Embodied Energy and Carbon IV Oxide Emission Analyses of Sandcrete Blocks and Compressed Earth Bricks Houses

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Abstract - *This study analyzes the Embodied Energy (EE) and Carbon IV Oxide (CO_2) emission of Sandcrete Blocks (SCB) and Compressed Earth Bricks (CEB) houses. Energy and CO_2 are emitted in the process of manufacture, transportation and construction of buildings materials. These energies and carbon dioxide are embodied in the materials. Thus, an exploratory research method was used to assess the EE and CO_2 emission impacts of building materials for the two types of houses in Nigeria. A detailed inventory analysis approach was used with EE and CO_2 emission factors obtained from Inventory of Carbon and Energy (ICE) database. The findings revealed the EE and CO_2 emission for the CEB are 436,343.49MJ (2,288.59 MJ/m^2) and 30,821.09 KgCO$_2$ (161.65 KgCO$_2$/m^2) while for the SCB house are 632,298.58 MJ (3,316.37 MJ/m^2) and 52,897.82 KgCO$_2$ (277.45 KgCO$_2$/m^2) respectively. Thus, the SCB house expends 30.99% more EE and emits 41.73% more embodied CO_2 than CEB. The comparison revealed that the CEB house is more sustainable and environmentally friendly in terms of EE and CO_2 emission than the SCB house. Also these findings indicate the importance of considering EE and CO_2 emissions impacts of various materials before using them in constructions.*

Keywords - Compressed earth brick; CO_2 emissions; Embodied energy; House; Sandcrete block.

1 INTRODUCTION

GLOBALLY buildings are responsible for a huge share of energy, water and materials consumption. In the construction industry, it has been established that 40% of CO_2 emission is from activities associated with buildings [1]. These activities include extraction of raw materials, processing the raw materials, manufacture of the building material, transportation to site and construction of the buildings. The EE and CO_2 emissions from the building materials make up an important share of the total life cycle energy and CO_2 emission of the building [2]. This is often ignored when only the energy efficiency of running the building (operational energy) is considered. Moreover, EE and CO_2 emissions are currently the two main parameters commonly used in assessing the importance of building materials [3]. The European Union (EU) Construction Products Directive recommended embodied energy as a key factor in the selection of building materials or construction products [4].

This paper analyzed the EE and CO_2 emission of SCB and CEB houses. The study used same building plan for the two different most common houses in Nigeria with equal area, features and fenestration in order to show the impact of material choice on the EE and CO_2 emission of the houses.

2 EMBODIED ENERGY AND CO_2 EMISSION

EMBODIED energy of a building is the energy consumed by all of the processes associated with the production of the building, from the mining and processing of natural resources to manufacturing, transport and product delivery. On the other hand manufacturing sector CO_2 emissions can be characterized as direct or indirect. The former are released as a result of activities directly related to manufacturing and construction processes on site. The latter are associated with the use of energy in construction-related activities [5]. Materials that have a lower embodied energy are more sustainable than those with a higher embodied energy.

Various approaches to measure EE and CO_2 emission employ different system boundaries and collect data from different sources, which could result in significantly different values of EE for the same product [6]. Basically there are four methods of measuring EE: process analysis, input-output analysis, hybrid analysis and inventory analysis. This study is based on inventory method of analysis.

Inventory analysis method involves the use of database containing EE and CO_2 values for common building materials. The data for the inventory were extracted from peer reviewed literatures on the basis of a defined methodology and criteria. It is considered that the strict criteria used in the selection of source material for the creation of the database serve to significantly increase its accuracy and relevancy [7]. This method provides results with greater accuracy, and because of its flexibility, it is considered the most suitable method for analysis of heterogeneous materials such as building. The use of emission factors reduces the tedious tasks that would have involved chemical equations. This is because emission factors are expressed as quantity of embodied energy or CO_2 per functional unit. This is modelled mathematically as in equations (1) and (2).

$$EE_k = \sum_{k=1}^{n} (1 + \zeta_k) * Q_k * I_k \qquad \dots \ (1)$$

$$EC_k = \sum_{k=1}^{n} (1 + \zeta_k) * Q_k * I_k \qquad \dots \ (2)$$

Where: EE_k and EC_k are embodied energy and embodied CO_2 of material type *k* with units MJ and $KgCO_2$ respectively;

ζ_k is the waste factor (dimensionless) of material type k;

I_k is the embodied energy factor or embodied CO_2 factor with unit MJ/functional unit and $KgCO_2$/ functional unit of material respectively.

