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Quantifying the Embodied Carbon of a Low Energy Alternative Method of Construction (AMC) House in Nigeria

Liman Alhaji Saba, Mohad Hamdan Ahmad*, Roshida Binti Abdul Majid

Department of Architecture, Faculty of Built Environment, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
b-hamdan@utm.my

CO_2 is a chemical compound in the process of climate change and the main cause of global warming. Efforts at arresting global warming, is to achieve the goal of carbon reduction or elimination. Greenhouse gases (GHGs) emissions are a global issue dominated by emission of CO_2. Residential buildings contribute to climate change through carbon emission to the environment in the building procurement process and utilization. The present study is aimed at allowing for required support to the decision-making process of residential building design and construction. To this goal, the study assesses the Embodied Carbon (EC) of Whole Process of Construction (WPC) for the building. Life Cycle Assessment (LCA) framework approach to a Low Income House (LIH) was adopted using process-based analysis method and Bath Inventory of Carbon and Energy (ICE). The findings reveal that the EC for the Alternative Method of Construction (AMC) stabilize clay block house is 16,175.67 kgCO_2 (234.43 kg/m^2). Even though, these findings cannot be generalized, but shows the significance of considering EC in making alternative choice for use in different building projects. Decarbonize schemes should be directed at the buildings' EC emissions. The best answer will be accomplished if the decarbonize attempts are aggregated with the prosperous and natural carbon sinks that exist in the context of this study.

1. Introduction

The period between 2015 and 2050 may be termed a transition period to zero carbon emissions in adopting the agreement at Conference of the Parties 21 (COP 21) at Paris, France (Sbci, 2009) for the built environment and buildings. The significance of building in climate change mitigation attempts was emphasized at the conference. Buildings contribute about 8.1 Gt of carbon dioxide (CO_2) to global ecosystem annually (Jennings et al., 2011). The high carbon dioxide emissions possess vast negative impacts on the global ecosystem. In 2014, at the International Union of Architects (IUA) Conference in Durban, South Africa, the architecture profession jointly followed 2050 as target year to achieve zero carbon emissions from buildings. The IUA declaration was anteceded by the initiating efforts of a no-profit company and nongovernmental, "Architecture 2030 Challenge" founded in 2002 to evoke action towards achieving zero-carbon and green buildings. Even though the greatest emissions share has been from developed countries but the greatest impacts load is on countries that are developing. Industrial flue gas emissions include CO_2, nitrogen oxides (NOx), hydrocarbons, carbon monoxide (CO), and sulphur dioxide (SO_2) Almost all of these emissions are greenhouse gases (GHGs) (Arocho et al., 2014). The emissions endanger human health, agricultural crops, forest species, various ecosystems and the overall environment as they enhance the greenhouse effect and contribute to global climate change (Afroz et al., 2003). There is need for both developed and developing countries to reduce the activities that add to climate change. The most important GHG is the carbon dioxide, which is the main chemical compound responsible for global warming and climate change. GHGs emissions contain approximately 77 % CO_2 (Khan et al., 2014). According to recent Intergovernmental Panel on Climate Change (IPCC) reports, the global mean concentration of CO_2 in the atmosphere is now close to 400 ppm; the most comprehensive research states that the safe level of CO_2 concentration is below 350 ppm (Wennersten et al., 2015).

This paper presents an assessment method that can both reduce and eliminate the environmental impact caused by CO_2 emissions and as well use that CO_2 to raise sustainability in construction of future generations.

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To achieve this goal, the following objectives have been set: to assess the embodied CO_2 of materials and assemblies used for alternative housing construction, to establish the baseline CO_2 emissions assumptions in buildings, and to relieve benchmark and afterward carbon mitigation targets. The paper provides an idea of admitting the cradle-to-gate, transportation and services emissions by using CO_2 as a raw material. It focuses on developing the idea and stimulating research on the assessment of CO_2 of materials and assemblies as a means to address the carbon reduction and elimination by including transportation and services emissions and enhance sustainability for the benefit of future generations.

