Applicability of inventory methods for embodied energy assessment of buildings in Sub-Sahara Africa

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Abstract

As the knowledge and understanding of environmental impacts associated with buildings increase, methods of assessing the impacts are also improving in building research. This paper attempts to analyse how applicable the conventional and improved process and input-output inventory methods are in assessing the environmental attributes in the construction industry in Sub-Sahara Africa (SSA). The paper presents preliminary findings based on an extensive literature review of an ongoing PhD research to analyse embodied energy of buildings in SSA. A basic outline on how the process and input-output inventory techniques operate is presented first followed by a discussion on factors considered to limit the application of the techniques in the region. It is noted that despite the limitations the methods have, they are still sufficient for use in the absence of other alternatives. While enhancement of data for this purpose is essential for appropriate results, further improvement on the methods to suit the local needs is highly recommended.

Keywords: building industry, developing countries, environmental impact assessment, inventory analysis.

Introduction

The use of energy analysis approach in evaluating the associated environmental impacts of goods or services is not a new phenomenon in the literature (IFIAS, 1974). Despite being considered as a single criteria not able to incorporate a broad range of environmental impacts (Cole, 1999), the approach is suitable for identifying opportunities for change hence acting as one way of addressing sustainability in the building industry as previously recommended by Holtzhausen (2007) among other authors. In life-cycle energy assessment of buildings, embodied energy analysis (EEA) involves the evaluation of upstream or front end components of a home (Hammond & Jones, 2008a). That is, EEA measurers the total initial energy incurred by a product at various levels of the production processes. In most studies the processes are limited to the extraction of raw materials, manufacturing as well as maintenance of a product over its usable life. Energy incurred for transporting raw materials to the factory and the processed product to its final destination, is also included. However, this depends on the system boundaries proposed basing on the purpose of the study as well as resources available for conducting the studies (Dixit, 2010).

Although the EEA is recommended in facilitating the selection of environmental friendly products and services at the initial stage of the building process in the building research, it suffers severe limitations. These include the lack of monetary value and the incapability to evaluate the natural capital in the assessment process (Herendeen, 2004). In addition to the limited scope due to the use of a single parameter (energy) as mentioned earlier, there are also other limitations associated with the methods used in compiling the inventory data, a significant stage in the analysis procedure (Dixit et al, 2010). It is important though to note that although this study puts more emphasis on embodied energy, basing on the ongoing research to evaluate embodied energy of low-cost housing in SSA, similar inventory methods are employed at other phases (such as the operation and demolition) of a building's life-cycle. In addition, considering that there a few empirical studies on embodied energy analysis in most developing countries particularly the Sub-Sahara Africa (SSA) Africa, most examples used in this study are based on other countries outside the SSA with a few exceptions from South Africa.

Preceding studies on inventory methods in energy analysis

The literature demonstrates a wide range of methods used in compiling inventory data necessary for embodied energy analysis or full life-cycle energy assessment of buildings. Examples include the coefficients developed for national use (e.g. Hammond and Jones, 2008a; Venkatarama Reddy & Jagadish, 2003), computer models based on tonnes of oil equivalent (toe) conversions (Dias and Pooliyadda (2004) and the commonly used process analysis and the economic input-output methods (e.g. Treloar, 1997; Crawford, 2008).

