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# Embodied Energy Analysis of a Pre-cast Building System

**D.M.K.W. Dissanayake[1*] and C. Jayasinghe[2]**

[1]Research Assistant, University of Moratuwa, Moratuwa, Sri Lanka
[2]Professor, University of Moratuwa, Moratuwa, Sri Lanka
*E-Mail: kasurikad@gmail.com, TP: +94717600489

**Abstract:** The embodied energy of a building can represent up to 40% of life cycle energy use of residential buildings. Residential buildings in Sri Lanka serve as one third of the local construction sector. However, extraction materials which are extensively used in building construction in Sri Lanka are being limited by the environmental regulations and depletion of resources. 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 at the same location using the two building systems. The results of the analysis reveal that the embodied energy of the precast building system is 19% less than the conventional in-situ building system.

**Keywords:** Building Materials, Embodied Energy, Expanded Polystyrene, Pre-cast Building

## 1. Introduction

Buildings consume more than 40% of global energy and contributes about 33% of greenhouse gas emissions, both in developed and developing countries. [1] The ever increasing population and commercial needs, demands for more and more buildings, each year and it results in a large consumption in material, energy and natural resources. In European building sector, residential buildings represent about 63% of total energy consumption and 77% of total CO2 emissions. [2] In the UK, residential buildings accounts for around 30% of the total final energy use of the country and responsible for more than 25% of CO2 emission. [2] And upto 40% of the energy consumend by a residential building over its life cycle will be represented by the embodied energy.

Sri Lanka’s residential buildings represent about one third of the construction sector, in terms of fixed capital formation. [3] 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. [4] According to Reddy [5], 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, stones and with the increasing cost of labour in Sri Lanka, the conventional housing systems are challenged with new alternative building systems.

Precast concrete products have become a natural choice of achieving sustainability in buildings since they incorporate holistic design, efficient use of material and minimize the construction waste and site disturbance. The system which is 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.

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 Kandana area.

## 2. Embodied Energy Analysis

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. [5] The importance of embodied energy is growing as a consequence of new regulations introduced to reduce the building consumption during the operation phase. [6]

Embodied energy analysis of a building or any product depends 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 of data, age of data 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. There are three widely used methods of energy analysis, which can assess how much energy is used for a certain activity. [7]

Table 1: Characteristics of the Precast Building System

| Building System | 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 (thickness 65mm×1m×4m) |
| Walls | Both interior and exterior walls out of EPS panels (100mm×600mm×2400mm) |
| Windows | Timber flamed single glass windows |
| Doors | Timber and plastic (PVC) |
| Roof | Timber truss and asbestos sheets |
| Ceiling | Steel grid, 68% recycled content ceiling tiles (600mm×600mm) |
| Flooring | Ceramic Tiles |

### 2.1 Process-based Analysis

Process-based analysis is one of the most widely used methods for the embodied energy analysis. Final production process of the building material is taken into account first, considering all possible direct energy inputs or sequestered energy of each contributing material. Then it works backwards as the energy of each contributing material or energy input needs to be ascertained. [7] It is like obtaining energy figures for each material.

Process based energy analysis has its own limitations because of the exclusion of many upstream processes as a result of truncation of system boundaries. The reason for this is the enormous efforts required to identify and quantify each small energy and product input of the complex upstream process. It is said that the magnitude of system incompleteness and error in process analysis is estimated to be as high as 50 percent and 10 percent respectively.

### 2.3 Input-Output Analysis

Input/output-based analysis can be considered as relatively complete, since it can account for most direct and indirect energy inputs in the process of production of building materials. The economic data of money flow among various sectors of industry are used, in the form of input/output tables which are made available by the national government, thereby transcribing economic flows into energy flows by applying average energy tariffs. The Embodied Energy is calculated by multiplying the cost of the product by the energy intensity of that product expressed in MJ or GJ/$1000 and dividing it by $1000[7]

It can capture that every dollar transaction, and hence every energy transaction, across the entire national economy. But the assumptions of homogeneity and propotionality across the economic sector, errors and uncertainty of economic data can make this analysis unreliable.

