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The influence of the Calsium Silicate panel on Soil-paper walls in low income houses in Indonesia

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ABSTRACT

Building materials used for the walls of simple houses in lower-middle-class areas in Indonesia are currently dominated by brick. This study proposes that soil-paper blocks coated with calcium silicate board may be a suitable alternative, with high embodied energy and density. The research aims to obtain an optimal wall thickness to provide protection against cooling and embodied energy in low income houses, as well as against the temperature conditions in these buildings in highland and lowland areas. Determination of wall thickness is performed by simulation of a 9 m^2 building model with thick variables. Cooling calculations involved the use of Archipak software. Temperature measurements were carried out using a data logger on a sample of soil-paper blocks. The results indicate that the optimal wall thickness for protection against cooling and embodied energy is 8 cm. Soil-paper block has a lower density than brick. The use of calcium silicate boards does not affect the internal temperature of a low income house, but they can be used as protection against rainwater and as a substitute for wall plastering.

Keywords—*low income houses; soil-paper; calcium silicate board; wall thickness; sample blocks.*

I. INTRODUCTION

Building materials for simple housed walls for the lower-middle class in Indonesia are currently dominated by red bricks. Such bricks have high embodied energy equivalent to 3677 MJ / m^2 [2], due to their use of combustion energy. It is therefore necessary to find a replacement material that does not require such a burning process. One such material is soil block. The disadvantage of this material is that is relatively heavy, with a density reaching 1700–1800 kg/m^3 [9]. Currently, in urban areas there is a significant amount of paper waste, which has potential to be processed into wall building materials. Soil block when mixed with paper material will decrease its density. The combination of these materials is referred to as soil-paper block.

This study discusses the building of walls using paper and soil. The raw material of this wall material is paper mixed with soil and cement, which provides additional wall strength [4][5]. The production process of this material involves not burning but rather compaction and drying in a natural way, similar to the production of compressed earth blocks [9]. The limitation of walls using paper materials is that they are not resistant to rainwater [6]. To solve this problem, the outer and inner wallsare coated with calcium silicate panels. Another function of the panel is replacing the cement plaster on the wall.

This research aims to obtain the ideal wall thickness. It targets the main issue of how to obtain optimal wall thickness and indoor temperature. There are two category energy in buildings Embodied energy and Operational energy [7]. In this study cooling as part of operational energy. The wall thickness in this case is optimal in terms of cooling and embodied energy. Cooling is energy produced by materials to cool buildings, while the energy for building material production processes from basic materials used for construction is termed embodied energy [8]. The value of these two energies is obtained by calculating the amount of cooling and embodied energy in the building; this value is calculated using a building simulation, while temperature measurements are taken from value thicknesses of the ideal wall according to the simulation results. The building model used for the simulation is a building of length 3 m, width 3 m and height 3 m. The wall thickness used in the building simulation varies. Production of block soil-paper samples is carried out on selected wall thicknesses, and the composition used is adjusted to the desired block density (1000kg/m^3).

II. RESEARCH METHODS

This study analyses wall-building material comprising soil-paper blocks coated with calcium silicate board. Cement is added as a binder between soil and paper, a process which improves hardness and density. Activities undertaken included producing a building design simulation model using a wall of soil-paper block coated with a calcium silicate board (Fig. 1).

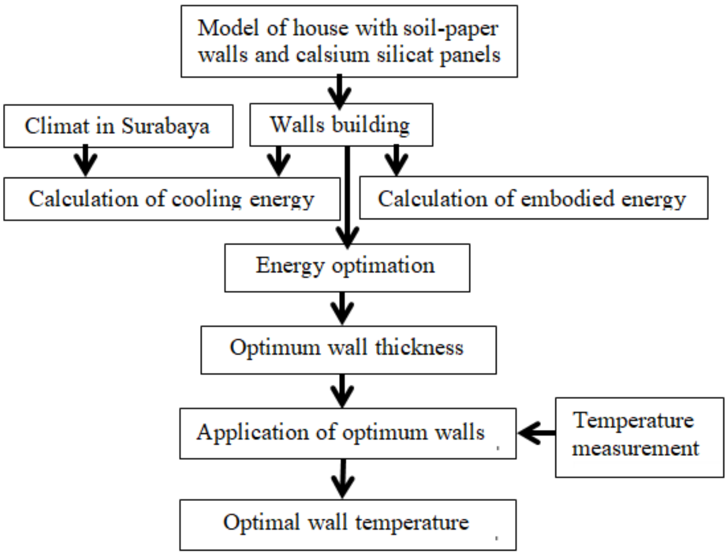


Figure 1 Flow of research approach

The dimensions of the building model were determined according to the size of the dwelling. In this case, the type of space chosen is a bedroom. Hence, the model dimension is a simulated building of size 3 x 3 m (Fig. 2). An alternative wall design is produced to obtain optimal results in terms of cooling and embodied energy conditions in the building. This aim was achieved using different wall thicknesses, which was one variable used in this research. The wall condition can be seen in Figure 3, while wall variables are shown in Table 1.

