WALAILAK JOURNAL
http://wjst.wu.ac.th Engineering and Physical Sciences

# Composition of Bamboo Walls and Compressed Earth Block Walls in a Simple House that Produces Energy Efficient to Heat and Embodied Energy in Indonesia

**Vincentius Totok NOERWASITO**

*Department of Architecture, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia*

**(Corresponding author's e-mail: vtonoer@arch.its.ac.id)**

*Received: 26 September 2014, Revised: 9 June 2015, Accepted: 8 July 2015*

**Abstract**

Building materials have a major effect on the depletion of natural resources and energy in the world. Local raw materials are some of the best building materials, which can be found in every location; for example, compressed earth block and bamboo. This study adds to previous studies on compressed earth blocks without using combustion in the same location. The study focused on how to obtain a rural housing design by using compressed earth block walls and bamboo walls, which are adaptive to local materials and climate. Moreover, the ratio of the use of the compressed earth block walls with the walls is also examined to produce optimum embodied energy and heat energy buildings. The method used in this study was to analyze the characteristics of the compressed earth block and bamboo materials used as wall construction. While embodied energy and heat energy were calculated by using simulation model building, the heat energy calculation was found using the Archipak program. The results of the study shows that the optimum wall materials for the embodied energy and heat energy was compressed earth block with an area of 11 $m^2$ and bamboo walls with an area of 19 $m^2$.

**Keywords**: Compressed earth block, bamboo, simulation model, embodied energy, heat energy

## Introduction

The world's resources and building materials have a close relationship. The use of building materials is one of the causes of depletion of the world's natural resources. Similarly, the energy world has a major effect on building materials. This is caused by building materials requiring energy to process raw materials. Local building materials are made locally, and they save the energy of transportation from one point to another. This is because the distance between the source of material and location is relatively close. So, the use of fuel for transportation is relatively minimal. Therefore, local building materials are highly recommended to save energy [2].

The amount of energy required for the production of building materials is called "embodied energy". Embodied energy is the energy used to manufacture building materials, passing through certain processes, from raw materials to finished materials [8]. Local building materials meet the requirement for low embodied energy, due to the low level of transport energy. So, a maximized use of local building materials will make energy-efficient buildings.

The study was conducted in the Pandaan area. This is a mountainous area, with cooler weather conditions during the day. The soil is not fertile, so it is not conducive for use as farms or fields. Bamboo grows in this area, so soil and bamboo have the potential to be developed as building materials.

Red brick is widely used in this area. Red brick has a high embodied energy. A building material like red brick, but with a lower embodied energy, is compressed earth block. The basic ingredients are local soil blocks, which are processed without using combustion methods, but by using a compaction method. So, compressed earth block can be regarded as an environmentally friendly building material.

A mixture of compressed earth block and bamboo will produce a wall which uses the maximum of local potential from the local area. Bamboo wall is very suitable for use during the day, while the walls of compressed earth block are suitable for use at night. The use of both materials will generate comfortable air conditions inside the building.

Comfort in buildings is affected by local weather conditions and the type of materials used. A major factor for comfort in buildings is heat energy (overheating, or lack thereof). A building which has a low overheated energy level yields comfortable conditions inside. The main problem for this study is of how the compositions of compressed earth block walls and bamboo can produce the optimum level of embodied energy and overheated energy. This study used a simulation model of a simple building, with a size of 3×3 $m^2$, and a height of 2.8 m. The end result of this research is that a simple building design has the optimum level of embodied energy and overheated energy.

**Materials and methodology**

This study uses a research design, as shown in **Figure 1**. As a simulation model, it is the simplest form of the existing buildings in a village. The design of the research activities are as follows:

1. To determine the characteristics of compressed earth block, bamboo, and local climatic conditions in which these activities take place.
2. To determine the simulation model building, with walls of a compressed earth block and bamboo combination.
3. To determine the area of alternative of compressed earth block and bamboo walls using the model.
4. To calculate the embodied energy and overheat of each alternative wall, using the software.
5. To determine the wall alternative having an optimum levels of embodied energy and overheated energy.