### 2.3 Hybrid Analysis

A hybrid analysis attempts to incorporate the most useful features of input-output analysis and process analysis by eliminating the fundermental errors. It starts with the readily available data for a process analysis. Sometimes it can go one stage more in the upstream where those energy data are usually the direct energy inputs of the final production stage and possibly the materials acquisition stages immediately upstream of that final stage. Then these values are substituted with the input-output method when it is difficult to achieve reliable and consistent information regarding complex upstream processes. [7]

Considering the availability of resources and availability of data in the Sri Lankan construction industry, process based embodied energy analysis is used in this research study.

## 3. Scope of study

Same location of the house with identical architectural house plans is assumed for the two building systems. *(Figure 1 & 2)* 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. So, 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,

$$(EE_T) = (E_p)+ (E_t)+ (E_c) \quad (1)$$

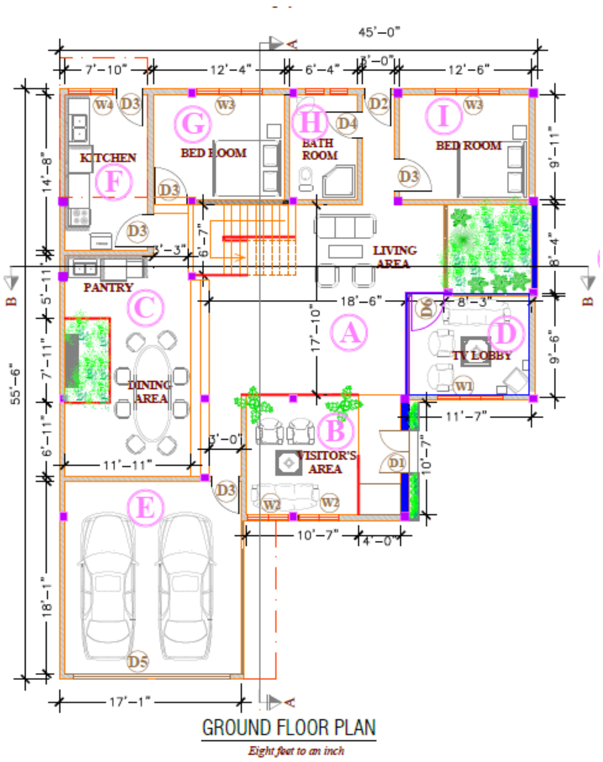


Figure 1: Ground floor plan

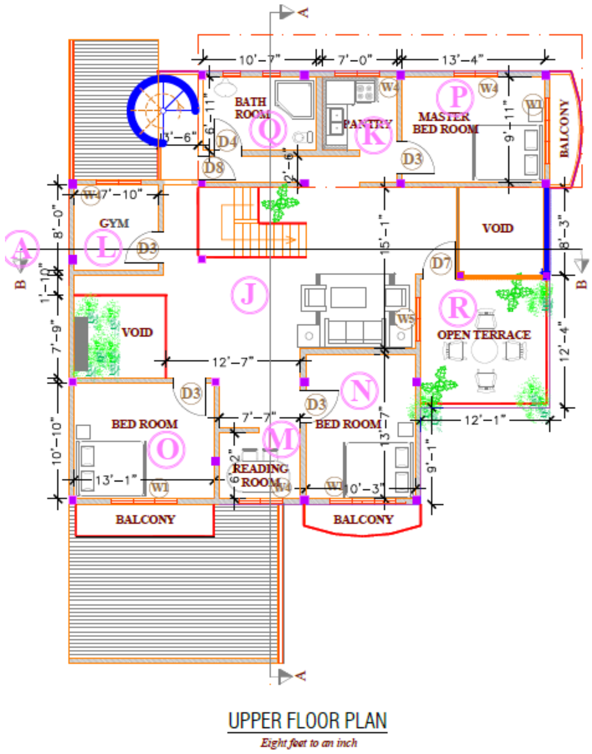


Figure 2: Upper floor plan

## 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 [8], Indian data [5] [9] [10] and Inventory of Carbon and Energy (ICE) which is prepared by University of Bath [11]. Due to 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 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 of different vehicles used in plants and sites as well as general transport equipment were collected and used to estimate the fuel consumption in transportation and then those data was converted to energy.

