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Strategies for Simultaneous Embodied Energy and Operational Energy Reductions in Buildings during the Design Stage

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Abstract. With the global energy consumption reaching unsustainable levels, the need for regulating energy consumptions has been emphasised. Hence a variety of methods are followed in different countries to minimise the impacts of embodied energy (EE) and operational energy (OE) in buildings. Considering either EE or OE in its individuality is not a pragmatic approach and it is important to consider means of reducing both EE and OE in parallel. The design stage was identified as the most suitable stage for integrating energy efficiency measures, since most crucial project decisions are taken at this stage. Although a multitude of research has been conducted on EE and OE individually, there seems a lack of research that focuses on both these aspects together. The extensive literature review was followed by 5 preliminary interviews with subject matter experts and then semi structured interviews with 12 experts were conducted. It was revealed that determining strategies for achieving simultaneous EE and OE reduction is difficult. The identified strategies to be implemented in the design stage were classified as material selection related, design approach related, building morphology related, procurement process related and other strategies, with a majority of strategies falling under the 'procurement process' category.

1. Introduction

The construction industry is a large, dynamic and multifaceted industry that encompasses developing new structures and engineering projects [1]. However, the positive impact of the construction industry on the socio-economic development is overshadowed by the industry's negative environmental impacts [2]. The contribution of the construction industry towards global green-house gas (GHG) emissions, resource depletion and overall pollution of the environment is monumental [3]. The building sector, which is a major subsector of the construction industry, consumes a staggering 48% of global energy production annually, during the stages of construction, operation, maintenance and deconstruction [4]. Moreover, the building sector is responsible for 1/3 of the global GHG emissions [5]. Implementing strategies to regulate building energy consumption would undoubtedly assist in managing the rapid increase of the global energy demand [6].

Energy consumption of buildings is found to be of two major forms as embodied energy (EE) and operational energy (OE) [7]. EE is the total quantity of non-renewable primary energy for direct and indirect processes involved in creation of a building, its maintenance as well as the end of life stages [8]. Alternatively, OE is construed as the energy required for preserving comfortable conditions within buildings and for their regular maintenance [9]. Even though the total energy consumption of modern



buildings in absolute terms have decreased as a result of the implementation of OE reduction measures, the percentage of EE has increased, necessitating a shift in focus towards EE reduction [10]. It is evident that the consideration of OE alone would not be sufficient to achieve energy efficient buildings and minimizing EE also needs to be factored, in the energy efficiency decision. Hence it is important to consider means of reducing both EE and OE in parallel [11] and this is a challenge faced by the construction industry at present [12]. The design stage is significant in any building project, since most crucial project decisions are taken at this stage [13]. Despite the significance of the design stage decisions being emphasized constantly in literature, the general practice is to consider sustainability assessments when the building designs are almost finalized and the potential for incorporating change is limited [14], which is highly non-productive. This paper therefore aims to determine potential strategies that could be implemented during the building design stage for achieving simultaneous EE and OE reductions.

2. Literature Review

Population growth, building services enhancement, rising comfort levels along with the increase in the time spent within buildings have increased life cycle energy consumption in buildings to substantial levels [15] and with accelerated urbanization which requires more built environments, building related emissions are expected to grow further in the future [16].

2.1. Life-cycle energy consumption of buildings

According to BS EN 15978:2011 (European Committee for Standardisation) (as cited in [17]), the building life cycle comprises of four main stages as product stage, construction process stage, use (operational stage) and the end of life stage. Buildings consume energy during these different life cycle stages, both directly and indirectly [18]. As stated by the authors, buildings consume energy directly for construction, operation, repair, maintenance and demolition and indirectly for the manufacturing of construction material and components.