For instance, in a study conducted by Dias and Pooliyadda (2004), combination of process and toe data was used to assess embodied energy and green house gases of different building materials in Sri-Lanka. With the combined data, the authors developed a computerised relational database management system which was used to develop a model for EE calculations of timber, concrete and steel. It is therefore noted that standard conversion factors like the British thermal units (Btu) or the toe are normally employed where data is not sufficient to develop energy coefficients basing on some examples: Dias and Pooliyadda (2004); Emmanuel (2004). Where reasonably sufficient data is available alternative attempts are made to avoid the use of imported data. However, this can hardly be achieved basing on the previous attempts by some authors. For example, Hammond and Jones (2008a) compiled energy and carbon coefficients based on various energy intensities developed in UK but moreover, data from other parts of the world was employed to fill some gaps. This energy and carbon inventory, originally developed at Bath University, comprises of energy and carbon intensities for approximately 200 building materials. This is considered important for enhancement of environmental assessment of activities related to the UK building industry with an aim to improve it for further use elsewhere (Hammond and Jones, 2008a). Basing on the validation study conducted earlier on (Hammond and Jones, 2008b), the criterion appears to yield satisfactory results when used on different building types in both UK and abroad as demonstrated by Hammond & Jones (2008b). With the author's idea to revise the contents frequently, it is expected that further improvements will enhance its usefulness at international level. As it is the case with other inventory methods, these coefficients have limitations too. One major weakness is the problem of using energy intensities based on imported data due to lack of relevant information within the UK (Hammond and Jones, 2008b). The other limitation is the lack of validation studies to enhance its reliability. Another example of attempts to use local data for inventory analysis is demonstrated by Venkatarama Reddy & Jagadish (2003). In their study to assess embodied energy of local building materials in India, local energy coefficients were used to assess the embodied energy of different building materials for dwellings in India. 41 case studies were assessed to compare the EE of clay bricks, reinforced concrete blocks and soil-cement stabilised building blocks but have been hardly replicated in the Indian context or elsewhere. However, details on how the coefficients were originally obtained are not clear in the literature.

For the past few years, some researchers have opted for country based inventory computer simulation tools such as the Athena (Canada), Sima-Pro (Netherlands) and many others (Dixit et al, 2010) as a way of minimising the use of foreign data. On the contrary though, these computer tools appear to be useful at country level especially where the initial data was obtained (Ibid). Therefore this limits their usefulness elsewhere because this is considered to provide misleading results in other contexts where the inputs (for example primary energy), are different (Menzies et al, 2007). Finally, the tradition process and input-output process are the commonly used inventory methods evidenced by the ongoing developments as discussed in the subsequent sections. Although most of the other methods are rarely applied in regions such as the SSA, a few examples exist on use of the input-output method to compile inventory data for embodied energy analysis of building materials and services in South Africa, Ghana for example (Irurah, 1997; Bruelisauer, 2007; Eshun et al, 2010). Despite its lack of validation (Bruelisauer, 2007) and updated studies to improve on the previous study using 1993 data, this has been one of the comprehensive databases which provide the basic information on energy values of building materials for comparison purpose. In another attempt, Bruelisauer (2007) employed a full life-cycle assessment of a straw bale house basing on the input-output coefficients established within South Africa Irurah (1997) and New-Zealand. Although embodied energy studies are few in the region, there are studies being conducted on single items focussing on other phases of the building life-cycle. For example (Eshun et al, 2010) conducted a life-cycle timber processing in Ghana. What is needed though in the region is to gather the available data and make it useful for the building industry.

Beside the fact that there are a few studies conducted in the SSA, little or no concern has been given by previous authors on how relevant the available techniques are for use in the region. Therefore this paper attempts to examine the common process and input-output analysis methods in order to understand how the methods work. It also analyses the limiting factors for associated with applicability of the traditional methods in environmental assessment in least industrialised countries such as the Sub Sahara Africa. It is expected that this synopsis provides an insight to construction management researchers for further enquiry on how further the existing methods can be improved. One of the ways forward though is to intensify the recording of process data at different levels of the building development. The question remains though on *how* this can be implemented.

Process and input-outputs inventory methods

Despite the existence of a wide range of inventory methods demonstrated in the literature, the traditional process and input-output (I-O) analysis recommended by the International Federation Institute for Advanced Studies (IFIAS, 1974) appear to be the most commonly used methods in EEA. This is evidenced through the latest developments in the building research as discussed later. Basing on the life-cycle assessment concept described in the ISO 14040 series, EEA involves four major steps namely; the definition of scope and boundaries, inventory data analysis, environmental impact assessment and interpretation of results (Udo de Haes & Heijungs, 2007). The *goals and scope* are defined first to establish the system boundaries and the functional unit as well as the method to be employed. This is followed by the *inventory data analysis* step where information for energy assessment is compiled and evaluated in terms of the associated environmental loads of the products or systems. However, these are to be determined within a set system boundary which relies on the purpose of study or the data availability hence making it a crucial step for the whole process. The results obtained at this level, which is also identified as the *inventory* step is essential for carrying out the *impact assessment* at stage 3. The step involves weighting and categorising the environmental impacts according to their level of importance. Finally, the results are *interpreted* and compiled into a report. According to Mithraratne, Vale & Vale (2007), interpretation of results is prone to subjectivity due to the qualitative assessment criteria employed. Therefore, the results could be affected depending on the way the involved parties will analyse the results. However, the process can be repeated several times until satisfactory results are obtained based on the goals and scope set in the first stage (ISO 2006) hence minimising the associated problems.