Walls with areas composed of compressed earth block and bamboo walls are investigated in this research. Both materials will generate embodied energy and overheated energy in different buildings. This study used a simulation program to calculate overheated and embodied energy. The calculation of overheated energy is done with the use of the Archipack program.

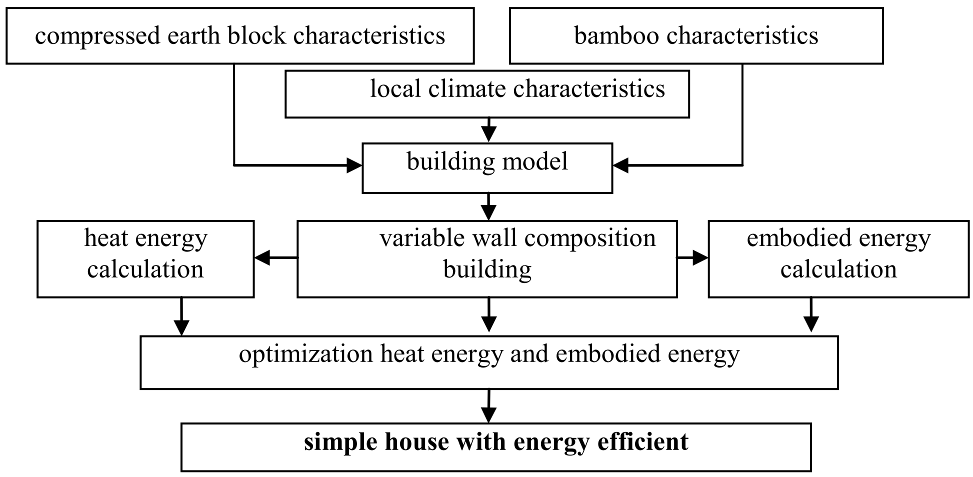


**Figure 1** Schematic design of the study.

Embodied energy per unit of compressed earth block and bamboo, thermal characteristic of materials, and local climatic conditions are the data required to calculate embodied energy and overheat in walls. The variable in this study is a comprehensive alternative to solid ground block walls and bamboo that has embodied energy and a different overheat. The variables obtained from calculation for embodied energy and overheated energy form each alternative composition of the building wall.

Embodied energy and overheated energy was balanced on all variables in the building wall investigated with optimization methods in a graphical form of x-y. The x-axis is the value of the embodied energy, while the y-axis is the value of the overheated energy. The selected alternative wall is a wall that has embodied energy and relatively low overheated energy.

**Results and discussion**

Building models were studied, using compressed earth block and bamboo as a wall. Both of these materials are materials that can be produced and easily obtained in a rural location.

**Building materials**

Compressed earth block is a wall building material which uses soil as a raw material. Materials are produced using the process of compaction and without using combustion processes such as in the production of red brick. This material has a compressive strength greater than the tensile strength. Compressed earth block walls with a thickness of 11 cm are good for heat insulation, as was tested by Nirwansyah & Noerwasito (2012). Therefore, this wall thickness is used as a reference in this study (**Figure 2**).

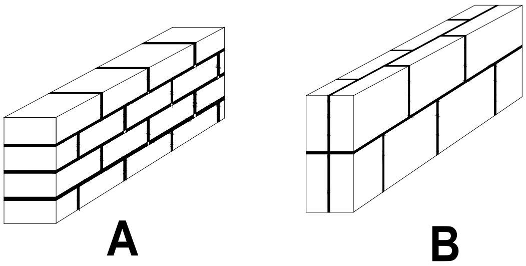


**Figure 2** Layer arrangement types of compressed earth block wall.

**Figure 2** describes how the 2 forms of the arrangement of the wall blocks were used, in an arrangement of horizontal and vertical. Wall A, with a horizontal arrangement, is the standard arrangement of walls in general. Wall B, with a vertical arrangement, has 2 layers of a vertical block arrangement. The arrangements of the horizontal and vertical walls have the same thickness. Both of the wall arrangements have the same heat resistance; they differ only in terms of the arrangement of the blocks. The conditions of the horizontal and vertical arrangements can be seen in **Table 1**.