The lifecycle energy consumption of buildings is of two main forms as EE and OE [7]. According to the authors, EE is defined as the energy utilized in manufacture and transport of materials, construction, repair and maintenance, demolition and end of life management of demolished materials. Alternatively, OE is defined as the primary energy demand for preserving comfortable conditions within the building and for regular building maintenance (i.e. the energy for HVAC systems, domestic hot water generation, lighting and for running electrical appliances) [9].

EE can be further divided into two main categories as initial EE (IEE) and recurring EE (REE). IEE refers to the primary energy consumed during both off-site and on-site building activities during the initial stages of developing and constructing a building, which includes extraction of raw materials, component manufacture, final assembly of products and transportation [8]. The authors further explained that REE refers to the primary energy consumed in maintenance and refurbishment of buildings over the entire life cycle. A further category, End of Life EE (EoL) has also been defined which refers to the primary energy demand required for the final disposal of the building [19].

2.2. Embodied Energy (EE) vs Operational Energy (OE)

As per the statistics of the World Business Council for Sustainable Development (WBCSD) (as cited in [20]), the ratio of the general energy consumption breakup of EE to OE of buildings is found to be 16:84 respectively. This shows that OE contributes to a major proportion of the building energy consumption when compared with EE. Therefore, it is the common practice to define energy efficient buildings in terms of the OE consumption. However, current research indicates the increasing significance of EE with the development of buildings that are highly efficient in-terms of OE consumption and the reason for this trend as the majority contribution of OE towards the total life cycle energy consumption of conventional buildings [21]. Furthermore, most research studies related to building energy efficiency have also mainly focused on OE aspects whereas only a limited number of studies have targeted the EE

aspects [22]. However, with the development of buildings that use highly energy efficient service systems and equipment, the OE demand has reduced significantly, thereby increasing the prominence of EE [23]. Robust evidence has proved that the EE impacts of buildings have become significant with the increased efficiency in OE consumption [24]. Accordingly, EE ranged between 2% and 38% of the total life cycle energy in conventional buildings, whereas for low energy buildings it was found to be in the range of 9% and 46% [18]. Similarly, EE accounted for approximately half of the total lifecycle energy of low-energy houses [25]. Furthermore, the impact of EE is expected to increase further over the next 50 years with the development of nearly zero energy buildings which are highly efficient in terms of the OE consumption [26].

These findings highlight the increasing prominence of EE, compared to OE. However, reducing both EE and OE simultaneously was found to be problematic. Reducing OE will generally be accompanied by an increase in the use of material, specifically those which are energy intensive in the building envelop and in technical installations [18]. The authors highlighted that this may result in a substitution effect where the resulting reduction of OE will, to a great extent be counter balanced by an increase in the associated EE, making it difficult to reduce EE and OE simultaneously. This disparity has been recognized by researchers, and the possibility of reducing both EE and OE in parallel is being considered.

2.3. Significance of the early design stage in achieving energy efficiency

Early design stage decisions can have a critical impact on the environmental performance of buildings [27] because the projects which are well planned, with sustainable criteria integrated during design, have a greater potential to reduce the negative environmental impacts [13]. Moreover, such projects are also benefited by reduced implementation costs as a result of the minimisation of late design changes. With energy consumption being a major criterion in the sustainability assessment of buildings, it is necessary to provide due consideration on reducing building energy consumption through design itself [28]. The early design stage therefore, seems to be the ideal instance to integrate energy efficiency measures into buildings.

3. Research Method

In order to pursue the aim, a qualitative research approach was adopted. Qualitative research enables researchers to gain an in depth understanding on new and emerging topics and is suitable for studies where the sample of respondents is limited [29]. Since the knowledge on developing energy efficient buildings among the Sri Lankan construction industry professionals is limited, drawing a large sample of interviewees was constrained.

