Embodied Energy Calculation in Mitigating Environmental Impact of Low-Cost Housing Construction

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Abstract. Reduction of the negative impacts of building construction, or mitigation, should be done in the early phase of a project. Particular method that can be used to reduce the negative impact is Embodied Energy (EE) calculation. This research develops a method to calculate the total EE of materials used in building construction by using the Material Selection Analysis (MSA) based on Indonesia's Construction Work Unit Price Analysis (WUPA). MSA breaks down the types, its unit, and total volume of materials within an object. Using the EE data from Inventory Carbon and Energy (ICE) Bath, in the UK, this research calculate the embodied energy in three small house types in Indonesia: Type 21 M2, Type 36 M2, and Type 45 M2. The result reveals a negative correlation between building's area and EE value. Nonetheless, the EE value is positively related to the volume of material used. Proposed strategies to decrease the value of EE in low cost housing construction manly; a) design approach in improving the efficiency of material usage, b) materials substitution to material with lower value of EE, especially on material on large volume of usage, c) socialization of EE value to stakeholders as consideration in determining the choice of materials used, thus, environmental mitigation is expected to be an important aspect in determining the design decisions and the choice of materials used.

1. Introduction

As a developing Country, Indonesia still has a problem with rapid population growth. Housing development in Indonesia does not follow the population growth, thus create a housing backlog problem. Based on data from Statistics Indonesia 2015 (National Bureau Statistic), housing backlog in Indonesia is about 11 million units. Indonesian Government builds not less than 600-800 thousand houses every year in order to fulfil the needs. The effort is also aided by private sector such as developers, in many Indonesian cities and regions.

Massive housing development clearly makes housing construction in Indonesia as a massive building materials consumer. The development tends to be more into low cost housing than another housing type. This type of housing is affordable to most of Indonesian people, which mostly have low income. Although, the housing unit is small in size, but if it is built in a massive number, there can be a significant material consumption [1].

Further, building material consumption, especially when used in a big number, has something to do with sustainability. Exploitation of natural resources due to building materials production need a special attention. Production processes of building materials use a lot of energy and emit considerable amount of CO^2 to the atmosphere. Octaviana (2007) in Siahaan [2] states that carbon emission of a low cost house relate strongly to three factors such as material source, transport of material to the site, and respiration of labour.

Energy used and carbon emission rate of a material is calculated in the Embodied Energy (EE) Calculation. The calculation is usually done in the phase of preliminary design and design development. The EE value is a useful tool to give an insight about the buildings environmental impact [3]. This paper develops an EE calculation model and how to implement it in housing development in Indonesia. Although the model is developed based on the low cost housing case, it shall be able to use in other type of projects.

2. Methodology

There are four phases in this study: 1) literature review on EE calculation model for low cost housing in Indonesia; 2) developing EE calculation model based on Material Unit Analysis (MUA) by referring to Inventory of Carbon and Energy from the University of Bath and field calculation; 3) comparison of EE value of different types of low cost housing in Indonesia; 4) questionnaire and design approach to proposing strategies in mitigating environmental impacts by reducing EE value.

3. Consideration of Embodied Energy in Selecting Building Materials

Treloar in Dixit [4] mentions that building embodied energy is responsible for 20-50 times of annual operational energy of a building. Another reference states that building materials industry consumes as much as 20% of world’s fuel consumption. It will even be higher if fuel used in material transportation is include [5]. Hence, EE calculation is something important to conduct.

All of the phase in building material production require a lot of fuel, and mostly come from fossil fuel. The production process clearly gives impact to the environment in form of carbon emission. Hence, architect should consider the EE value earlier in the design process. Considering EE value earlier can reduce the environmental impact of a building in a lower cost than if it is done later. Reducing EE value of material can be done by selecting low EE materials, low-energy construction method, closer material source, and efficiency in material transportation.

In practice, embodied energy calculation requires a database of materials’ EE value. There are many EE value inventories with different level of quality and accuracy. However, Indonesia did not have an inventory of materials’ EE until now. Even, there is no standardise EE calculation model. Thus, EE calculation model for Indonesia is important to develop. As a starting, the model can use Inventory of EE materials from other countries.

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4. Embodied Energy Calculation Model Development

Haynes [6] says that there are three phases of EE calculation based on the materials production stage. Firstly, cradle to the gate EE calculation, which calculates EE value of materials from natural resources extraction until it becomes a product. This EE calculation approximately counts 59% of the actual total embodied energy of materials. Secondly, EE calculation that measures the materials transportation and it counts for 10% of the total embodied energy. Thirdly, EE calculation that calculates energy used in construction method when the materials applied to a building and it counts for 9%. The third type of EE calculation also measured the recurring embodied energy based on a 'churn rate' during a building life cycle, and counts for 22% of the total embodied energy of materials.