**Tabel 1** Thermal properties of Wall A and B types.

| Thermal properties | Wall type | | Unit |
|---|---|---|---|
| | A | B | |
| U-Value | 2.26 | 2.03 | $W/m^2K$ |
| Admittance | 4.26 | 4.20 | $W/m^2K$ |
| Time-lag | 6.23 | 6.66 | jam |
| Decrement factor | 0.41 | 0.41 | - |

Source: Archipak

Bamboo is a building material that is widely used for building in villages; therefore, bamboo is a local building material. Bamboo has a fiber that is very strong, so that the tensile strength is extremely good. Also, bamboo has good compressive strength. Since both of these characteristics are present, bamboo rods can be used as columns and as stiffeners in building construction. Bamboo has a variety of types. Not all types of bamboo can be used for column functions. The bamboo species suitable for building construction is called bamboo "petung" [13].

**Application of materials for building**

The study uses a model of the building. This model is taken from the most minimal building dimensions, namely the bedroom. The model building has dimensions of 3 m length, 3 m wide, and 2.8 m high. These dimensions are the minimum dimensions of a building in a village.

The main column, using bamboo type "petung", is coated with compressed earth block. In addition, bamboo is also used as a stiffener wall. The roof of the building uses clay tile. The frame of roof uses bamboo material type "petung". The rafters and batten use bamboo material type "Ori".

The materials for the foundation include stone. It is a material commonly found in the area. The foundation serves as a support and liaison system structure to the ground. The foundation also serves to hold the groundwater from rising up the wall.

The walls of the building model use compressed earth blocks on the bottom wall, and the wall of bamboo lies at the top. The wall type used is a type of vertical wall (see **Figure 2**). It is a wall that is not plastered. The raw material of the compressed earth block walls is obtained from the soil around the area. The content of the soil is 40 - 50 % sand. The compressive strength of the block reached 30 kg/cm$^2$.

The roof used is saddle-shaped. The roofing materials use materials that are resistant to rain water, and are a material that is readily available in the area. There are 2 alternative building materials that can be used for the roof. These are bamboo and clay tile. The roofing materials are appropriate and in accordance with the local climate.

**Table 2** Characteristics of bamboo roofing materials and roof tile.

| Criteria | Roofing material | |
|---|---|---|
| | Bamboo | Tile |
| Local material | No | Yes |
| Durability of material | No | Yes |
| Resistance to termites | No | Yes |

Bamboo roof is a good roof in comparison to a tile roof, when viewed from the origin of the material. However, the durability of bamboo roof is less resistant to the climate than bamboo roof tile. Also, it is not resistant to termites. Therefore, clay tile is the right choice for roof coverings in a building in this area (see **Table 2**).

**Table 3** Variable wall building models.

| Building models | Compressed earth block wall | | Bamboo wall | |
|---|---|---|---|---|
| | height (m) | area (m$^2$) | height (m) | area (m$^2$) |
| I | 1 | 11 | 1.8 | 19.8 |
| II | 1.5 | 16.5 | 1.3 | 14.3 |
| III | 2 | 22 | 0.8 | 8.8 |
| IV | 2.5 | 27.5 | 0.3 | 3.3 |
| V | 2.8 | 30.8 | 0 | 0 |

The composition of the wall area of compressed earth block and bamboo in this research will result in levels embodied energy and heat energy of buildings that are varied. For the sought variable, the right composition of variable was used to derive optimum results for embodied energy and heat energy levels. The variables used the heights of the 2 types of walls. The heights of the walls of compressed earth block are 1, 1.5, 2, 2.5, and 2.8 m (see **Table 3**), while the heights of the walls of bamboo are 1.8 m, 1.3 m, 0.8 m, and 0.3 m.