It is important though to note that all steps are important for appropriate results to be obtained. On the contrary, the inventory analysis stage requires a special consideration when comparing the results from one study to the other because of the variation of methods employed at this stage which, as a result, affect the final results. Table 1 summarises the structure of process and input-output (I-O) inventory methods. It shows how the two methods they benefit from each other's strengths while minimising their weaknesses when combined into hybrid methods. A detailed discussion on how the methods have developed in the past few decades is discussed subsequently.

Table 1: Embodied energy analysis methods. Main sources: Treloar (1997); Treloar et al 2000; 2001; Crawford & Treloar (2005); Crawford (2008).

	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

Process analysis

The process analysis assessment method takes into account of direct and indirect upstream energy flows of a product (Alcorn & Baird, 1996). Direct energy is categorised as the energy utilised in the processes of manufacturing the product. The additional energy beside the manufacturing energy is considered as indirect energy. Bullard et al (1978) demonstrated the following three steps for assessing energy requirements in buildings. The first one involves the identification of both the energy paths and direct energy whose data is available as well further paths within the established system boundary. It also identifies the functional unit to be used which could be in form of area (m^2), mass (kg) or volume (m^3) (IFIAS, 1974). The second step is the quantification of materials required in the manufacturing process and, finally, the evaluation of energy intensities. Therefore the results obtained will be either in Gigajoules per unit volume or mass or area depending on the functional unit in use. For this the method is regarded as simple, systematic and most accurate. In addition, because it focuses on detail, it is recommended for assessment of single products such a building material or a component.

However, the method suffers several limitations such as time consumption and truncation errors (Pullen, 2000; Treloar, 1997). That is, there is need for adequate time to trace all the upstream process energy paths related to a product as observed in the straw bale house (Bruelisauer, 2007). However, due to the complexity of the upstream processes, this is hardly achieved. Consequently, as it is not know as to how much the remaining paths contribute to the total process energy is not reflected in the value obtained (Boustead and Hancock, 1979; Lave et al, 1995) the results obtained using the process method are considered as incomplete. Among the several examples in the literature on how the process method works and the extent of gaps created are the ones conducted by Lave et al, (1995); Crawford and Treloar, (2005); Crawford, (2008). Despite the problems with the method, this is a basic starting point particularly where data problems prevail like most parts of the SSA. In attempt to assess lifecycle energy of a straw bale house in South Africa, Bruelisauer (2007) used a process method although due to lack of sufficient data coefficients of previous studies were employed. Although the use of the I-O economic analysis technique seems capable to fill in gaps related to process method, it also suffers severe problems.

Input and output analysis

Unlike the process method which relies on the processes involved, the input-output (I-O) approach uses national statistical tables and figures of monetary value to assess energy inputs and outputs of particular goods or services. The I-O technique concentrates on evaluation of the supply, demand and value added components within an economy. The results obtained are then converted into energy values which are presented as energy per national currency. For example, kilojoules per dollar (KJ/$). Considering the excess work involved in tracing the $ output for final demand, the Leontief inverse matrix (LIM) tables (Leontief, 1936) have been useful in calculating the direct and indirect output per each $ demanded in an economic system. Therefore, one of the advantages of the I-O method is its capability to detect high energy intensity sectors. Since the I-O method has clear boundaries, it is also considered capable to accurately estimate industrial sectors of a given economy. Consequently, the I-O method, embraces policy formulation and decision-making in environmental monitoring and assessment (Lave et al, 1995). The use of LIM tends to be an added advantage in I-O method. It reduces the work of using the entire economic system if any changes occur in the final demand. Instead, the LIM acts as an inter mediator between the producing sectors. However, this varies from one economy to the other as demonstrated by Rowley et al (2009), Acquaye, (2008) who used the LIM to assess energy consumed in different types of economic activities with regard to the Australian and Irish economies respectively.