Table 1 Variables of papercrete wall with calcium silicate panels

wall thickness (cm)	code
8	W1
10	W2
12	W3
15	W4

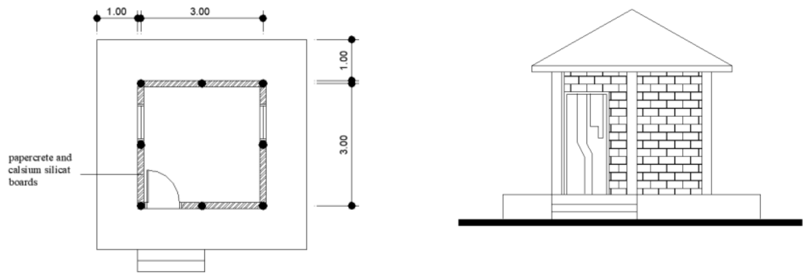
The simulation of cooling calculation is performed using the wall thickness variable. Results are expressed as cooling per years and temperature inside the building. A good wall thickness alternative is walls that are minimally cooling. The local climate (Surabaya, Indonesia) was a primary driver of this study. Simulation of cooling calculation used Archipak software. The calculation of embodied energy is supported by standard data of embodied energy per unit from each material. In this case, the material used the same wall variables, and hence the embodied energy from the wall variables will be the same and the wall volume becomes more important.

Energy optimization was performed on alternative buildings with different wall thicknesses. Regarding cooling and wall volume, a good building is one that has optimum levels of these factors. Further temperature measurements on soil-paper block wall samples with calcium silicate boards and without calcium silicate panels were performed on selected wall thicknesses. Temperature measurements involved use of a data logger.

III. DISCUSSION AND RESULTS

The research was conducted by taking the case of the Surabaya area of Indonesia. Surabaya is located at position 7.20 LS. Mean temperatures are 23.6–33.8 ° C and humidity levels average between 50–92%. Observing local climatic conditions is important in terms of energy saving in buildings to obtain more comfortable conditions inside them.

Factors studied include the extent to which the wall can reduce cooling in the building. The efficient use of building materials also received attention. Therefore, in this study the calculation of cooling and embodied energy was performed for energy saving in the building.A simulation model involving a building of width 3 m, length 3 m and height 3 m was used (Fig. 2). The building has recycled paper walls coated with calcium silicate panels. The roof is tiled, with the floor being plastered.



Plan model Facade model

Figure 2 Plan and facade of building model

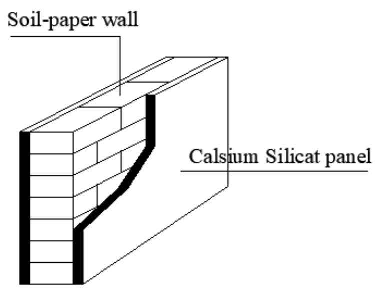
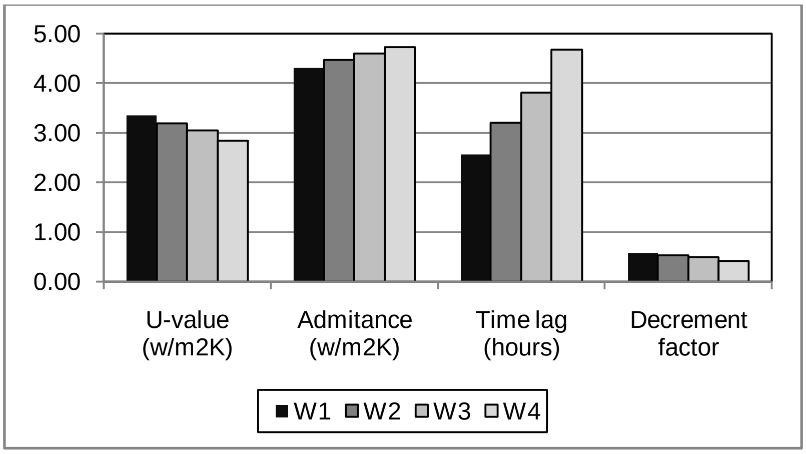


Figure 3 Wall details

III.1. Cooling energy

Materials have thermal characteristics which respond to the climate, hence the warm humid conditions in Indonesia significantly influence the material types selected. The decrease of energy in this research is enabled by using a soil-paper wall building with calcium silicate boards. Cooling involves those temperatures which are above thermal comfort inside buildings. The cooling calculations were performed by simulating the building model using Archipak software. The important factors required to obtain cooling in buildings comprise the thermal properties of the walls and the climatic conditions of Surabaya.