Semi-structured interviews were selected, since it enabled the researcher to gather specific information that could be compared and at the same time allowed the researcher to remain flexible to gather any other important information that arose in the course of data collection [30]. The extensive literature review was followed by 5 preliminary interviews with subject matter experts from Sri Lanka and the potential avenues for achieving energy reduction through building design, identified in literature were classified in to 6 categories as material selection, design approach, internal building morphology, external building morphology, building services and procurement processes. The feedback from the preliminary interviews was used to model the interview guideline for the detailed survey and at the same time, refine the literature findings. Subsequently, 12 semi structured interviews were conducted as the detailed survey with construction industry professionals representing the disciplines of architecture, structural engineering, services engineering and quantity surveying as presented in Table 1.

Content analysis technique is commonly used for qualitative data analysis because it derives subjective interpretations of text data, through coding and identifying patterns [31]. Manual content analysis was used in this research to analyse the data collected through the interviews.

Table 1. Profile of the respondents of the detailed survey

Interviewee ID	Discipline	Designation	Experience
IP-1	Architecture	Chartered Architect	15 years
IP-2	Architecture	Chartered Architect & Town Planner	12 years
IP-3	Architecture	Chartered Architect	10 years
IP-4	Civil Engineering	Senior Professor	35 years
IP-5	Civil Engineering	Senior Professor & Consultant	15 years
IP-6	Civil Engineering	Senior Professor & Chairman	19 years
IP-7	Civil Engineering	Deputy Director	17 years
IP-8	Services Engineering	Manager-Facilities Management	14 years
IP-9	Services Engineering	Chief Executive Officer	23 years
IP-10	Services Engineering	Director	15 years
IP-11	Quantity Surveying	Project Quantity Surveyor	8 years
IP-12	Quantity Surveying	Project Quantity Surveyor	10 years

4. Research findings and discussion

The findings are presented under the following sub-sections.

4.1. Material selection related strategies

As expressed by the interviewees, the best way to optimally select material to minimize both EE and OE in parallel is to resort to a life cycle energy analysis approach in material selection. This is in line with the work of [4] where the life cycle analysis (LCA) was highlighted as the most suitable approach for material selection in the design of low energy buildings. Certain software such as the Eco-invent, which facilitates the comparison of life cycle energy demand of alternative building designs with different material combinations have also been developed [4]. Most of the commonly used OE reduction strategies such as the use of material with high thermal mass, use of glazing with improved thermal performance and use of insulation to insulate the building envelop results in an increase in the use of material which are high in EE. Despite the increase in EE, these strategies are still widely used. This is due to the significant OE savings that could be achieved during the building use phase by the implementation of these strategies. Such OE savings generally outweighs the associated increase of EE. The use of natural material such as clay bricks and rammed-earth bricks which has less process requirements and are sourced locally, was also found to provide more comfortable internal environmental conditions within buildings, especially under tropical climatic conditions. Materials being locally sourced and having less process requirements reduces the EE. Similarly, the provision of better internal environmental conditions reduces the energy required to condition the internal spaces thus reducing the OE demand as well, thereby providing simultaneous EE and OE reductions. However certain limitations in applicability was identified since the potential for OE reduction depends upon the climatic conditions, temperature, humidity levels of the area in which the building is located. Therefore, this strategy is not universally applicable and due consideration needs to be given to these limitations prior to its implementation.

4.2. Design approach related strategies

Literature identified the reuse of existing building structures as an EE reduction strategy since it conserves already expended EE. But the reuse of existing building structures was found to have a negative impact on the OE, since these structures are not optimized to meet the requirements of the intended new use and also due to leakages and infiltration losses caused by weakened structural integrity and poor lighting and ventilation conditions. Past researchers also highlighted the need to balance EE