METHODOLOGY

TO allow for clear comparison, same plan and specifications were used for both buildings. The plan size is 14775 x 12900 mm, which occupies 190.66 m^2 of land as shown in Figure 1. The plan containing 3 bedrooms, 1 living room, 1 kitchen, 1 dinning, 3 toilets, and a car porch. The materials used for the construction of the two houses are: aluminium, blocks, bricks, cement, glass, paint, laterite, plaster clay, steel, concrete, tiles and timber. The only variation in the two houses is the choice of block or brick materials. The 3-D views of the SCB and the CEB building were presented in Figures 2 and 3.

In general, the mass, Q, of any substance is related to the Volume V through the formula: Q = ϱV, where ϱ is the material density; Volume (V) = Length (L) × Width (W) x Thickness (T) of the material. The calculations of quantity of materials are shown in Table 1. Equations 1 & 2 were used to compute the EE and CO_2 emissions of the building materials. The results obtained are presented in Tables 2 for SCB and CEB houses respectively.

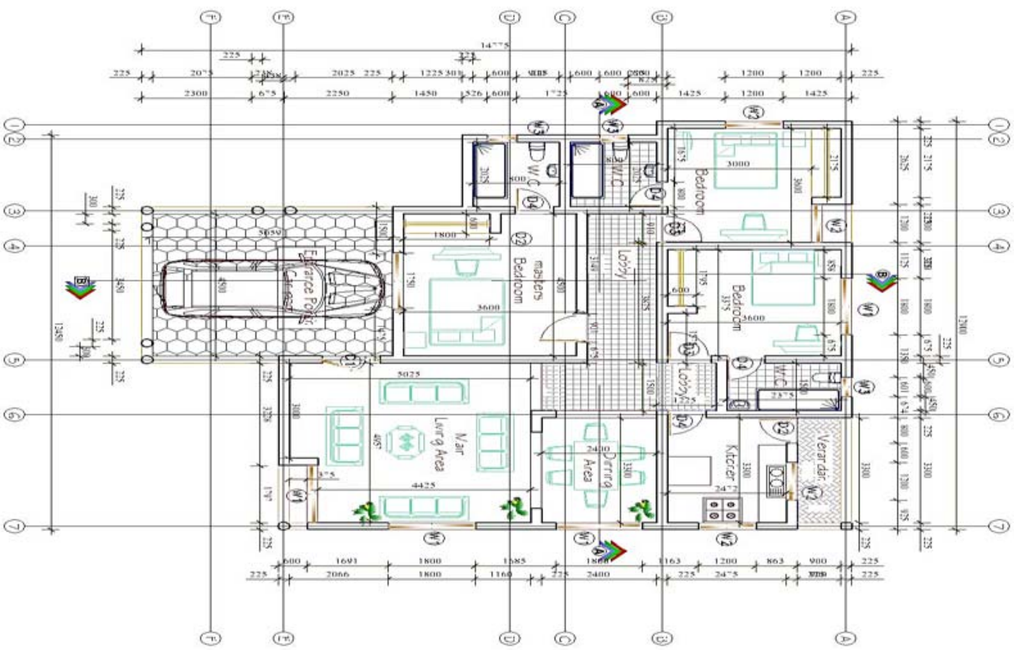

Figure 1: Plan for both the SCB and CEB houses

Figure 2: 3-D view of the SCB house

Figure 3: 3-D view of the CEB house

Table 1: Quantity of Materials for CEB and SCB houses

Member	Volume Calculations	CEB house	SCB house
Beam	Volume of concrete = (L x b x t) = 54.550m x 0.225m x 0.225m	2.762 m^3	2.762 m^3
Column	volume of concrete = Area of circular column x length of column + Area of rectangular column x length of column = 7(0.070695 m^2 x 4.4m) + (0.225 m x 0.225 m x 4.4 m) = 2.177 m^3 + 0.22275	2.399 m^3	2.399 m^3
Floor	volume of concrete = Area of floor slab x thickness of floor slab = 155.05 m^2 x 0.15 m	23.26 m^3	23.26 m^3
Brick wall	volume of brick wall = Area of brick wall x thickness of brick wall = 29.400 m^2 x 0.225 m	6.615 m^3	-
Block wall	volume of block wall = Area of block wall x thickness of block wall = 337 m^2 x 0.225 m	-	75.825 m^3
Tiles	volume of tiles = Area of tiles x thickness of tiles = 100 m^2 x 0.008 m	0.8 m^3	0.8 m^3
Glass	volume of glass = Area of glass x thickness of glass = 22.66 m^2 x 0.004 m	0.09064m^3	0.09064 m^3
Paint	volume of paint = Internal wall + External wall x 2 = 178.5 m^2 + 158 m^2 = 337 m^2 x 1 m x 2	-	674 m^3
Plaster	volume of plaster = Area of plaster x thickness of plaster = 674 m^2 x 0.025m	-	16.85 m^3
Laterite	volume of laterite = Total area of laterite filling x thickness of laterite = 102.01 m^2 x 0.15 m	15.30 m^3	15.30 m^3
Steel	steel door = (L x b x t) = (2.1 m x 0.9 m x 0.003 m) x 2	0.01134m^3	0.01134 m^3