Likewise as in process method, I-O analysis method has a number of limitations. First, the method fails to distinguish the data inputs and outputs of different sectors in an economy therefore all sectors are treated as the same (Treloar, 1997). The method also suffers problems of double counting according to Treloar et al (2001). Similarly to the process method, time-consumption in tracking the upstream indirect energy sources although this depends on the complexity of the economic system being used. Finally, Rowley et al (2009) identifies periodical gaps as another major problem with I-O method which occurs due to the changes in the technological and commodity prices. Consequently, this limits the validity of the results for future use considering that the data inputs are time specific. Interestingly, in less industrialised economies, due to slow progress in technological changes the effects could be minimal although the fluctuation of commodity prices has a potential to affect the energy intensities obtained using the I-O approach. Contrary though there is need for further enquiry to verify this.

Although there could be several studies being conducted to improve the I-O method, the one conducted by Irurah and Holm, (1999) for the South African economic sector is one of its kind in the region hence worth mentioning. The authors proposed a sectoral energy conservation framework to improve on the energy intensity figures delivered from the traditional I-O method focussing on the South Africa. According to the authors, the multiplication of use intensity coefficients and the total embodiment energy coefficients provided more significant energy intensity values compared to the use of the latter only. The intensity figures were obtained from a wide range of sectors with higher intensities as listed in the South African intensity list. Although the authors considers the method as appropriate for the SA economy, there is no evidence of further application of this method hence lacks validation. In addition, it suffers similar problems related to the tradition I-O methods highlighted earlier. The hybrid methods are considered to be more reliable due to the combination of the two tradition methods that benefit from each other's strengths while minimising weaknesses.

Hybrid analysis methods

Upon the realisation that the indirect energy constitutes the largest portion of EE contrary compared to what was perceived in previous findings (Treloar, 1997; Crawford and Treloar, 2005), there has been a dramatic increase in interest to trace further energy paths related to building processes. That is, the conventional methods are being developed further into hybrid methods to facilitate the assessment of the other paths that cannot be addressed by either of the traditional methods. In previous studies, it was estimated that almost 90% of the energy requirements of a product is obtained from the first 2 levels. Ultimately, the energy rate decreases with the increase in energy levels (IFIAS, 1974). However, as research advances in this area, it is noted that further energy values can be obtained using the hybrid methods. For instance, Crawford (2008) observed that by employing a new input-output based hybrid (I-O-bH) method on Australian buildings, the gaps realised due to the use of the process method were almost 87%. Therefore, as the methods develop further, it is likely that further gaps will be realised hence further approaches will be required to minimise them.

The hybrid techniques, which were first developed in the late 1970's by Bullard et al (1978), allow the process and I-O methods to benefit from each others' strengths while minimising their weaknesses (Treloar et al, 2000). For instance, the (P-bH) analysis though suffering the weaknesses of incompleteness due to truncation of energy paths, benefits from the I-O data which fills the remaining gaps. Several hybrid methods exist in the literature most of which are summarised in figure 1. These include the process-based, input–output based, tiered hybrid and integrated hybrid analysis methods form part of the methods demonstrated in the literature. According to Rowley et al (2009) and Menzies et al (2007), the first two are the commonly used approaches although till now it is still unclear on how the process based method works.

