Comparison of Embodied Energy between a Conventional Building System and a Pre-cast Building System

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ABSTRACT: The environmental impact of a building construction varies with the selection of materials and technology of construction. The embodied energy of a building is a good indicator of these environmental impacts. The embodied energy of a building can represent up to 40% of life cycle energy use of residential buildings. In Sri Lanka, residential buildings serve as one third of the local construction sector. Precast concrete products are generally chosen for achieving sustainability in buildings since they incorporate holistic design, efficient use of material and minimize the construction waste and site disturbance. This paper presents a comparative analysis of embodied energy of a conventional in-situ building system and a precast building system: a case study for two identical buildings constructed in Kurunegala area, using the two building systems. The results of the analysis reveal that the embodied energy of the precast building system is 14% less than the conventional in-situ building system.

1. INTRODUCTON

Depending on the selection of materials and technology of construction, the energy consumption and environmental impact of a building can vary. New construction technologies and methodologies, such as precast wall panels, are considered as a sustainable alternative to the conventional building construction. (Omar, et al., 2013) Buildings represent about 40% of global energy and contribute about 33% of greenhouse gas emissions, both in developed and developing countries. (Devi L, et al., 2014) Increased population and commercial needs, demand for more and more buildings, each year. It results in a large consumption in material, energy, and natural resources resulting increased emission of greenhouse gases in to the atmosphere. Embodied energy can represent upto 40% of the total energy consumend by a residential building over its life cycle. Therefor it is a useful to compare the embodied energy of two the building systems, to identify the better system, in terms of reduced environmental impact.

Sri Lanka's residential buildings represent about one third of the construction sector, in terms of fixed capital formation. (CBSL, 2014) 92% of occupied housing units, of the country are collectively single storied or two storied, while 58% of the houses are constructed with brick walls and 33.8% are constructed with blocks, which are the major walling materials of permanent housing in Sri Lanka. (2012) According to Reddy (Reddy, et al., 2001), bricks, cement and steel are the major contributors to the energy cost of building construction. With the depletion and environmental restrictions on natural resources like clay, sand, metal and with the increasing cost of labour in Sri Lanka, the conventional housing systems are challenged with new alternative building systems.

The precast building system, studied under this research, consists of a precast pre-stressed concrete beam, column, and slab system, with wall panels constructed out of Expanded Polystyrene (EPS). The foundation of the house is generally constructed as the in-situ concrete isolated pad footings. The characteristics of those building elements in the precast system are listed down in Table 1. Timber framed glass windows, roof with cement fibre sheets, ceiling with recycled steel ceiling tiles and floors with ceramic tiles, will be the same as a conventional building.

This research paper is based on a comparison of total embodied energy, for construction using the conventional in-situ building system and the studied precast building system of a residential building with two stories located in Kurunegala area where the site is located about 110km away from Colombo.

Table 1: Characteristics of the Precast Building System

Building Item	Specific Characteristics
Structure	Precast pre-stressed beams (150mm×350mm) / columns (200mm×200mm)
Foundation	In-situ isolated pad footings with precast pre-stressed tie beams
Floors	Ground floor: 50mm G20 screed and 1st floor with precast pre-stressed slab panels (thick-ness 65mm×1m×4m)
Walls	Both interior and exterior walls out of EPS panels (100mm×600mm×2400mm)

2. EMBODIED ENERGY ANALYSIS

Energy use during the total life cycle of the building consists of embodied energy, energy used at operation and maintenance of the building, and demolition energy. Embodied energy is the energy consumed by processes associated with the total production of a building, from the acquisition of natural resources from processes including mining and manufacturing, through transport and other functions. (Reddy, et al., 2001) The importance of embodied energy is growing as a consequence of new regulations introduced to reduce the building energy consumption during the operation phase. (Initiative, 2009)

Embodied energy analysis of a building on several parameters. System boundary defines how much upstream or downstream processes are included in the scope of the study. Geographical location of the study is also important, because the climate conditions, material properties, transport distances and methods, and many other parameters can change depending on the location of study. Source, age and completeness of data and technology of the manufacturing process can also have an impact on the analysis. Another major factor which governs the final result of an embodied energy analysis is the method of embodied energy analysis. (Dixit, et al., 2010)

3. SCOPE OF STUDY

The total embodied energy analysis of the building includes energy consumed in the production process of raw material and energy needed for transportation at various stages of the production till they arrive to the construction site. Energy used in installation/assembling of products or at the construction stage is also included in the calculations since it provides a comprehensive comparison between the precast building system and the conventional building system. A house with identical architectural house plan, located at the same place (Kurunegala) is assumed for the two building systems. *(See Fig. 1 & 2)* This paper will present the embodied energy of the following 3 aspects of embodied energy.