Hardcore	volume = Total area of hard core filling x thickness of hard core = 102.01 m^2 x 0.15 m	15.30 m^3	15.30 m^3
Rafter	volume of rafter = volume of wall plates + tie beam + king post + struts + rafter + purlins + noggins = 4.28 + 8.06 + 4.54 + 13.22 + 7.21 + 4.86 + 5.74	47.91 m^3	47.91 m^3
Ceiling	volume of ceiling = Area x thickness = 100 m^2 x 0.004 m	0.4 m^3	0.4 m^3
Aluminium window	volume of window = Area x thickness = 22.66 m^2 x 0.00045 m = 0.010197 m^3	0.010197m^3	0.010197 m^3
Aluminium roofing sheet	volume of roofing sheet = Area of roofing x thickness of aluminium = 363.8 m^2 x 0.00045 m = 0.1638 m^3.	0.1638 m^3.	0.1638 m^3.

3 RESULTS AND DISCUSSION

TABLE 2 shows the results of EE and CO_2 emission of the two houses. The Embodied energy for the SCB and CEB houses are 632,298.58 MJ (3,316.37 MJ/m^2) and 436,343.49 MJ (2,288.59 MJ/m^2) respectively. Also, CO_2 emissions for SCB and CEB houses are 52897.82 $KgCO_2$ (277.45 $KgCO_2/m^2$) and 30,821.09 $KgCO_2$ (161.65 $KgCO_2/m^2$) respectively. The results for the two houses are presented on a bar graph shown in Figure 5. The results showed that the SCB house has higher EE and CO_2 emission than the CEB house.

Percentage Difference in EE of the two houses is:

$$\frac{[illegible]}{[illegible]} \times 100 = \frac{[illegible]}{[illegible]} \times 100 = 30.99\%$$

Percentage Difference in embodied CO_2 emission of the two houses is:

$$\frac{[illegible]}{[illegible]} \times 100 = \frac{[illegible]}{[illegible]} \times 100 = 41.73\%$$

Hence, the SCB house expends at least 30.99% more embodied energy and emits at least 41.73% more embodied CO_2 than CEB house. This study agrees with the findings of Abanda *et al.* [8] who conducted similar research on EE and CO_2 analyses of mud-brick and cement-block houses in Cameroon, they reported that the cement- block house has more EE and CO_2 emission impact than the mud- brick house.

As described by Abanda *et al*. [8] embodied energy and CO_2 are important factors, but it is also important to consider the effects of material choice on the energy requirements for cooling and heating over the life time of the building. Some studies have revealed embodied energy to be equivalent to a few years of operating energy [9], although cases in which embodied energy can be much higher have also been reported [10]. In particular, in most developing countries, embodied energy of most traditional buildings can be largely compared to operating energy [9]. What these discrepancies suggest is that a holistic approach should be undertaken where embodied energy and operational energy should be considered in assessing the energy use and environmental impacts of a building.