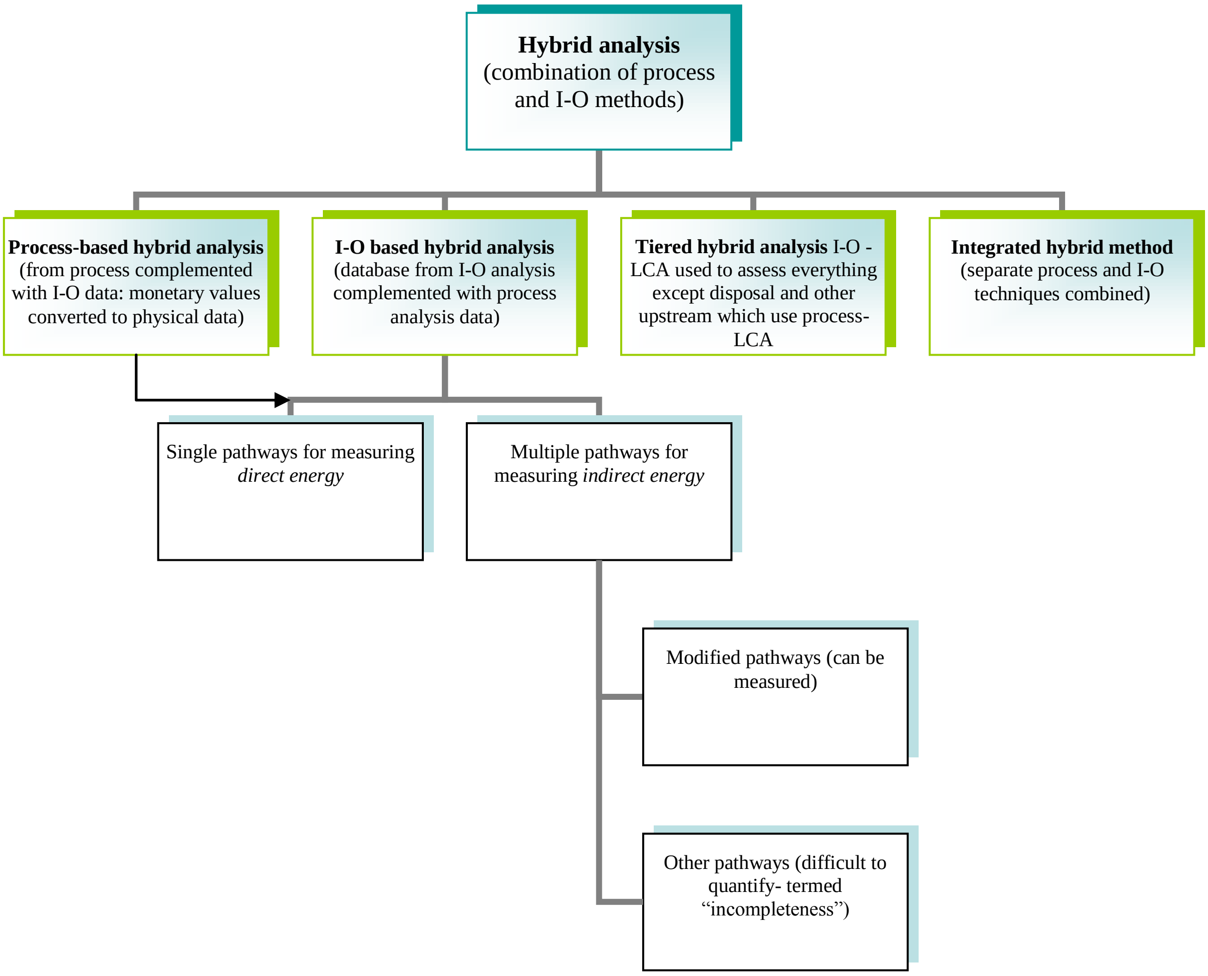

Figure 1: Hybrid energy analysis methods. Source: Menzies et al 2007; Rowley et al, 2009; Bullard et al (1978)

Input-Output-based hybrid analysis method

As the name suggests, the I-O- based hybrid (I-O-bH) analysis method, adopts the principles of the I-O method but the process data is used to complement the statistical data. To minimise the errors related to the I-O, the I-O-bH involves intense disaggregation of the matrix of the total energy requirements in a given economy. Therefore the expanded power series computation of the Leontief inverse matrices becomes:

$(1\text{-}A)^{-1} = I + A^{-2} + A^{-3} + A^{-4} + \ldots\ldots\ldots\ A^{-n}$

where:

I = Identity matrix;   A = matrix of total direct requirement coefficients

Following this sequence, each value obtained by multiplying NxN demonstrates the sum of the individual N value. Therefore every product obtained is a potentially significant energy path (Goggins et al, 2009). Depending on the scale of inputs in a given economy, there could be hundreds of potential paths obtained as a result. However, it is not practically possible to analyse them all in a single study. To ensure subjective exclusion of unwanted paths, Treloar et al (1997) proposed a threshold value method for selecting the energy paths to eliminate the unnecessary paths. With this approach, the total energy intensity of a path is compared to the threshold value and, if the former is less than the latter, the rest of the upstream paths are eliminated. Based on I-O hybrid method, Treloar et al (1997) considered the 8th level as the most appropriate yet Goggins et al (2009) managed to reach the 9th level using the P-bH method.

