the monetary values and the incapability to evaluate the natural capital in environmental assessment (Herendeen, 2004). Thus, improvements are required in its processes and methods in order to enhance its usefulness.

Embodied energy analysis methods

Upon the realisation that the indirect energy constitutes the largest portion of EE (Treloar, 1997; Crawford and Treloar, 2005), there has been a dramatic increase in the interest to trace these energy paths. Traditionally, the process and input-output (I-O) analysis methods, recommended by the International Federation Institute for Advanced Studies (IFIAS, 1974) have been the most commonly used methods for EE analysis. However, more techniques for tracing multiple energy paths related to the building processes are evidenced in the literature (Treloar, 1997; Crawford, 2008). Table 2 on EE analysis methods demonstrates that both the process and I-O analyses benefit from each other's strengths while minimising their weaknesses when these are combined in hybrid methods. For instance, the process-based hybrid (P-bH) analysis though suffering the weaknesses of incompleteness due to truncation errors, it benefits from the I-O data which complements the process data. Previously, it was estimated that almost 90% of the energy requirements of a product is obtained from the first 2 levels of the upstream energy. Thereafter, the quantities decrease with the increase in the energy levels (IFIAS, 1974). However, as research continues in this area, significant energy values seem to be traced using the hybrid methods. For instance, Crawford (2008) observed that almost 87% of gaps are realised with the use of the process method with reference to the Australian buildings when validating the I-O-bH. However, more validation studies are needed in this area.

Table 2: Embodied energy analysis methods

	Process analysis	Input-Output (I-O) analysis	Hybrid methods
Composition	Based on energy data requirements from manufacturing processes	Based on national statistical I-O data tables converted into Leontief inverse I-O	Combination of process and I-O data sets. Can be either process or I-O based
Evaluation criteria	Energy per unit mass /volume/area e.g. Giga joules per kilogram/cubic metres/square metres	Equates energy input per monetary output e.g. Mega joules per $	Combines the two methods but leaning on what each is based on i.e. process or I-O method
Advantages	Simple, systematic and accurate. Useful for analysing energy of individual items in a system therefore providing specific results	Encapsulate entire energy flows of an economy	Minimise the weaknesses of the traditional methods
Disadvantages	Time consuming, truncation leads to incompleteness	Aggregation of data inputs of different economic activities, use of previous years' I-O statistical data sets, variation in commodity prices	Process-based: adopts the disadvantages of the traditional methods I-O based: use of old process method data

Selected sources: Treloar (1997); Treloar et al 2000; 2001; Crawford & Treloar (2005); Crawford (2008).

Hither to, the I-O-based hybrid (I-O-bH) is recommended as being able to trace multiple energy paths as indicated by Treloar, (1997); Crawford (2008) among others researchers. Nevertheless, the reliability on comprehensive and frequently updated data sets is one of the major weaknesses of the method (Treloar, 1997). It is therefore expected that the use of the P-bH. In the current study, where the process data is the fundamental part of the method, it is expected that the use of P-bH will enhance the basic data availability traced throughout the manufacturing process of conventional and alternative materials. However, there are a number of challenges that have to be seriously considered in conducting embodied energy analysis such as those discussed below.

Limitations of embodied energy analysis approach

Although several other limitations have been highlighted in the literature (for example, Menzies et al, 2007; Dixit et al, 2010) this paper discusses a few factors considered significant for the current study. These include the emphasis on precision of energy values, data related issues, obsolescence of energy values and the lack of incorporation of energy of labour.

The need for precision of energy values
As emphasised in previous sub section, energy analysis in buildings is becoming more and more complex as researchers emphasise on precision (e.g. Hamilton-MacLaren et al, 2009; Crawford, 2008). It is appreciated though, that by incorporating a wider range of energy paths like capital and services, enhanced values of energy requirements are obtained (Baird & Chan, 1983; Crawford, 2008). Consequently it becomes clearer to identify areas of significant effects hence stimulating policy changes (Ibid). Further, the improvement of energy values enhances development of theories for use in construction research as demonstrated by Langston & Langston (2008) for example. However, it is equally important to consider the importance and the extent of contribution of extra energy paths being included. With the data problems in developing countries, accuracy in energy values appears to be one of greatest challenges in conducting EE analysis.

Data availability and quality
The need for reliable and good quality data for energy analysis is emphasised in most studies in the literature. Researchers indicate that data is not always available where needed hence in some parts of the world the use of coefficients from elsewhere cannot be avoided. For example, when compiling the comprehensive UK inventory of carbon and energy, Hammond & Jones (2008) used a wide range of data from different contexts in the absence of the required locally based data. Although this seems to have yielded satisfactory results when used on different building types in both UK and abroad (Hammond & Jones, 2008a), there are mixed thoughts researchers in this area. For instance, Baird and Chan (1983) expressed a concern that the values obtained by the use of imported data are usually not a true representation of the energy requirements in the latter contexts. This is due to differences in primary energy employed, the age of data used and the grade or form of the materials being assessed. However, Hammond & Jones (2008) argue that variations will always be there but the extent has to be seriously reconsidered.