4 CONCLUSION

THIS study analyzed the EE and CO_2 emission of SCB and CEB houses. The study used same building plan for the two different most common houses in Nigeria with equal area, features and fenestration in order to determine the impact of material choice on the EE and CO_2 emission of the houses. The results revealed that the SCB house expends 30.99% more EE and emits 41.73% more embodied CO_2 than CEB. The comparison showed that SCB consumed more EE and emitted more CO_2 than CEB. Although these findings cannot be generalized, they nonetheless indicated the importance of considering embodied energy and CO_2 in making alternative choices for various building materials.

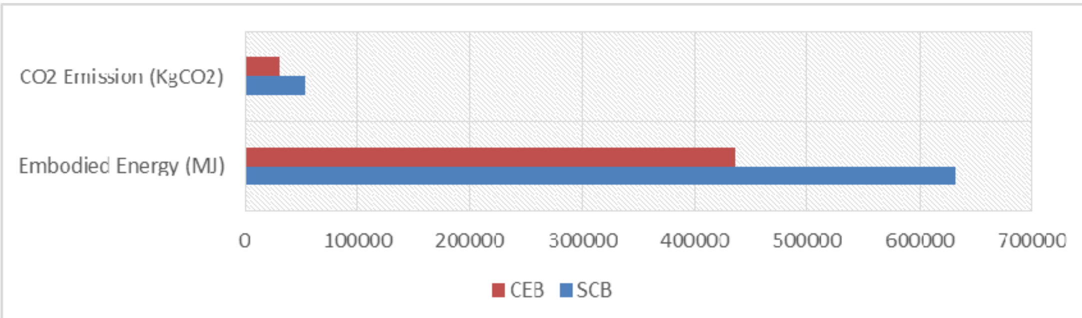

Figure 4: Comparison between the EE and CO_2 Emission of the SCB and CEB House

Table 2: Embodied energy and CO_2 Emission of SCB and CEB houses

Materials	Volume (m^3)	Density (kg/m^3)	Quantity (kg)	EE Intensity (MJ/Kg)	**CO_2** Emissions Intensity ($KgCO_2/Kg$)	Embodied Energy (MJ)		**CO_2** Emission ($KgCO_2$)	
						SCB	CEB	SCB	CEB
Beam	2.76 2	2400	6628.8	0.95	0.130	6297.36	6297.36	861.744	861.744
Reinforcement	-	-	393.02	8.80	0.42	3458.576	3458.576	165.0684	165.0684
Column	2.399	2400	5757.6	0.95	0.130	5469.72	5469.72	748.488	748.488
Floor	23.26	2400	55824	0.95	0.130	53032.8	53032.8	7257.12	7257.12
Block wall	75.825	1800	136.485	0.99	0.136	135120.15	-	18561.96	-
CEB wall	6.615	1920	12700.8	0.83	0.082	-	10541.66		1041.47
Tiles	0.8	1700	1360	9.00	0.59	12240	12240	802.4	802.4
Glass	0.09064	2580	233.8512	15.00	0.85	3507.768	3507.768	198.7735	198.7735
Paint (Double Coat)	674	-	-	20.4	1.06	13749.6	-	714.44	-
Plaster	16.85	1900	32015	1.80	0.12	57627	-	3841.8	-
Laterite Soil	15.00	2500	37500	0.45	0.023	16875	16875	862.5	862.5
Door (Steel)	0.01134	7800	88.452	31.50	2.51	2786.24	2786.238	222.01	222.01452
Hard Core	15.00	2880	43200	1.00	0.056	43200	43200	2419.2	2419.2
Rafter	47.91	540	25871.4	7.80	0.47	201796.92	201796.92	12159.56	12159.558
Ceiling	0.4	540	216	20.00	0.98	4320	4320	211.68	211.68
Window (Aluminum)	0.010197	2700	27.53	155	8.24	4267.15	4267.15	226.85	226.85
Roofing Sheet	0.1638	2700	442.26	155	8.24	68550.3	68550.3	3644.2224	3644.2224
Grand-Total						632298.58	436343.49	52897.82	30821.09

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