2. Greenhouse gas emissions and energy consumption of buildings

The residential building climate change mitigation strategy was directed towards CO_2 reduction or riddance. CO_2 in buildings are principally dependent on the quantity and kind of energy depleted by buildings during the construction and utilization process. Particularly, residential buildings account for a big proportion of energy utilization and CO_2 emissions to our natural environment by building procurement and operation. This has been calculated at approximately 40 % global energy utilization, 60 % global electricity utilization and 30 % global GHG emissions that are connected to buildings (Ezema et al., 2016). For instance, approximately buildings account for 50 % of all extracted material resources (Union, 2014). It has been calculated that bettered processes as well as procedures in the building construction sector can attain up to 50 % minimization in the extracted materials utilization, 42 % minimization in energy utilization and 35 % minimization in GHG emissions (Ezema et al., 2016). The enhancing care from the developing countries has been reflected in their participation in some of international conferences like COP 15-Copenhagen in 2009; COP 17-Durban in 2011; and COP 18-Doha in 2012. An amount of GHGs is in the atmospheric system that aids to take up thermal radiation from the surface of the earth and then re-expels (gases or odors) the radiation back to the earth. The greenhouse effect is important as it traps energy and maintain the temperatures on earth suitable for living things. In the absence of this, the average temperature on planet would be lower and incapable of sustaining life. Excessive GHGs caused by building activity may cause the temperature of the plate to gain which will result in climate change. It is very significant to center on the CO_2 control and promote sustainable construction practice in all sectors.

Sustainability is defined as a way of meeting “the needs of the present generations without compromising the ability of future generations to meet their own needs” (Giovannoni and Fabietti, 2013). In order to achieve sustainability, the three elements of economy, equity and ecology must be considered (Awadallah et al., 2013). Sustainability concept is relevant to the environmental improvement and maintenance, economic and social resources with the objective of meeting the needs of present and future generations. Thus, regional resource inputs must be within the natural system regenerative capacities that generate them. The extraction of non-regional resources should be reduced, so that it does not exceeding the minimum strategic levels (Aziz et al., 2015). The rapid economic development in many countries has led to pollution and environmental deterioration worldwide. Therefore, a way needs to be found to ensure the survival of current and future generations. Among the important problems facing the environment is unreasonable GHGs production as well as air pollutants. The immediate past research has indicated that fossil fuel combustion in relating to or resulting from industry calculates for about 56 % of CO_2 emissions (Center, 2012). Figure 1 portrays the statistical relationship between CO_2 strengths in the atmosphere and the surface of the planet temperature. It can be figured that there exists a substantial gain in temperature of the planet and CO_2 emissions since 1850. It is believed that these emissions will continue to increase in the future due to industrial development and economic growth (Peters et al., 2012).

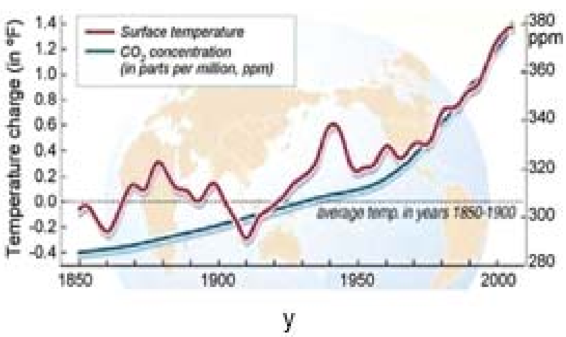

Figure 1: Statistical relationship between CO_2 strengths in the atmosphere and the temperature of the planet surface (Rahman et al., 2017).

The review of the available literature shows that most of the research to date has focused mainly on energy emissions of Conventional Method of Construction (CMC), whereas few studies discussed the AMC. Only a few studies have discussed the carbon from flue gas emissions. Among these few studies, Henry et al., 2014 focused on comparing CMC using cement block house and AMC using mud-brick block house, that centres on only cradle-to-gate emissions but without inclusion of transportation and services emissions. This paper provides an idea of admitting the cradle-to-gate, transportation and services emissions by using CO_2 as a raw material. It focused on developing the idea and stimulating research on the assessment of CO_2 of materials and assemblies as a means to address the carbon reduction and elimination by including transportation and services emissions and enhance sustainability for the benefit of future generations.

3. Methodology of assessment

The EC dissolution is directly linked with each life cycle stage of a building and varies by building types (Verbeeck and Hens, 2010). Even though consensus was lacking as to the dissimilar kinds of stages in a building construction life cycle, usually include, product stage; construction stage; use stage and lastly end-of-life stage are rather common and encompass most other life cycle categorizations (Blengini and Di Carlo, 2010). The most utilized method is the LCA which looks at the life cycle of the building (Blengini and Di Carlo, 2010). In this particular study, the evaluation methodology used complies with the European Standard, which has been used as portion of the British Standard for assessing building projects environmental impacts (Moncaster and Symons, 2013). The chosen case study was the existing Low Income House (LIH) building in Abuja of Nigeria. The building selected had a floor area of 69 m^2, with average headroom of 3.0 m. The graphical drawing of the outlines of the prototype as indicated in Figures 2 shows the layout plan of the building. In process LCA, experienced environmental inputs and outputs are consistently modelled by the use of a process flow diagram (Henry et al., 2014). The process LCA technique is frequently known as bottom-up approach, because the analysis in process LCA are each processing units and the flow rate and streams entering composition and getting out such units and can be composite if the building possesses several dissimilar kinds of building construction materials.