1. Energy consumption at production of building materials *(E_p)*
2. Energy in transportation of building materials *(E_t)*
3. Energy at construction stage of the building *(E_c)*

There for total embodied energy *(EE_T)* may expressed by, $(EE_T) = (E_p) + (E_t) + (E_c)$.

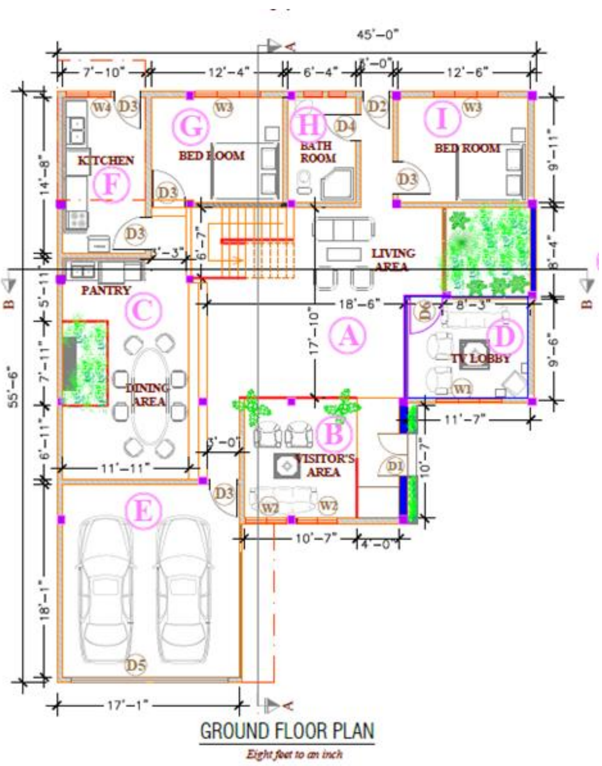

Fig. 1: Ground Floor Plan

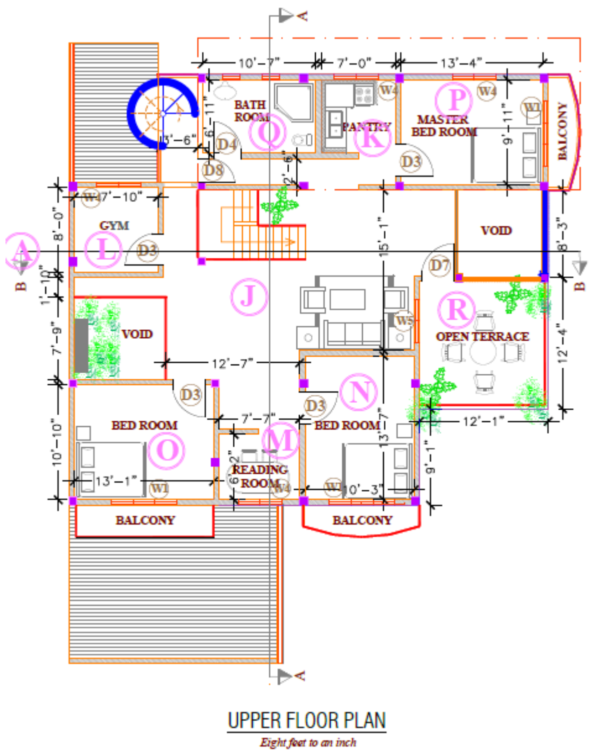

Fig. 2: Upper Floor Plan

4. METHODOLOGY

The Bill of Quantities (BOQ) and the architectural/structural drawing prepared for the building are taken as the basis for to obtain the quantities of materials. To calculate the embodied energy of these materials, three data sources were used, namely, Sri Lankan data (Jayasinghe), Indian data (Reddy, et al., 2001) (Jagadish, et al., 2003) (Biswas, 2014) and Inventory of Carbon and Energy (ICE) prepared by University of Bath (Hammond, et al., 2008). Due to the unavailability of information about the manufacturing procedure and energy spent on the manufacturing of products used in plumbing and wiring, most of the embodied energy is calculated considering only the particular material energy only. The embodied energy of electrical work and wiring of the house has been eliminated in the calculation because of non availability of details. Work studies and interviews with industry related people are used to calculate the energy spent in the construction stage of the building. Generally the equipment intensive activities are taken for the energy calculation since it is difficult to estimate the energy consumed as physical labour by humans at labour intensive activities. Fuel usage data for different vehicles used in plants and sites as well as general transport equipment were collected and used to estimate the fuel consumption during their operation stages and then those data was converted to energy.