Until lately, the I-O-bH has been considered as the most appropriate method able to trace multiple energy paths according to recent studies (Crawford & Treloar, 2005; Crawford, 2008). Conversely, Crawford, (2008) emphasises that more validation studies are needed to assess the reliability of the I-O-bH methods. One of the ways to improve it is by enhancing the old process data in used in the I-O-bH techniques. By doing that, it is assumed that the I-O bH will be more reliable than it currently is. However, as highlighted by previous researchers, in most developing countries, it is nearly impossible to reach the highest threshold with the I-O bH due to the limited scale of the national statistical data. This is attributed to the scale of economic activities and poor data recording systems (Dias & Pooliyadda, 2004).

Process-based hybrid

Apart from including it in the hybrid life-cycle inventory in recent studies by Crawford (2008); Goggins et al (2009), there are very few examples using the process-based method P-bH as noted by Dixit et al (2010). Therefore, it is not surprising that it is rarely used in the building research. Although it is easy to assume that P-bH is merely supplementing the process data with I-O data, according to Rowley et al (2009) it is still unclear on how the process-based hybrid method works. In the few examples of studies where P-bH is used, it is part of other I-O calculations particularly those conducted by Crawford and Treloar (2005); Goggins et al (2009). Incompleteness of the method is one of the major shortfalls, in addition to the complexity in the calculation of inventory data. Most of its limitations are inherent from the process method discussed earlier on. However, the P-bH is suitable for single case evaluations hence it will be used in the research underway on which the current paper is based. The ongoing study's major objective is to assess embodied energy of residential buildings in SSA in order to explore alternative ways to enhance the environmental sustainability in the building industry.

Hybrid Life-cycle Inventory (H-LCI)

The difference between hybrid lifecycle inventory and the other hybrid methods is that it is considered to include capital inputs excluded in the previously discussed hybrid methods. Crawford (2008) applied the hybrid life-cycle inventory (H-LCI) method on Australian residential buildings, and concluded that it improved the reliability and completeness of the former methods. The H-LCI method which includes the basic steps of process and I-O methods also combines the I-O-bH and the P-bH methods. Further details of the methods are presented by Crawford and Treloar (2005) who also employed the method to assess embodied energy and water using a 3 storey commercial building in Melbourne, Australia. Similarly Goggins et al (2009) in Ireland used the H-LCI to assess the EE of reinforced concrete using two different concrete mix based on the Irish construction. In

Crawford's (2008) study the H-LCI was employed to validate the I-O-bH method. In this a combination of commercial and residential buildings in Melbourne was used in the assessment. Since the method is still in its early stages, more application studies are required to assess its validation. However, it is not clear though on the extent of contribution these further paths make and how the results will be compared with studies where data is not adequate for such thorough analyses.

Based on the literature, it is concluded that the existing methods are so far sufficient in the absence of alternative methods. However, this is relative to availability of data (Crawford, 2008). The major challenge remains though on their applicability in the building research in the developing countries which are still lagging behind in environmental assessment research related to the built environment. Contrary though, the existing methods used could be part of the contributing factors in slow progress in research and development in this area.

Problems associated with process and I-O methods for EE analysis in SSA

EEA widely used for environmental impact assessment in buildings is associated with a broad range of limitations most particularly related to the inventory data analysis step. As the techniques for tracing multiple energy paths continue to advance, the associated problems are also being brought to light by different researchers as evidenced in the literature (Menzies et al, 2007; Ortiz et al, 2009, Dixit et al, 2010; Optis and Wild, 2010).

Although each inventory method has certain limitations, most of which have been highlighted earlier, here we emphasise on issues considered to play an important role in the applicability of the traditional inventory methods in environmental assessment of buildings in least developed countries. These include, though not limited to, the emphasis on precision of energy values, data inadequacy, obsolescence of energy values and the lack of incorporation of energy of labour in the current methods.