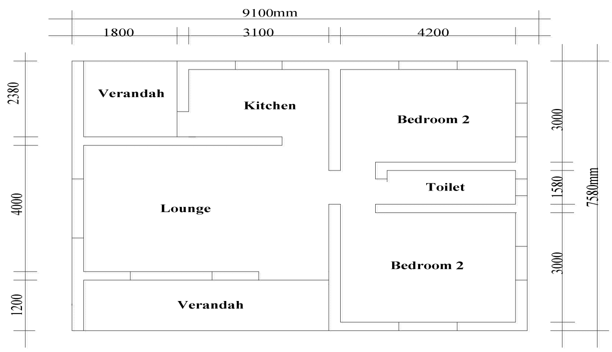

Figure 2: Typical layout plan of AMC stabilize clay block house

3.1 Mathematical model

The results obtained from the case study and inventory stages were utilized in colligation with the database of Inventory of Carbon and Energy and the process-based LCA analysis technique to calculate the building EC emissions. The materials quantities obtained from a standard bill of quantities were designated in measure units compatible with the Inventory of Carbon and Energy (ICE). The CO_2 emissions being traced to the buildings embodied stage were computed by utilizing the CO_2 emission factor. This was accomplished by utilizing the EC emission coefficients of Carbon and Energy Inventory of the Bath University as formulated (Hammond and Jones, 2008). Emissions that are linked with materials transportation and mobile equipment were calculated by utilizing emission factors for mobile fuel combustion (Heede, 2014). For materials and components whose emission coefficients were not included in the ICE database, available emission factors from literature were utilized (Elijošiutė et al., 2012). The material EC emission was computed by utilizing the formula:

$$CEM = Q_M * ECC \tag{1}$$

Where CEM = material carbon emission, QM = material quantity and ECC = embodied carbon coefficient.

Operational carbon emissions were computed by using the operational carbon calculation protocols as formulated (Aldy and Pizer, 2016) with base data from the International Energy Agency (IEA). In the fuel input analysis method, the process data assessed by fuel quantity depleted is multiplied by the stationary emission coefficient for the particular fuel type. Given the non-availability of emission factors for common fuels specific to Nigeria, default emission factors from IPCC were utilized. Carbon emission for direct fuel combustion was computed by utilizing the formula:

$$CEF = A * EC \qquad (2)$$

Where CEF = carbon emission from direct fuel consumption, A = process or activity data (litres of fuel), EC = emission coefficient (kg CO_2/litre of fuel).

4. Results of assessment

4.1 Cradles-to-gate emission

The results obtained on the cradle to gate EC computations were performed by utilizing the bill of materials derived from standard bill of quantities as well as the related materials EC coefficient as incorporated in the database of ICE. And the only local coefficient utilized was for cement as formulated (Ohunakin et al., 2013). The coefficient was discovered comparable with the inventory of carbon and energy coefficient for cement. The results obtained were expressed in a functional unit that represent building elements (that is m^2 of floor area). The case study house EC emissions total is 15,689.70 kg of CO_2, which is about 227.4 kg/m^2 of available floor area as indicated in Table 3. Further results details of the Life Cycle Inventory (LCI) and the EC values as well as density (kg/m^3) of the materials used are summarised in Table 4. The remainder of this study presents the carbon results as kg of CO_2. Approximately 80 % of the overall EC is embodied in the building materials integrated in the building (waste exclusive). The balances were assigned to the activities of building construction like transportation of building materials to site, waste and energy utilized onsite.

Table 3: Cradle-to-gate embodied carbon emissions

Building component	EC Emissions (kg)	Percentage (%)
Site installation	No data	
Substructure	10,001.89	64.0
Walls and frames	810.35	5.0
Roof structure and covering	1,804.56	11.5
Finishes	76.89	0.5
Doors/windows/fixture/fittings	1,127.86	7.0
Plumbing installations	980.37	4.0
Electrical installations	1,615.51	8.0
Waste	No data	
Total	15,689.70	100

4.2 Transportation emissions

Transportation emission was computed from the direct fuel consumption linked with material transportation from gate to the site. The building materials and components transportation in the study area was by diesel-powered vehicles. See the results of computation in Table 4.