**Building performance**

The simple building model has dimensions of length 3 m, 3 m wide, and 2.8 m high. The walls of the building consist of 2 types of material, that is, compressed earth block and bamboo, while the main structure of the building uses bamboo. The appearance of the building can be seen in **Figures 3 - 6**. The roof of the building uses clay tile. The foundation uses stone.

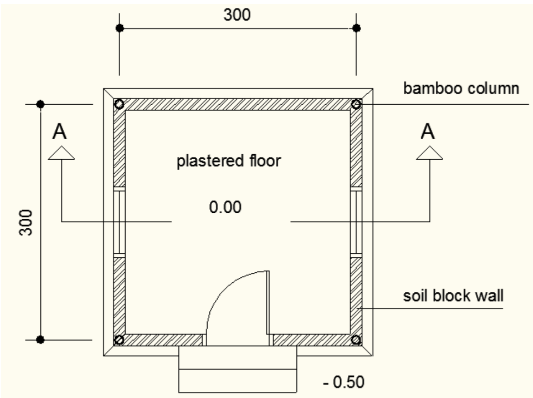


**Figure 3** Plan of model.

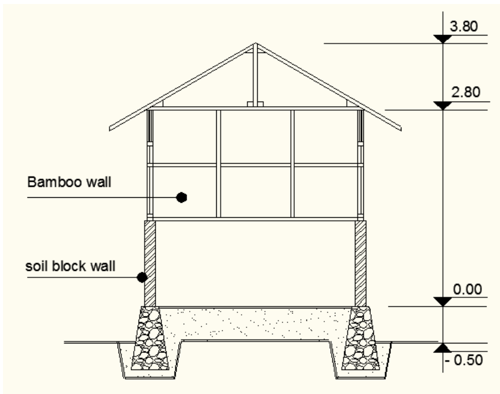


**Figure 4** Section of model.

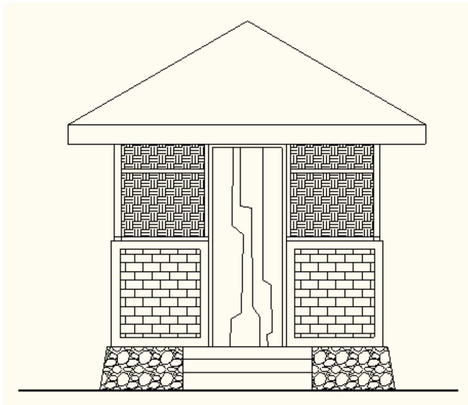

**Figure 4** Front of model.

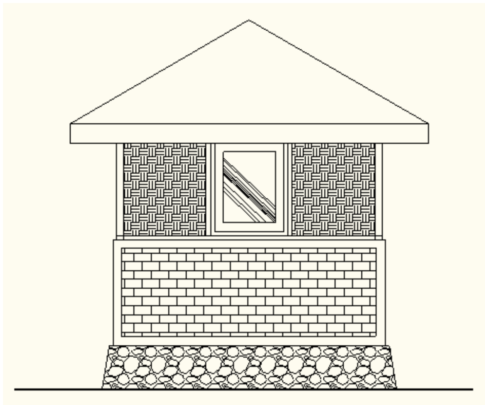

**Figure 5** Side of model.

**Embodied energy**

Embodied energy is closely linked to the characteristics of building materials. Embodied energy is the energy used for the production of building materials from the beginning of the process to the finished material. Therefore, each embodied energy level of a building material possesses a different amount depending on the manufacturing process and the raw material. Compressed earth block uses local soil as a raw material, and the manufacturing process does not require much energy, so this material has a low embodied energy. Similar to bamboo, this material is obtained from plants around the area, and does not require transportation energy, so this material has a low embodied energy. The following table, **Table 4**, shows the embodied energy/unit of the building materials used in this study.