## 5. 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 remain 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

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 [12] |
| Cement Motar | 2.55 | SL |
| Ceramic tiles | 12 | ICE |
| Sanitary products | 20 | ICE |
| Bricks | 2.3 | SL [8] |
| Wood | 10.8 | IND [1] |
| Plywood | 15 | ICE |
| Steel | 35.1 | IND [1] |
| Stainless steel | 56.7 | ICE |
| Brass | 62 | ICE |
| Asbestos | 7.4 | ICE |
| PVC | 105 | IND [1] |
| Glass | 15 | ICE |
| Paints | 70 | ICE |
| Putty | 5.3 | ICE |
| Primer | 144 | IND [1] |
| Lime | 5.63 | IND [5] |
| EPS | 36 | EU [13] |

*SL: Sri Lanka, IND: India, ICE: Inventory of Carbon & Energy V1.6a*

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 where the supplier's plant is located in Kandana area, which is within 50km from the precast yard. Building materials which are used predominantly are given here with the transportation distances to the construction yard/ building site in the table 3. 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. [13] 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 3: Transportation distances of several construction materials

| Material | Transportation Distance (km) | | |
|---|---|---|---|
| | to construction site | to redimix plant | to precast yard |
| Cement | 200 | 200 | 180 |
| Sand | 100 | 100 | 100 |
| Aggregate | 50 | 50 | 50 |
| Steel | 30 | - | 50 |
| EPS | - | - | 30 |
| Fly ash | - | 200 | 200 |
| Bricks | 40 | - | - |
| Plywood | 130 | - | - |
| Wood | 100 | - | - |

## 6. 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 4: 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 [14] | 0.054 | MJ/(t*km) |

## 7. Energy at construction stage of the building (Ec)

For a small scale construction like this, the energy usage at construction stage is minimized, since most of the work is labour intensive and machinery usage is minimized. At in-situ building construction, a concrete mixture is used and several electrical machinery is in used like grinders, bar-cutters, arc-welding plant, and electrical drill. 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 are in use and its wattage or fuel consumption.

## 8. Results and discussion

Using the process based embodied energy analysis of the conventional in-situ building system, it was found that 1231.34 GJ of energy is used for the completion of building construction. Table 5 shows the final results of the analysis at different stages/activities of the construction process. It is 3.8 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/$m^2$. [7] 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 invertible 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. [15]

Table 5: 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 | 89.20 |
| Total Reinforcement | 86.25 |
| Masonry Works | 231.13 |
| Floor finishes with ceramic tiles | 78.41 |
| Wall finishes (plastering and painting) | 280.36 |
| 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 | 1231.34 |

Calculated embodied energy values for different precast elements are given in the table 6. The embodied energy analysis for the precast building system shows that the total embodied energy of the house after construction is 995.1 GJ and it is about 3.06 GJ/$m^2$ of energy for the house. (Table 7) It is a reduction of 19% of embodied energy, compared to the conventional building system.

Table 6: Embodied energy results for precast elements in the alternative building system

| Building element | EE per item | Unit | No of units | Weight | EE (GJ) |
|---|---|---|---|---|---|
| columns | 2166 | MJ | 41 | 11808 | 89.19 |
| beams | 543.25 | MJ/m | 92 | 11592 | 50.36 |
| slabs | 2480 | MJ | 48 | 29491.2 | 120.56 |
| EPS panels | 420.8333 | MJ/$m^2$ | 433 | 38104 | 182.98 |
| Screed | 1828 | MJ/$m^3$ | 5.85 | 14040 | 10.88 |
| Total embodied energy for precast elements | | | | | 453.97 |

Table 7: 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 | 995.10 |

## 9. Conclusions

Residential buildings represent a reasonable proportion of the construction sector. Resource depletion and environmental restrictions provide strong case for new alternative building systems over conventional buildings. 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 has been used for the study. Energy consumption at production, transportation and construction stages were considered in the calculations. The results showed that total embodied energy of the precast building system (3.06 GJ/$m^2$) is 19% less than the conventional building (3.8 GJ/$m^2$). So it can be concluded that the studied precast building system is a more sustainable alternative to the residential house construction than a conventional building system.

Further studies on the production process of EPS wall panels and construction stage the energy usage of the building will help to improve the accuracy of the results. The ongoing research is seeking to optimize the section sizes and strength properties of EPS panels, which will help to further reduce the embodied energy as well as the cost of the precast building system.


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