Precision of energy values

Upon the realisation of the further energy paths that were previously ignored due to lack of appropriate methods (Hamilton-MacLaren et al, 2009; Crawford, 2008) further developments in methods to trace them are evidenced in the literature. The incorporation of indirect energy paths like capital and services has enhanced the percentage of energy values that were hardly obtained in previous studies (Baird & Chan, 1983; Crawford, 2008). Consequently, as the impacts become clearer to identify, it is easy to stimulate policy changes where necessary basing on the findings (Crawford, 2008). Eventually, such improvements enhance development of theories for use in construction research even though further validation studies are still required (Langston & Langston, 2008). On the contrary though, it is noted that as the methods advance, energy analysis in buildings is also becoming more and more complex. Even though it is important to obtain precise values, it appears that the concern is more on getting precise values but not focussing much on the extent of contribution the further paths make to the environment. It is understood though that for a single study this would seem insignificant yet accumulatively the further paths have a considerable contribution. However, in some regions like the SSA, for instance, where data problems exist, the initial studies can be used as the basis for further investigation of certain levels of energy, green house gases and other environmental effects in the building research. However, getting precise values can be hardly achieved. Therefore, if the emphasis is merely on accuracy this will be a major hindrance to further development of research in this area.

Data availability accessibility and quality

In the literature Menzies et al (2007); Crawford's (2008) are among the several authors calling for reliable and good quality data for energy analysis. It is well known that data is not always available where needed hence use of energy coefficients obtained from elsewhere cannot be avoided for some studies. 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 locally based information. Although this seems to have yielded satisfactory results when used on different building types in both UK and overseas (Hammond & Jones, 2008a), there is no worldwide consensus among researchers on the use of foreign data. For instance, Baird and Chan (1983) expressed a concern that the values obtained using imported data are usually not a true representation of the energy requirements in the latter contexts. Basing on their findings related to Australian buildings, the authors highlighted a number of factors considered to have played an important role in results that are obtained in particular studies. These include the primary energy and age of data used as well as the grade or form of the materials. However, Hammond & Jones (2008) argue that variations will always be there but the extent of such variations has to be seriously reconsidered where necessary.

Paradoxically, where data is available, quality of data used is another area that needs to be taken into consideration. For instance in Crawford's (2008) study to assess the reliability and completeness of an I-O-based hybrid (I-O-bH) analysis method, it was demonstrated that the I-O-bH used for the energy assessment is weakened by the quality of process data employed in the analysis procedure. Therefore, the author urges researchers to come up with more process data for Australia where the study was based. However, data quality and data quantity is a need elsewhere particularly in the regions where studies are rarely conducted as well as for such materials not normally evaluated (Menzies et al, 2007). So far, data issues pose a great challenge for energy studies to be conducted in most SSA countries. If data is available it could be either based on estimates or outdated. But mostly, it will not be in existence at all (Ebohon & Rwelamila, 2001).

Obsolete energy values

In EEA, the use of up-to-date data is essential for the development of models, as well as theories related to the building research. In addition to this, it is important for facilitation of decision making and policy formulation. It is therefore, 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). Contradictory though, higher energy values are also expected where these are justified for lower future operational energy of buildings (Milnes, 2005). However, a few studies are being conducted to assess the changes that might have occurred so far compared to previous findings. For instance, according to CSIRO (2000), EE in buildings in Australian was estimated at 1000 Giga Joules an equivalent of almost 10-15 years of operational energy. In a different study focussing on residential buildings, EE was estimated at 20-50% of the annual operational energy, according to Harrington et al (1999). Further, Kohler (1991) estimated a 7-10% of the total building's embodied energy focussing on site-works alone and based on the European and USA buildings. Surprisingly, most of these studies, carried out over a decade ago seem not to have been revised to investigate the extent of improvement occurred as a result of the ongoing research related to energy performance in buildings. Although there are advanced methods developed from the conventional process and I-O inventory methods, it appears that the techniques are rarely used to assess the changes occurring in the building sector in terms of previous, current and future comparisons of energy use. Due to lack of data in the SSA for instance, the use of obsolete energy data some of which is employed in inventory methods for validation of findings can be misleading as observed earlier (Crawford, 2008).

Exclusion of energy of labour (eco-energetics)