**Table 4** Embodied energy/unit of the building materials of the model.

| **Material in model building** | **Embodied energy/unit** |
|---|---|
| Bamboo wall | 2400 MJ/m$^2$ |
| Compressed earth block wall | 6818 MJ/m$^2$ |
| Stone foundation | 235 MJ/m |
| Clay tile | 251 MJ/m$^2$ |
| Plastered floor | 5250 MJ/m$^3$ |
| Window | 388 MJ/m$^3$ |

In this study, there is a total embodied energy and embodied energy per unit area of the building. The total embodied energy is a multiplication of the embodied energy per unit by area or volume of the materials used in building the model. The average embodied energy is the total embodied energy divided by the floor area of the building model. In this study, embodied energy is used as the average embodied energy, because the floor areas of all the models are the same. The embodied energy of each model can be seen in **Figure 7**.

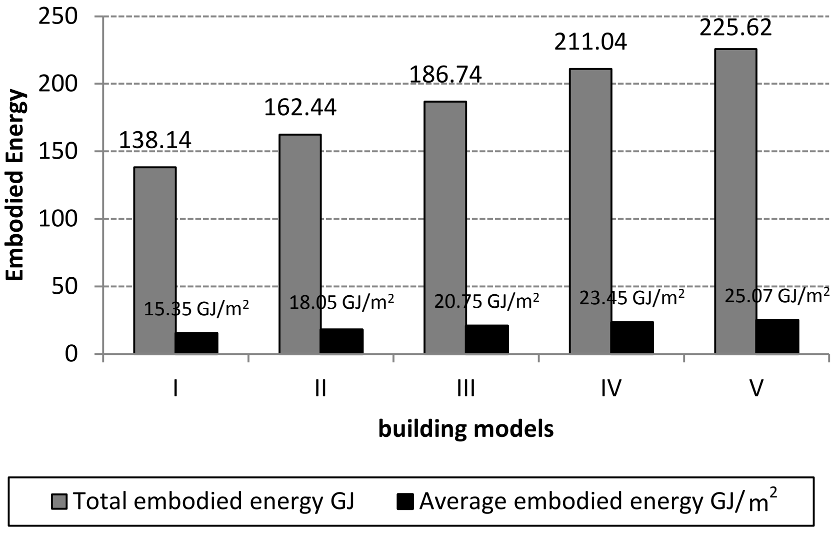


**Figure 7** Embodied energy in each building model.

**Figure 7** shows that each model has a total embodied energy and an average embodied energy level that is different. The increased total and the average embodied energy in the building model can be seen as a result of differences in the area of wall building materials. Model I has the lowest embodied energy, while higher embodied energy is possessed by Model V. Model V is a model without a bamboo wall.

Model I has a compressed earth block wall area of 11 $m^2$, while Model V has a wall area of 30.8 $m^2$. Differences of area in the compressed earth block walls have led to differences in embodied energy in the models. Differences of area in the bamboo walls did not affect the building embodied energy when compared with the compressed earth block wall area. This is due to the value of embodied energy per unit of compressed earth block walls being higher than bamboo (see **Table 4**).