As explained above, EE in the cradle to the gate phase has the most significant value to the total embodied energy. Therefore, this paper focuses on EE value measured in this phase. Embodied energy calculation begins with materials' volume calculation. Every materials used in the building should be calculated, even to the smallest materials like sand, gravel, PC, etc. The materials' volume is calculated based on building components such as foundation, floor, wall, and roof. After determining the materials' volume, the calculation goes through some steps as follows:

- Step 1: Data collection. This step collects all of available data about energy in the materials making process, and then summarise the minimum and maximum EE value of each materials.
- Step 2: EE value selection. The mean EE value data from the first step are then analysed using boundary system cradle to the gate to get the most reliable value.
- Step 3: Eliminating the unnecessary aspects in the EE calculation, in order to get the fine value of embodied energy.

Further, the calculation model is shown by Figure 1 below.

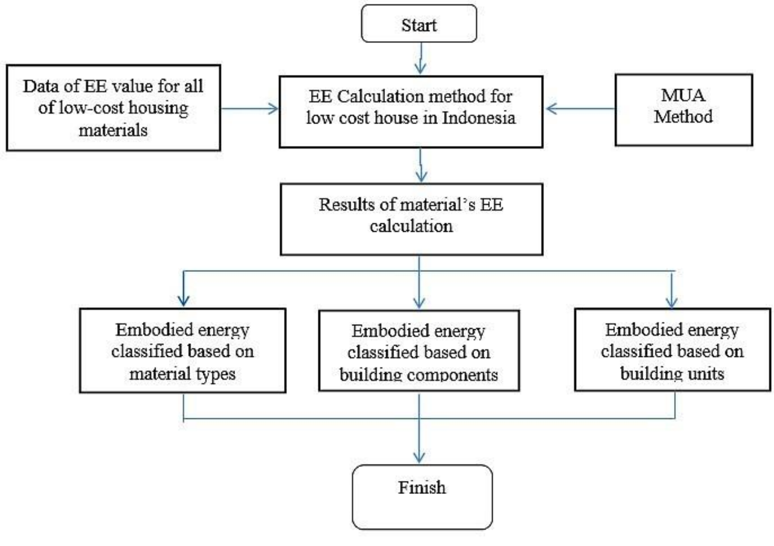

Fig. 1.. Calculation of material's embodied energy value used in this study [7]

4.1 Development of Material Unit Analysis (MUA) and Unit Conversion

Material Unit Analysis (MUA) as a basic tool in the EE calculation is developed in reference to Construction Work Unit Cost or *Analisa Harga Satuan pekerjaan* (the AHSP*)*.

The AHSP is a standard used for bill of quantity and cost estimation of construction projects in Indonesia. AHSP *guideline is issued by the National Standardization Agency (BSN).* It consists of work components of building, are; 1) materials coefficients, 2) unit, 3) description of work, 4) work volume.

In terms of embodied energy calculation for this study, information used from the AHSP is the materials list, and its coefficients of a construction work. Material's coefficients reveal the volume of materials needed per unit area/volume of a construction work. MUA analysis can extract the all of materials needed in a construction of building components and its measurement unit such as kg, m^2 or m^3.

Data resulted from MUA analysis is then converted into kilogram (kg). This is due to the fact that the embodied energy is calculated in Joule per kilogram (J/kg). So, all of volume units other than kg needs a conversion. The following table (Table 1) explains an example of MUA analysis and unit conversion.

Table 1. MUA Analysis and unit conversion

Code	Coeff.	Unit	Unit Conversion	The Standard Unit	Construction Work's Description
K	70	piece	70 x 3 kg = 210	Kg	Red brick, 5 x 11 x 22
	18,95	Kg	18,95	Kg	Portland Cement
	0,0380	m^3	*p* = m/V, so m = *p* x V	Kg	Sand

Table 1 above shows a unit conversion from brick wall construction. The work needs three materials, red brick, Portland cement, and sand, each material has different unit, and thus requires conversion. The coefficient state volume needed for the material in per 1 m^2 brick wall construction. The process is then repeated in all construction works for the low cost house. Based on MUA analysis of general design of low cost housing in Indonesia, there are at least 47 different materials used in low cost house construction. However, there are 8 materials used in a big volume, which the value of EE for each material as displayed in Table 2.