The need to incorporate energy of labour has been a controversial and much disputed subject in EEA and life-cycle assessment. Despite the realisation of its contribution at pre-use stage (Langston & Langston, 2008), this is not often included in the current methods used for inventory analysis. One of the reasons relates to the assumption that contribution of human labour in energy analyses is insignificant more particular in highly industrialised countries as perceived by the IFIAS (1974). Although there are few studies to demonstrate the extent of the contribution of human labour, in a study conducted in Canada, Cole (1999) demonstrates that human labour contributed almost 3% of embodied energy of residential buildings. Although it was only based on energy requirements related to commuting to and from the construction site, the authors considered this to be significant. Unfortunately, there is little or no evidence of further studies of this nature making difficult to evaluate the extent of contribution such values would make. According to Emmanuel (2004), the exclusion of eco-energetics is also associated with problems in identifying the elements that certainly contribute to environmental degradation. This therefore raises a third reason considered to contribute to the exclusion of human labour. This is the issue of complexity in converting human energy into values that can be used in the assessment. Previously, Odum (1971) suggested that conversion of calorific values into energy intensity values could be one of the ways for obtaining the required values based on human labour. However, this appears possible where a number of parameters such as food intake and the related calorific values are well known. Hither to, there is no clear cut to establish such values in developing countries particularly the SSA where human labour is highly utilised in the building industry. Therefore, to agree with the previous researchers, we conclude that there is no straightforward method for obtaining energy values for human labour. Yet on the contrary, since its contribution appears significant where human workforce is highly utilised, the need for further investigation in this area cannot be overemphasised. However the current inventory methods including the hybrid methods do not seem to be developing towards that direction. Therefore, for thorough energy analysis future research needs to explore the extent of contribution the inclusion or exclusion of human labour makes in regions where human labour is highly utilised.

To sum up, although there are several methods used to compile inventory data in embodied energy analysis, process and economic inventory data methods appear to be the most commonly used techniques. However, the challenges related to use of these methods need to be seriously taken into consideration when choosing appropriate methods for inventory methods in EEA.

Conclusion and further work

As the need for new structures, ongoing renovations or extensions of existing houses, in addition to the reconstruction of housing in disaster areas continues to rise in developing countries the construction sector also needs to be equipped with appropriate tools to enhance reduction of associated social economic and environmental impacts. The use of energy analysis for environmental analysis is not a new phenomenon in the literature. Basing on lifecycle principles, energy analysis can be conducted at various levels namely pre-use, operation or demolition phases depending on the system boundaries set. However, it appears that little evidence of actions being taken in improving the environmental assessment methods particularly in the building industry in SSA. This paper is based on an ongoing research to explore ways for promoting environmental sustainability in the construction industry in SSA. In this paper an attempt has been made to analyse how the process and I-O inventory methods operate, discuss the developments that have been taken in improving the energy analysis procedure using these methods. The major implications for employing the traditional inventory methods for EEA in the construction industry in regions like the Sub Sahara Africa are also discussed. It is concluded here that despite the limitations the methods have, they are still sufficient for use in the absence of other alternatives. However, further improvements are needed to make these suitable for use in regions where data availability continues to be a great challenge.

Taking the afore mentioned factors into account it appears that adequate recording of the system boundaries established, the data age, fuel used and other factors including human labour incorporated in the analyses can will limit the use of obsolete data in most regions particularly where studies are rarely conducted. This could be attributed though to shortage of reliable data for conducting such analyses. Improving the data recording systems is one of the ways forward although this is a great challenge considering that most activities are conducted by the informal sector. One of the ways to achieve this is by devising ways for the small and medium enterprises working with the informal sector to enhance the recording of their activities. The use of locally compiled inventory data is recommended for EEA although the obtained results will depend on the technological advancement of a country or a region which determine other parameters such as the primary energy used in the analysis as well as the inventory methods employed (Menzies et al, 2007; Ortiz et al, 2009). Consequently, the results obtained using this approach need to be analysed thoroughly taking into consideration of these and several other factors highlighted already.

The other way forward is to develop models incorporating the basic processes that provide benchmarks for the associated environmental impacts based on data obtained at local level. However, if this is not enforced by policy makers, in the industry will lead to inaccurate estimations of energy quantities and their associated impacts. On the contrary, considering that the building industry relies on the use of informal sector often associated with lack of record keeping lack of reliable sources will continue to be a challenge in environmental assessment in the building sector using process and input-output related methods. Yet from another perspective, further improvement on the existing methods is that suit the local technological systems highly recommended. Bearing in mind of the limitations existing with the process and the economic inventory methods, and that there is little evidence on studies being conducted to enhance the availability of process data in sub Sahara Africa, the need for such studies cannot be overemphasised. It is anticipated that the PhD research underway results will play a major role in this respect by advancing a few developments already done in this area in the region and beyond. Although the process-based analysis method employed suffers severe limitations highlighted earlier on, the study contributes information and data required for further developments in this area of study.

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