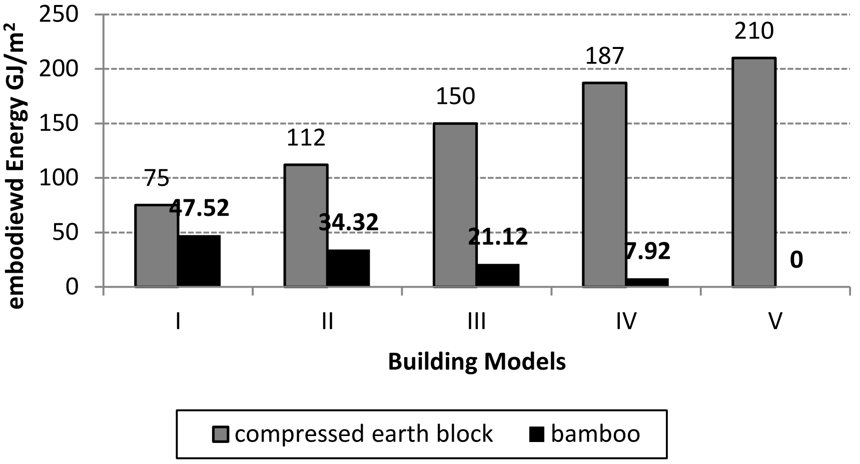


**Figure 8** Comparison of embodied energy between the walls of each building.

**Figure 8** shows the relationship between the uses of wall area in each model. Model I has an embodied energy ratio between the compressed earth block and bamboo which is not too large, while the IV and V models have an embodied energy ratio between them and the wall which is very large. Embodied energy Model 1 is smaller than the IV and V models. This indicates that Model I is the most optimum model in terms of embodied energy. Model I is a model of a building that has a height of wall made of compressed earth block of 1m, and a 1.8 m high wall of bamboo.

**Heat energy**

All models have embodied energy buildings that are different from other buildings. The buildings also have different heat energies. The calculation of thermal energy in the building is based on the climatic conditions in the hottest areas in eastern Java. The selected building is a building that has a relatively low embodied energy, of building models I, II and III.

**Table 5** shows the conditions of temperature and overheated energy of buildings within a year. The model building which has the highest heat energy is Building III. The building is suitable for building in cold temperatures, while Building I, with low heat energy, corresponds to heat buildings in the region.

**Table 5** Heat energy in the building models.

| Building models | Average of highest temperature (°C) | Average of lowest temperature (°C) | Overheated energy per year (K.h) |
|---|---|---|---|
| I | 30,2 | 27,5 | 6887 |
| II | 30,7 | 28,1 | 10622 |
| III | 30,7 | 28 | 11787 |

Building I in **Figure 9** is overheated, and the buildings that have the lowest average temperature are Buildings II and III. This indicates that Building I has resistance to the local climate. The volume of wall building materials greatly affects the condition of heat energy in the building.

Bamboo wall material usage greatly affects the low thermal energy in the building. Building III has the greatest heat energy, this is caused by the volume or wider field of bamboo walls of the building, in this case, very few of the buildings I or II. In this case the bamboo wall is a wall that is important in saving heat energy.

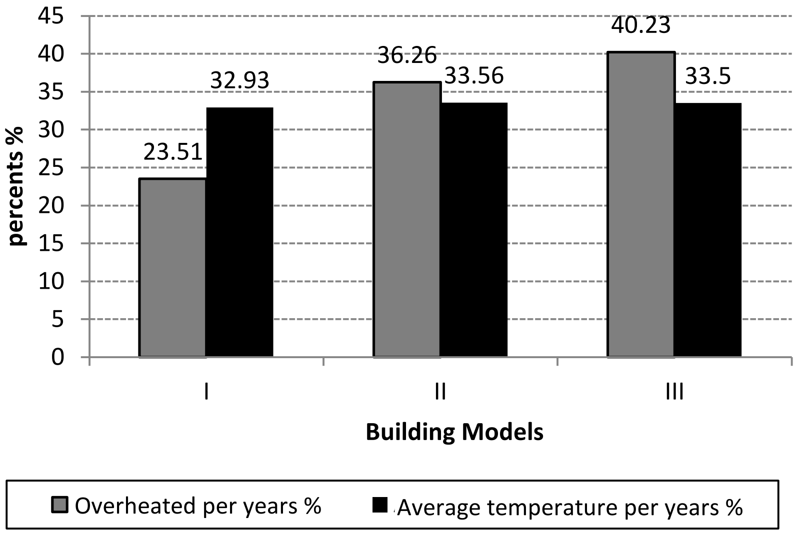


**Figure 9** Comparison of overheated energy and the temperature inside the building.

**Optimization of embodied energy with overheated energy**

**Figure 10** shows that Building I has the lowest embodied energy, while the building which has the highest energy is Building type III. Building I can be used as a building model for the next stage, because the building has the lowest energy among the 3 samples of buildings used. Building I has an area of compressed earth blocks wall of 11 $m^2$, while the bamboo wall has an area of 19.8 $m^2$.