4.1 *Energy consumption at production of building materials (Ep)*

The bill of quantities of the conventional in-situ house was used to obtain the amount of the building materials, required for each building component. Since the same house plan is used to estimate the quantity of embodied energy of the precast building system, several elements of bill of quantities remained the same such as excavation and earth work, ceiling, roof, floor finishes, waterproofing, etc. Material quantities of other structural elements such as beams, columns, slabs, and wall panel are estimated individually and embodied energy of each building element is calculated separately. Number of each elements required to construct the house is obtained according to the architectural drawings of the house. The embodied energy of some of the materials are given in the Table 2

The embodied energy of aggregates was estimated from a result of work-study related to production of aggregates in a crusher plant. Diesel fuel usage and electricity usage of the crusher plant was collected for a 6 month period and those data were converted to energy. For a one litre of diesel 45.71 MJ was considered and 1kWh of electricity was taken as 3.6MJ, for this study.

The precast element construction yard of this particular precast building system is located in Ekala area. So, the transportation energy of different materials in the precast yard has to be considered in calculating the embodied energy of final products. Precast concrete elements are manufactured with Grade 40 concrete and in current practice ready-mix concrete is used from a supplier's plant is located in Kurunegala area, which is within 75km from the precast yard. However the energy usage to manufacture expanded polystyrene (eps) wall panels is not based on any work-study but it was calculated based on literature. (Red) The manufacturer of these panels in Sri Lanka is yet to start the production of panels and with that more reliable value for the analysis can be obtained.

Table 2: Main construction materials and their energy density

Materials	Energy Intensities (MJ/kg)	Source
Aggregate	0.11	SL
River Sand	0.08	SL
Aluminium	155	ICE
Cement	4.9	SL (Namal, 2003)
Cement Motar	2.55	SL
Ceramic tiles	12	ICE
Sanitary products	20	ICE
Bricks	2.3	SL (Jayasinghe)
Wood	10.8	IND (Devi L, et al., 2014)
Plywood	15	ICE
Steel	35.1	IND (Devi L, et al., 2014)
Stainless steel	56.7	ICE
Brass	62	ICE
Asbestos	7.4	ICE
PVC	105	IND (Devi L, et al., 2014)
Glass	15	ICE
Paints	70	ICE
Putty	5.3	ICE
Primer	144	IND (Devi L, et al., 2014)
Lime	5.63	IND (Reddy, et al., 2001)
EPS	36	EU (Red)

4.2 *Energy in transportation of building materials (Et)*

As described above transportation of building materials may happen in different stages of manufacturing of products. At the production stage, transportation, energy usage at raw material extraction and in-plant transportation are included. The fuel consumption data and the transportation distances or waiting/idle times at different activities with those machinery related to this building construction were studied. In Table 4, energy consumption of several vehicles which are heavily used in construction site are given.

However, to estimate the energy at transportation the amount of material/equipment transported by the vehicle, and transportation distance alone will not be enough, since the vehicle is not loaded fully at each time. So, enough work-study was done to identify the details of the payload per trip, at different activity happen in constructing this building. For example, precast slab panels are transported in a 25 ton truck with only 10 slab panels per trip. The weight of the payload is approximately 6 tons, but fuel consumption is almost the same as 25 ton load.

Table 3: Energy consumption of some of the vehicles used in transportation [7]

Vehicle	Energy Consumption	Unit
25 Ton truck (while operating)	0.76	MJ/(t*km)
25 Ton truck (idle)	15.21	MJ/h
7.5 Ton truck	2.08	MJ/(t*km)
750kg mini truck	3.17	MJ/(t*km)
7 m^3 truck mixture	66.53	MJ/km
Container ship (MacKay, 2015)	0.054	MJ/(t*km)

4.3 *Energy at construction stage of the building (Ec)*

For a small scale construction like this, the energy usage at construction stage is minimal, since most of the work is labour intensive and machinery usage is minimized. At in-situ building construction, a concrete mixer is used and several electrical machinery- grinders, bar-cutters, arc-welding plant, and electrical drill are used. So, the quantification of energy for different activities were done along with the data from the work-studies, considering the time duration of each machinery in use and their wattage or fuel consumption.

5. RESULTS AND DISCUSSION

Using the process based embodied energy analysis of the conventional in-situ building system, it was found that 1195.19 GJ of energy is used for the completion of building construction. Table 4 shows the final results of the analysis at different stages/activities of the construction process. It is 3.67 GJ/m^2 for residential house construction. Previous studies conducted in several other countries have found embodied energy for a residential house is within the range of 3.6GJ/m^2 - 6.8GJ/m^2. (Dixit, et al., 2010) So the value obtained from this study is a reasonable value in a country like Sri Lanka, since human labour is extensively used in house construction which is not accounted for calculations.