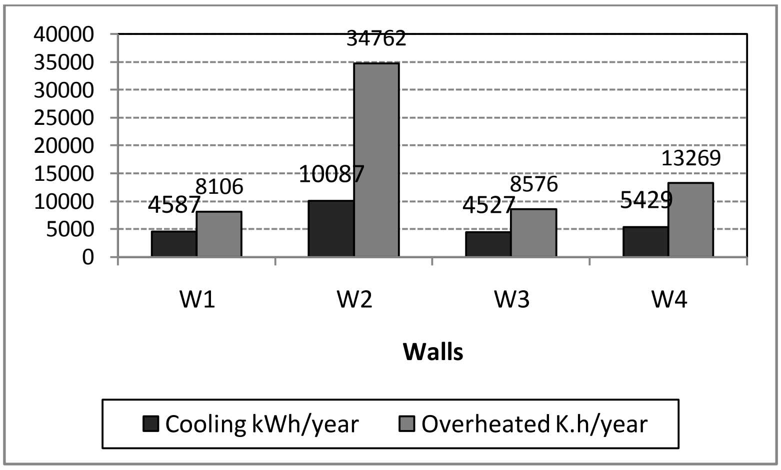
The research variables included building wall thickness. The number of variables that form the building model amounted to four pieces with different wall thicknesses. In this study, the code for the building model is 'W' and is characterized by '1, 2, 3, 4', which indicate the model types with different wall characteristics. The thermal properties of each wall of the thickness of the building model can be observed in Figure 4.



Source: calculation by Archipak5.

Figure 4 Thermal properties of soil-paper walls and calcium silicate panels

This figure illustrates that the wall thickness affects its thermal properties. The U value and decrement factor decrease for walls of increased thickness, as observed in the W4 model. Admittance and time lag increased in buildings with larger wall thicknesses. Based on the thermal properties of wall materials, cooling in buildings can be calculated. The value of cooling is determined for a year because it is more evenly distributed over that time period (Fig. 5).



Source: calculation by Archipak5.

Figure 5 Cooling energyper year for wall soil-paper and calcium silicate panels

Figure 5 illustrates that the highest cooling load is in the W2 building model, which is a building with a wall thickness of 10 cm, while the lowest cooling load was observed for the W3 building model, with a wall of thickness 12 cm. Differences between the cooling load for buildings in W1 and W3 were not significant (1.3%). The comparison between low and high cooling loads in all four buildings was 5560 Kwh/year or 123%. The condition of cooling in buildings without use of calcium silicate boards is also required (Table 2).

Table 2 Cooling energy types of Soil-paper wall without panels (WP)

code	cooling kWh/year	overhetedK.h/year
W1WP	4595	7588
W2WP	4557	8052
W3WP	5058	8788
W4WP	5007	8917

Table 2 shows the increase in cooling of the building model. In buildings with increased wall thickness, the value of cooling of the wall without panels differs in each building. This result indicates that the effect of calcium silicate board use is different for each building. For example, for walls of 8 cm thickness, the use of a panel has little effect, while for 10 cm thick walls, such panels were highly influential.

III.2 Embodied Energy

The energy required to produce a final product from raw materials is termed embodied energy. One of the characteristics of green products is that they have low embodied energy [1]. Transportation and product delivery is one way to reduce the embodied energy value [11]. Each material has a different embodied energy. Materials used for the building model with their embodied energy per unit provided can be seen in Table 3.

Table 3 Embodied energy per unit material

materials	embodied energy/unit
Soil-paper wall	4,81 MJ/kg
Panel calsium silicat	13550 MJ/m^3
Roof tile	251 MJ/m^2
floor	5250 MJ/m^3
Wooden door/window	388 MJ/m^2

In this building model, the most influential material is the embodied energy of the paper composition and calcium silicate boards, due to the weight and volume of both materials. Embodied energy calculation results from each building are illustrated in Figure 7. Figure 6 shows the increase in embodied energy due to the increase in wall thickness. In the building model, an 8 cm thick wall (W1) has the lowest embodied energy, while the 15 cm thick wall (W4) has the highest of such energy. This result demonstrates that large material volumes will also produce high embodied energy per m2. Therefore, in this case, the wall volume becomes important.