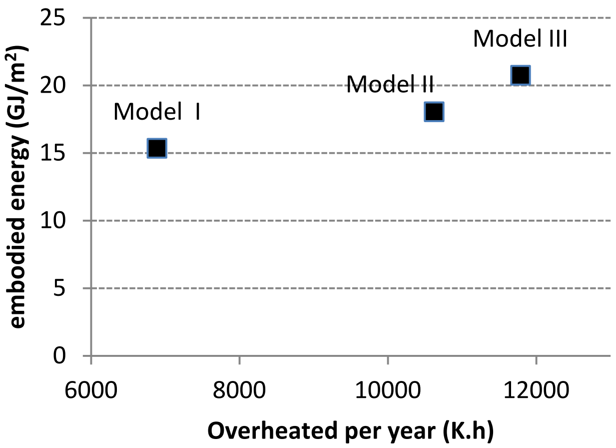


**Figure 10** Position of building models to the embodied energy and overheated energy.

## Conclusions

Uses of local building materials for walls have a good potential for the local climate. In this study, the types of local building materials are compressed earth block and bamboo. The exact composition of the wall area between the 2 materials produces embodied energy and optimum heat energy. Walls of compressed earth block without bamboo have heat energy, and embodied energy is greater than the wall of the building made from a combination of compressed earth block and bamboo walls.

Therefore, to generate the energy optimization of the use of the types of wall materials in this study, both types of wall are combined. The results of optimization heat energy and embodied energy for the combination of a wall of compressed earth block and bamboo is a wall of compressed earth block with an area of 11 $m^2$ and a wall with an area of 19.8 $m^2$ of bamboo. This shows that the composition of wall area affects embodied energy and heat energy in the building. From the analysis above, there is a tendency that the building has low embodied energy, which will have low heat energy.

## Acknowledgements

The author is very grateful to Institut Teknologi Sepuluh Nopember for the financial support.

## References

[1] B Adamson and A Olle. *Design for Climatization Houses in Warm Humid Areas*. Building issues. LCHS Lund University, Lund, Sweden, 1993.
[2] J Amatruda. Green Product, National Institute of Building Sciences, Available at: http://www.wbdg.org/design, accessed Augusts 2004.
[3] J Astrand. *Block Making Machines for Soil Blocks*. Sadel-Arskitektur I, Lund, Sweden, 1986.
[4] S Kenneth. *Mortars for Masonary and Rendering Choice and Application*. Building Issues, LCHS, Lund, Sweden, 1995.
[5] T Noerwasito. Bata lempung bahan bangunan dinding alternative. Dimensi Teknik Arsitektur, Universitas Kristen Petra Surabaya, Indonesia, 2001.
[6] T Noerwasito. *Pelatihan Pembuatan Blok Lumpur Bergaram Tanpa Pembakaran Sebagai Bahan Renovasi Dinding Rumah Nelayan Di Desa Sidopekso Kraksaan Probolinggo*. Research, 2008.
[7] N Nuriyatin. 2000, Studi Analisa Sifat-sifat Dasar Bambu pada beberapa Tujuan Penggunaan, Thesis Magister Sains, Pascasarjana Institut Pertanian Bogor.

[8] BD Petrossian and E Johansson. *Construction and Environment Improving Energy Efficiency*. Building Issues, LCHS Lund University, 2000.
[9] R Vincent. *Blocs de Terre Comprime*. Vol I. Manuel de Production, CRA-Terre EAG, Grenoble, France, 1995.
[10] R Stulz and M Kiran. *Appropriate Building Materials*. 3rd ed. SKAT Publication, Switzerland, 1993.
[11] R dan Noerwasito. *Blok Non Bakar dari Tanah Liat Lokal Untuk Dinding Rumah Sederhana yang tahan gempa studi kasus di Pasuruan*. Research, 2010.
[12] T Mumma. *Reducing the Embodied Energy of Buildings*. Construction, Home Energy Magazine, 1995.
[13] EA Widjaja. *Indonesia dalam Bamboo*. Research in Asia, 1980, p. 63-8.