and OE in the reuse of existing buildings, especially focusing on adaptive reuse [32]. Nevertheless, the research findings revealed that the reuse of existing building structures coupled with energy retrofit measures could reduce both EE and OE simultaneously. As stated by the interviewees, with modern technology, existing buildings can be brought to a good level of operational efficiency through energy retrofit measures. For example thermal imaging can be used to identify the areas in the building envelop through which a major proportion of heating/cooling energy is dissipated to the external environment, so that such areas can be well insulated to minimize the energy loss. It is important to note that retrofitting increases EE and therefore a balance should be struck between additional EE expended in retrofitting and the EE conserved through the use of existing building structures. Development of flexible and adaptable building designs with provisions for future extensions was also recognized as an avenue for achieving simultaneous EE and OE reductions through the interviews. Buildings designed with flexibility and adaptability in mind can be changed easily to meet changing requirements and the refurbishment can be accomplished with minimum use of resources, thereby achieving EE savings. Furthermore, since the building is done with provisions for extension, the building can be expanded as and when the operational capacity increases so that the need for the building to operate in full swing from the initial stages, even when occupancy levels are low is avoided. This facilitates the reduction of OE. This strategy was highlighted by the interviewees to be especially applicable for buildings such as universities and schools where occupancy levels are expected to increase over time.

4.3. Building morphology related strategies

Majority of the interviewees were of the opinion that most OE reduction strategies associated with building morphology results in an increase of EE. Strategies such as the introduction of shading, use of double skinned curtain walls and integration of green roofs and facades, all required additional resources and therefore resulted in increased EE. However, these measures are still used due to the OE savings provided over the additional EE expended, as in the case of the selection of high EE material for insulation. However, the use of passive design measures that facilitates natural lighting and ventilation was identified by the interviewees as a potential strategy for achieving simultaneous EE and OE reduction. By avoiding the need for artificial service systems, EE associated with supply and installation of artificial service systems is avoided and at the same time the energy expended to operate these systems is also conserved. But it should be noted that the level of congestion and level of pollution in the locality around the building would act as limiting factors for the use of natural lighting and ventilation. Moreover, reducing the floor-to-floor height was identified by the interviewees to provide OE savings in air conditioned buildings, since it reduces the volume of air to be conditioned. While reducing the OE, reducing the floor-to-floor height reduces the resource consumption as well which in-turn also reduces EE. However, it should be emphasized that such changes in the floor-to-floor height may impact the possibility of adapting the building for alternative uses in the future.

4.4. Building services related strategies

OE was identified to be of greater significance in building services than EE. The interviewees expressed that data regarding the EE of building services is very limited and therefore is not given much consideration. According to the interviewees, in selecting service equipment with improved OE efficiency, EE could also be calculated in parallel. However, since the calculation is tedious and complex, it is not practiced generally. It should be noted that no significant strategies were identified that could reduce both EE and OE associated with building services simultaneously.

4.5. Procurement process related strategies

The use of collaborative contractual arrangements was the most highlighted procurement process related strategy for simultaneous EE and OE reduction. However, according to the interviewees the current level of implementation of collaboration is not at a satisfactory level when considering the Sri Lankan context. As further explained by the interviewees, the application of latest technologies such as Building Information Modelling (BIM) which facilitates collaboration is at a very primitive level due to the lack

of technology and the additional investment required for such initiatives. With governments being a major client of the construction sector, importance of the adoption of procurement guidelines such as the Sustainable Public Procurement (SPP) guidelines was highlighted. The need for including energy efficiency benchmarks in these guidelines was expressed. Sri Lanka is also in the process of moving towards sustainable procurement especially in the public sector, with the development of the Green Public Procurement guidelines. While shifting public sector procurement towards green concepts, the interviewees pressed on the importance of encouraging green procurement in the private sector as well. The need to shift procurement from the lowest initial cost approach to a life cycle cost (LCC) approach was also reiterated by the interviewees, to achieve more energy efficient buildings with balanced EE and OE requirements. Basing procurement decisions on the initial cost alone may provide invalid outcomes. For example, an air-conditioning system with low initial cost might consume more energy in operation, resulting in higher life cycle costs. Reliance on the initial cost alone therefore seems to provide an inaccurate assessment of the potential alternatives. The need for specification of energy efficiency requirements to be met by the contractors/suppliers in the procurement documents for contractor/supplier selection was also underlined by the interviewees.