Table 4: Material Transportation emissions

Material	Quantity	Weight (kg)	Truck Size (t)	Trips	Distance (km)
Aggregate	15000kg	7.0	10	1	30
Clay blocks	3700units	121	20	5	10
Cement	150 bags	7.5	5	1	10
Sand	15.5m^3	21	20	2	40
Filling Sand	33m^3	56	10	2	30
Steels	3.5kg	3.5	5	1	10
Hardcore	22m^3	49	10	2	30
Timber	10.500kg	10.5	10	1	35
Others	20.450kg	20.45	5	3	25
Total		295.95		18	220

The process or activity based technique shown in Eq(2) where carbon emission from mobile combustion is computed as the product of fuel consumption and the fuel emission conversion factor, and using the emission conversion factor of 2.7 kg/L diesel as given by the World Resources Institute (Aldy and Stavins, 2012) was considered. Then, the CO_2 emissions from transportation of materials was computed to be 207.9 kg with the detailed calculation: total diesel quantity used for transportation = 77 L, emission factor for diesel mobile combustion = 2.7 kg/L, overall emissions = 77 x 2.7 = 207.9 kg of $CO_{2.}$

4.3 Site construction emissions

The use of equipment was limited to manual block making machine, concrete mixers, hand held vibrators, cutting machines, water pumping machines, on-site electricity generators and site office gadgets like office equipment, air-conditioners, lighting fittings as well as electric fans. The debris-moving equipment where essential and was leased from equipment leasing organisations but its use was for over-site excavation and site clearance.

The total EC emission was estimated to be 16,175.67 kg, which is equivalent to embodied carbon intensity of 234.43 kg CO_2/m^2. The major components of embodied emissions were the cradle-to-gate emissions (97 %). Transportation was found to be 1.3 % and construction emission was found to be only 1.7 % of total EC emissions. Carbon emissions from the building sector are determined by the type, building component element and quantity of energy consumed in the buildings.

5. Discussion and findings

The different life cycle boundaries utilization has effect upon the LCA result. The present study utilized the cradle-to-grave life cycle boundary which is the same adopted in the Chinese study (Li et al., 2013), the Turkish study (Atmaca and Atmaca, 2015), the Cameroon study (Henry et al., 2014) and Nigeria study (Ezema, et al., 2016). Relatively, the current study computed the overall life cycle carbon intensity to be 16,175.67 (234.43 $kgCO_2/m^2$ as against 1808 kg/m^2 (Li et al., 2013), 5222- 6485 kg/m^2 as computed by (Atmaca and Atmaca, 2015), 228.03 kg/m^2 by (Henry, et al., 2014) and 2395 kg/m^2 by (Ezema, et al., 2016). In the results of conventional materials study case, the smaller of the Turkish example is more carbon intense because of the use of coal as operational energy source. The above implies substantial variability of intensities even within the same context with the Chinese building being the least carbon intense while the Turkish examples are the most carbon intense. While in the results of alternative (local) materials study case, the smaller the Cameroon example is more carbon intense even without the inclusion of transportation emissions, this is because of the use of mud-brick block as wall component. The difference between performance of one material from another material exclusively and the difference between performance of the same materials used in the construction highly varies. Also, it is not only material used in the construction that is responsible for the impacts on environment but also the way the component elements constructed is the factor that highly influence the performance from an environmental perspective. Nevertheless, if the boundary conditions are combined generally into the embodied stages, the findings of the present study are generally in accordance with previous findings. For example, the computed embodied intensity of 227.4 kg/m^2 in present study is lower than the 228.03 kg/m^2 computed without transportation emissions in Cameroun (Henry et al., 2014). However, the latter intensity is lower because it did not integrate site installation, waste emissions and recurring emissions. Carbon intensity depends mainly on the type, building component elements and quantity of energy utilized for building operation and to a lesser extent on the energy linked with building procurement. Emissions from the building construction sector should not be dismissed in the check towards low carbon development as the findings of this study show that emission from the building construction sector is gaining besides rapidly with raising building stock.

6. Conclusions

The results reject conventional perceptions, modifies the suspicion that natural materials are more environmentally pleasant and beneficial in nature compared to the present developed CMC of conventional materials. Such results further reinforced the significance in taking a multi-attribute approach to assessing a building product's sustainable performance. The case study exposes the way in which the proposed system transparently demonstrates the implications of each analysis. It also modifies the practicality of using the system, as it gives an insight of combining environmental performance into an integrated performance value that is easily interpreted. The case study shows that the decision-making analysis can provide design guidelines and a criterion for materials and assemblies to achieve Environmental Conscious Design (ECD). This decision support system developed by this research will expand the development of embodied carbon studies. The inclusion of site installations, waste and operational energy emissions as well as preservation and promotion of natural carbon sinks such as green infrastructure into total materials and assemblies embodied carbon emissions calculation of building projects were recommended.

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