Paradoxically, where data is available, the quality is another area of concern. Among several examples, Crawford (2008)'s recent study to assess the reliability and completeness of an I-O-based hybrid analysis method demonstrates that the I-O-bH used is weakened by the quality of the process data employed in the analysis. Therefore, Ibid urges researchers in this area to come up with more process data for Australia where the study was based. It should be noted though, that improved data quality and data quantity is needed everywhere else especially where EE studies are rarely conducted and for the materials not usually assessed as commented before by Menzies, et al (2007). The data issue poses a great challenge mostly in developing countries where data is either not in existence, calculated using estimated information or it is outdated (Ebohon & Rwelamila, 2001).

Obsolete energy values
It is expected that as knowledge and actions to reduce the energy use at different levels within a system boundary increases, lower EE values would be obtained (Verbeeck & Hens, 2010). Similarly, higher energy values are also expected where higher EE values are justified for lower future operational energy of buildings (Milnes, 2005). Based on the literature reviewed, it appears that there is lack of review to re-evaluate the changes in EE values related to the building industry at global level. Some previous studies demonstrate the EE values obtained at various levels of the building process. For instance, EE in buildings is estimated to be almost10-15 years of operational energy, an equivalent of 1000 Giga Joules in an Australian context (CSIRO, 2000). In the same region, but with reference to the residential buildings, EE was assessed to be 20-50% of the annual operational energy (Harrington et al, 1999). According to Kohler (1991) the site-works alone in European and USA buildings were approximately 7-10% of the total building's embodied energy. Interestingly, most of these studies, carried out over a decade ago seem not to have been revised to assess any changes occurring as a result of the improvements being undertaken in energy conservation. The obsolete energy data can be misleading yet the updated information also needs to be prudently used especially where the selection of building materials is concerned. This problem is also exacerbated with the use of energy of labour where information on production of materials is seldom recorded.

Exclusion of energy of labour (human labour)
The need to incorporate energy of labour has been a controversial and much disputed subject in the field of EEA despite the realisation of its contribution at pre-use stage (Langston & Langston, 2008). The literature highlights several reasons though, for its exclusion. First is the assumption that the contribution of human labour to the energy requirements in the highly industrialised countries is insignificant as perceived by the IFIAS (1974). Interestingly, Cole (1999) demonstrates that human labour contributed almost 3% of embodied energy of residential construction in Canada. This was considered significant although it is based only on the energy requirements related to commuting to and from the construction site. The second reason for the exclusion of eco-energetics is the problem of determining the elements that certainly contribute to environmental degradation relative to human labour (Emmanuel, 2004). Finally, the conversion of the human energy into values that can be used for the assessment forms part of the reasons for its exclusion. Odum (1971) suggested earlier that the conversion of calorific values into energy intensity could be one of the ways for obtaining such energy values. However, this seems possible where such values are known. Hither to, very little is known in this area especially in developing countries. To agree with the previous researchers, it can be concluded that there is no clear-cut for obtaining energy for human labour. On the contrary, since contribution appears to have a potential to affect the energy values where human workforce is highly utilised, further investigation in this area is needed. This will help to explore how the inclusion or exclusion of human labour affects the results EE values in particular contexts.

To summarise, the challenges highlighted here have various implications for EEA in the construction industry in developing countries particularly with regard to obtaining accurate energy quantities. Due to the lack of systematic recording of information in the informal sector which dominates in most construction processes, this exacerbates the existing data problems. In the current study, although the incorporation of the I-O is expected to enhance the completeness this also relies on the availability of data in the national I-O statistical datasets. It is anticipated though, that by engaging the P-bH method this provides an opportunity not only to enhance the quantity of process data but also to carter for materials rarely assessed as lamented by Menzies et al (2007). Hence, with comprehensive process data the study will ensure most of the activities within the set boundaries are incorporated in the analysis. However, for future studies, data recording systems need to be established where the informal sector's activities are incorporated. These for instance could be models incorporating the basic processes that provide benchmarks for the associated environmental impacts in a particular region as opposed to the Dixit (2010)'s worldwide standard proposal.

CONCLUSION AND FURTHER WORKS

As mass housing projects for new structures, renovations/extension in addition to the reconstruction of housing in natural disaster areas continue to rise in developing countries, the construction sector also needs to be equipped with appropriate tools for minimising the associated impacts. Energy analysis is commonly used and accepted in the construction research to evaluate environmental impacts of products in order to identify opportunities for change. The EEA is used in this study as one of the approaches that provide quantitative assessment of the environmental effects to complement the traditional policy and regulations. Despite the limitations highlighted in the literature, locally based evaluations are needed for quantification of impacts and the selection of appropriate building materials.

This paper explores the concept and of embodied energy based on literature review as one of the major objectives of an ongoing research to promote sustainability in the construction industry in developing countries. This preliminary work demonstrates that different methods in tracing energy paths are deemed capable to incorporate a wider range of paths such as the capital and services affecting a product. However, more process data is still needed in the literature to enhance the data inputs required for the hybrid analysis methods.

The next stage of this study presents the empirical findings of EEA of the low-cost housing. Although the study focuses on Malawi for inner depth investigation, the findings can be used for future comparative studies elsewhere in the sSA and other parts of Asia and the Pacific where similar materials are used.

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