Since the whole study was conducted as a process based embodied energy analysis, it is inevitable of having certain errors in the calculations. These calculations can be fine tuned if the analysis is conducted as a hybrid analysis, where data from the process based analysis is substituted with the input-output method, since it is difficult to achieve reliable and consistent information regarding complex upstream processes. (Lenzen, 2006)

Table 4: Embodied energy calculation for the conventional in-situ building

On site construction activity	Embodied Energy (GJ)
Excavation and earthwork	2.80
Total in-situ concrete	138.13
Total formwork items	91.44
Total Reinforcement	86.68
Masonry Works	184.81
Floor finishes with ceramic tiles	78.41
Wall finishes (plastering and painting)	280.36
Ceiling construction	128.93
Metal Work	5.63
Roof construction	39.78
Windows/ Doors	56.72
Plumbing & sanitary work	101.49
Total embodied energy of the house	1195.19

Table 5: Embodied energy calculation for the precast building system

On site construction activity	Embodied Energy (GJ)
Excavation and earthwork	2.80
Total in-situ concrete (10% from in-situ)	13.81
Total formwork items	0.50
Total Reinforcement (5% from in-situ)	4.31
Masonry Works	0.10
Floor finishes with ceramic tiles	78.41
Wall Finishes (painting 50% less)	116.14
Precast concrete elements	453.97
Ceiling construction	128.80
Metal Work	5.63
Roof construction	39.48
Windows/ Doors	49.65
Plumbing & sanitary work	101.49
Total embodied energy of the house	1022.95

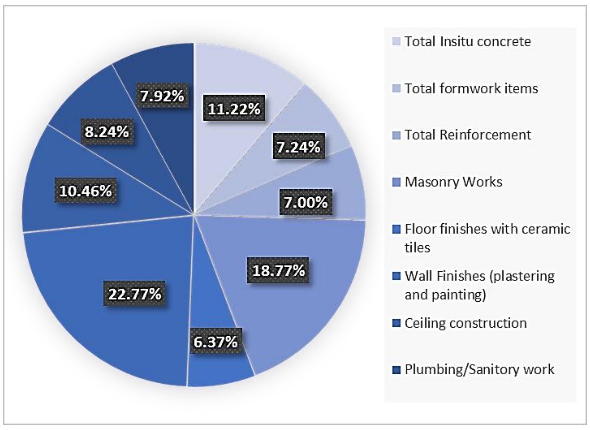

Fig. 3: Results of embodied energy analysis for conventional in-situ building

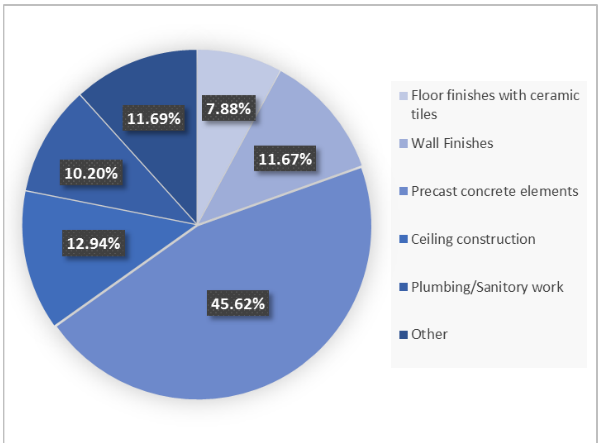

Fig. 4: Results of embodied energy analysis for precast building

The embodied energy analysis for the precast building system shows that the total embodied energy of the house after construction is 1022.95 GJ and it is about 3.15 GJ/m^2 of energy for the house. (Table 5) It is a reduction of 14% of embodied energy, compared to the conventional building system. Even though this is not a huge saving, in terms of energy, still an impressive figure since all precast elements should be transported 75km away from the manufacturing facility.

It was observed that the largest contributor for the embodied energy of conventional buililding suystem was the masonary works, which was 22.77% of the total embodied energy (see Fig. 3). The minimal usage of steel and concrete in this house, is the main factor for the propotion of embodied energy of masonary walls to increase. The precast building elements, in the precast building represented 45.62% of total embodied energy of the building. (see figure 4) Bigger transportation distances and usage of products with high embodied energy, like cement and steel has resulted in this. The largest reduction of embodied energy is the wall finishes, masonry work and formwork items.

6. CONCLUSIONS

Residential buildings represent a one third of the construction sector of Sri Lanka. There is enough opertunity for new alternative building systems at Sri Lanka, with the resource depletion and environmental restrictions of the country. This paper presents a comparative analysis of embodied energy of a conventional in-situ buililding system and a precast building system using process-based analysis. Energy consumption at production, transportation and construction stages were considered in the calculations. The results showed that the total embodied energy of the precast building system is 14% less than the conventional building. So it can be concluded that this particular precast building system can be a sustainable alternative to the conventional in-situ building system. But it should be noted that the transportation energy of precast products represents a reasonable amount of total energy and this study is based on a construction site within 75km of the manufacturing yard of precast products. The results can be fine tuned with more accurate work measurements and with the aid of softwares like GaBi and SimaPro.

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