Table 2. 8 materials used in big volume in the low cost housing construction in Indonesia

No	Material Name	EE (MJ/Kg)
1	Wood	2,50
2	Steel	25,00
3	Glazing	15,00
4	Stone	142,40
5	Red brick	2,50
6	Ceramic roof tile	12,00
7	Ceramic	12,00
8	Paint	59,00

4.2 EE Calculation Analysis Based on Building Component

From the 8 (eight) materials, there is only one material comes from sustainable resources (wood). Meanwhile, 7 (seven) other materials are made of non-renewable sources. The result also reveals that red brick and ceramic roof tile have the most energy embodied in them compared to other materials. The amount of EE value on the percentage of material usage in construction of ow cost housing Type 21 M2 can be seen in Figure 2 below.

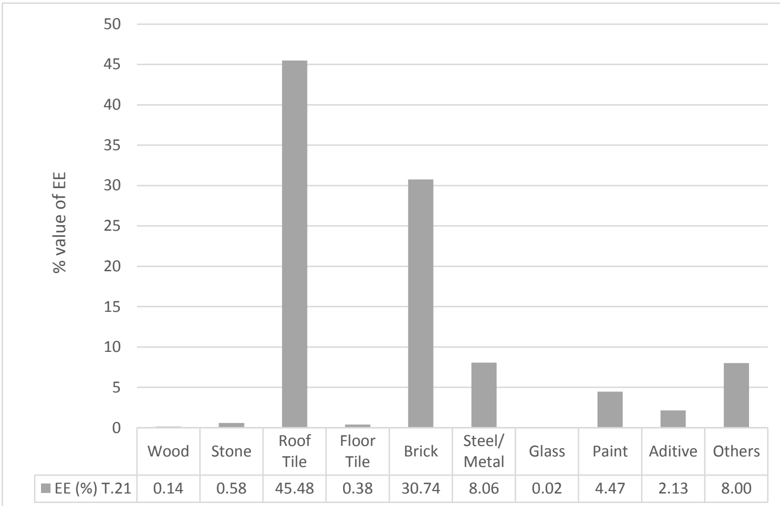

Fig. 2. Value of EE based on percentage of material usage in Type 21 M2 low cost housing construction in Indonesia

Figure 3 below displays EE calculation results in Type 21 M2 low cost house. EE value appears in roof component (46%) and wall (42%). Further, Type 36 M2 low cost housing also shows that roof is the main contributor to the embodied energy of the building (48% and wall is in the second place (38%). Meanwhile, Type 45 M2 calculation result comes with the highest EE value of all, and still with roof as the main contribution (48%) and wall (36%).

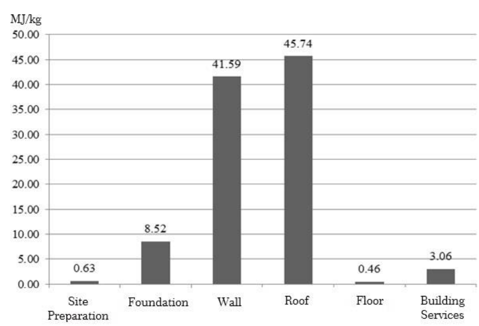

Fig. 3. Comparison of EE value by building components for Type 21 house

4.3 EE Calculation in Comparison in Different Type of Low Cost Houses

Figure 4 below reveals the increasing of total EE value along with the increasing house area. Although, if the comparison is made for two Type 21 house which have total area of 42 m^2 and one Type 45 house, the Type 21 houses have more EE regardless its smaller area.

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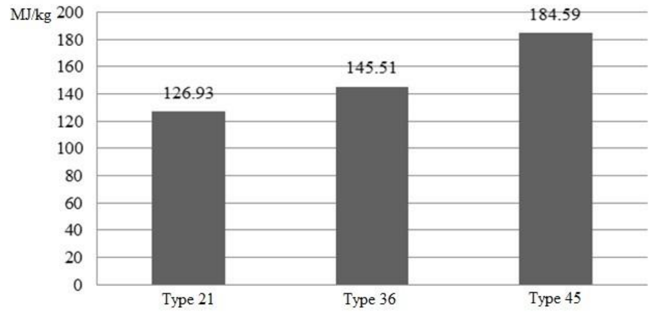

Fig. 4. Comparison of EE value by house types

Furthermore, the comparison of EE value based on building components in Figure 5 shows a same pattern in each component for different type of houses. The figure also shows that roof has the highest embodied energy, followed by wall, and foundation and soil works.