4.6. Other strategies

Apart from the specific strategies discussed under the areas mentioned above, common strategies for EE and OE reduction that can be applied across all the above areas were also identified. A majority of the interviewees identified the need for professionals involved in building design to follow building design guidelines on energy efficiency. Guidelines developed for international green rating systems such as LEED, BREEAM, Green Mark etc. could be followed since they provide valuable guidance in terms of energy benchmarks and avenues for energy reduction, to design buildings with low EE and OE. Further, the importance for 'energy efficiency' concepts to be adopted from early design stages was expressed. Delaying the adoption of energy efficiency concepts reduces the flexibility to integrate energy efficiency measures, making it difficult to harness the full benefit of moving towards energy efficiency.

4.7. Potential for simultaneous EE and OE reduction

The literature review highlighted that it is difficult to achieve simultaneous reductions in both EE and OE. However, the need for achieving parallel EE and OE reductions was established [11] and was recognized as an immediate challenge to be met by the construction industry [12]. The need for addressing this challenge drove the research to identify strategies to reduce both EE and OE in parallel. Therefore, questions were included in the interview survey to capture strategies that could be used to achieve simultaneous EE and OE reductions, and the related findings were explained in the previous sub-sections. The findings shows that the potential to achieve simultaneous reductions in both EE and OE exists. Table 2 summarizes the research findings.

5. Discussion and Conclusions

Recent research conducted in the field of building energy efficiency expressed the necessity for determining means of reducing both EE and OE in parallel. Moreover, achieving such simultaneous EE and OE reductions was recognized as a challenge, which the construction industry is currently faced with. This drove the focus of this research on identifying common strategies that could be used for both EE and OE reduction. The common view of the interviewees was that determining strategies for achieving simultaneous EE and OE reduction is difficult. This is line with the findings from literature.

The interviewees identified certain strategies that can be implemented during the design stage, having the potential to reduce both EE and OE simultaneously. These strategies were classified under five categories as material selection related, design approach related, building morphology related, procurement process related and other strategies, with a majority of strategies falling under the 'procurement process' category. In an environment where the global energy demand is increasing rapidly, the application of the identified strategies in building design can go a long way in managing the energy demand associated with the building sector and it necessitates further research in this arena.

Table 2. Summary of strategies for achieving simultaneous EE and OE reductions.

Criteria	Strategies	Points to be considered
Material Selection	Construction with the use of natural material such as clay bricks and rammed earth	Material should ideally be sourced locally and factors such as the climatic condition, temperature and humidity levels in the area where the building is located needs to be considered
	Follow a life cycle energy analysis approach in material selection	Software packages providing life cycle energy analysis capability can be used to improve efficiency of the process
Design Approach	Reuse of existing buildings coupled with energy retrofit measures	EE expended in retrofitting should not outweigh the EE conserved through building reuse
	Development of flexible and adaptable designs with provisions for future extension	Especially applicable for buildings such as universities or schools where occupancy levels increases over time
Building Morphology	Passive design measures such as open areas to promote natural lighting and ventilation	Consider the level of congestion and level of pollution in the locality around the building
	Reduction of roof height in air conditioned buildings	
Procurement Process	Collaborative contractual arrangements	Consider the availability of access to BIM technologies and the added costs
	Novel procurement approaches such as BIM integrated procurement to determine alternative designs with increased energy efficiency	
	Adoption of procurement guidelines such as the SPP guidelines	
	Encouraging green procurement in the private sector	
	Shift procurement from the lowest initial cost approach to a LCC approach	
	Specification of energy efficiency requirements to be met by the contractors/suppliers in the procurement documents	
Other Strategies	Designers to follow design guidelines on energy efficiency	
	Adoption of energy efficiency concept from early design stages	

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