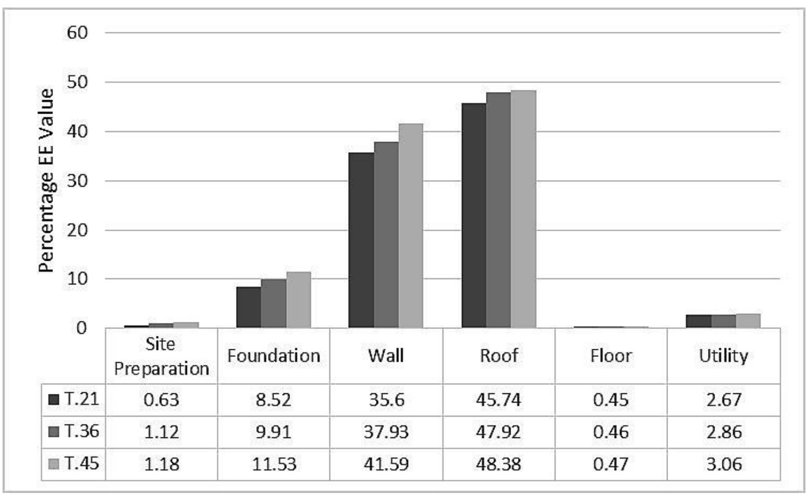

Fig. 5. EE value of building components for the low cost house types (MJ/kg)

5. Reducing Embodied Energy of Low Cost Housing in Indonesia

In order to decrease the embodied energy of low cost housing in Indonesia, first thing first is to increase the awareness of the people about the environmental impact of a construction. From that awareness, people with their own motive, will construct a building efficiently.

The results of the questioners to stakeholders regarding the proposed substitute material that have high EE values to material with low value of EE, indicating a good response from stakeholders, including proposal in using sustainable and environmentally friendly materials as long as the material has criteria as follows:

- Easily obtainable during construction,
- The price of material is low and affordable
- The mass of material is light, aesthetic and user friendly

Regarding the strategy for reducing the Value of EE in low cost housing construction, some actions that can lead to embodied energy reduction are mention below:

- Focus on reducing the materials that have large volume such as making the wall area smaller by adding windows or put proportional doors in the wall. Another strategy is by using exposed brick instead of plastered brick wall.
- Focus on the high volume of materials usage, substituting them with alternative materials that have lower embodied energy can be a good practice. This can be done by thoroughly searching for lower embodied energy materials in the inventory.
- Optimisation of low cost housing type. According to the result, Type 21 house is less efficient in material usage than other types. Therefore, Type 21 house should be cut down, and build more type 36 or 45 houses. Also, it is still better to divide the Type 45 house into two 22 m^2 houses than build two Type 21 houses.
- Dissemination of EE calculation model by using simple software to make the stakeholders more aware about the reduction of EE value of their building.
- At the policy maker level, the regulation should be promoted to emphasis the construction of green low cost housing. It can also use a rewards or incentive to encourage the developer to be more sustainable.

Conclusion

Some conclusions can be drawn from the analysis above. Fabricated materials tend to have higher embodied energy compared to materials that extracted directly from natural resources. However, material's volume also drives the embodied energy value of the low cost house types. Thus, no-fabricated materials such as wood or even sand can have a high embodied energy value in the low cost house types. Hence, substituting high volume materials that has high embodied energy with the lower embodied energy one is significant for reducing the total embodied energy value. Government policy is needed in providing incentives for stakeholder who applies materials with low EE values. On the other hand, it is necessary to undertake material dissemination and socialisation of low EE values in facilitating the wider use of environmentally friendly and sustainable building materials by the stakeholder. Further research is needed to explore the possibilities of such alternative materials and the acceptability of them by the low cost housing resident.

References

1. Thormark, C. "A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential". Build. Environ. **37**, 429–435 (2002).
2. Siahaan, N. "Model Pengendalian Perumahan Sederhana Dalam Sistem Perumahan Berkelanjutan Perkotaan Berbasis Rendah Emisi CO2". (2012).
3. Dixit, M. K., Fernández-Solís, J. L., Lavy, S. & Culp, C. H. "Identification of parameters for embodied energy measurement: A literature review". Energy Build. **42**, 1238–1247 (2010).
4. Dixit, M. K., Culp, C. H. & Fernández-Solís, J. L. "System boundary for embodied energy in buildings: A conceptual model for definition". Renew. Sustain. Energy Rev. **21**, 153–164 (2013).
5. Dixit, M. K., Fernández-solís, J. L., Lavy, S. & Culp, C. H. "Need for an embodied energy measurement protocol for buildings : A review paper. **16**, 3730–3743 (2012).
6. Haynes, R. "Embodied Energy Calculations within Life Cycle Analysis of Residential Buildings Table of Contents : 2010", 1–16 (2013).

DOI: 10.1051/matecconf/201713801001

7. Wahyuni, Y. S. “Perkembangan Riset Embodied Energy dalam Arsitektur”. in Prosiding Seminar Doktor LPPM Universitas Muhammadiyah (UMMIPress, 2015).