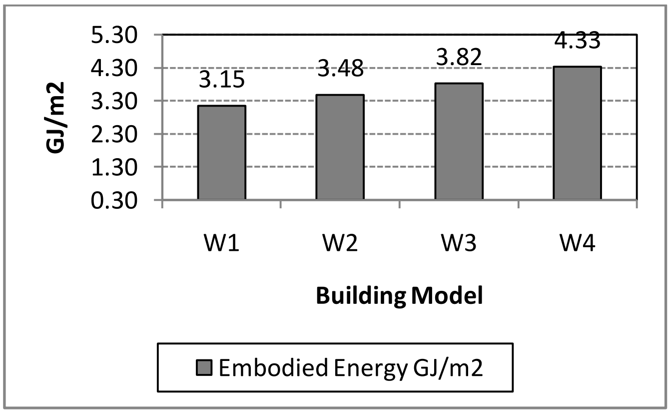


Figure 6 Embodied energy graph of each building model

III.3 Optimization

The condition of each building model has a different energy rating value between cooling energy with embodied energy. Some building models have low embodied energy but have high cooling energy, while there are also models of high embodied energy but low cooling energy. It is therefore necessary to optimize the two energies of each building model. To perform the energy optimization, data is required for annual cooling energy and embodied energy per year. The values of cooling energy and embodied energy are provided in Table 4.

Table 4 Cooling energy and embodied energy for each building model

no	code	wall thickness (cm)	cooling energy (Kwh/years)	embodied energy (GJ/m^2)
1	W1	8	4587	3,15
2	W2	10	10087	3,48
3	W3	12	4527	3,82
4	W4	15	5429	4,33

Optimization is carried out by examining the energy position of cooling energy and embodied energy value of the building model. The optimization process uses graphs (Fig. 7). On the graph there are four zones. The best and worst zones are 1 and 4, respectively. Because the main consideration criterion for the appropriate assessment of the building model is the low cooling energy value, the embodied energy value must also be relatively low, based on consideration of good zone scale criteria, starting from zones 1 through 4.

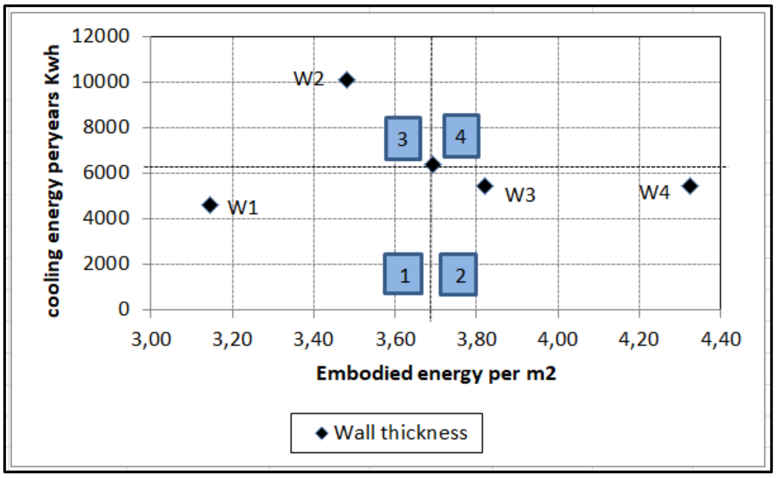


Figure 7 Position chart of each model of building in terms of cooling energy and embodied energy

In Figure 7, the position of the building model in zone 1 is model W1. The building model located on zone 2 is W3 and W4. W2 is located in zone 4. The W1 model has an cooling energy higher than W3, but the difference is relatively low (5.8%). The annual embodied energy value of W1 is lower than for W3 (21.3%). The W1 building model has a lower cooling energy value compared to W2 (201%), while the embodied energy value of W1 is lower than that for W2 (10%), based on the position of the W1 model with respect to both W2 and W3 building models. Hence, W1 is the optimal building model. The building has an annual cooling energy of 8106 K.h and an embodied energy value per year of 3.15 GJ /m^2.

The effect of using calcium silicate boards on the optimal building must be determined. Therefore, wall conditions without calcium silicate boards require values of cooling energy and embodied energy from the model to be determined. Figure 8 show the difference in cooling energy load (6.3%) and embodied energy (5%) of a building model with 8 cm wall thickness. The value of the difference is relatively small and insignificant. This result indicates that the presence of the calcium silicate panel has little effect on building energy.

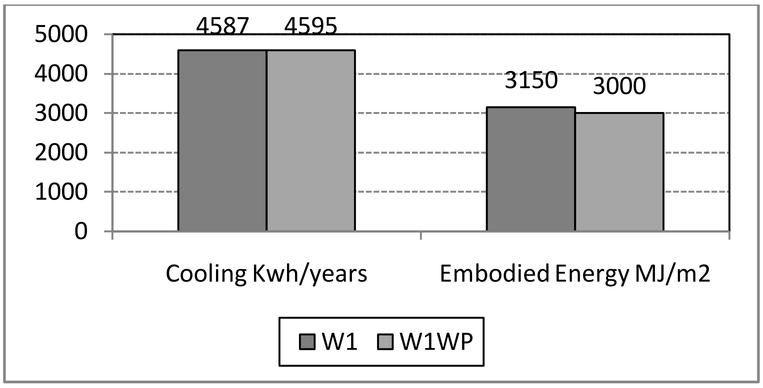


Figure 8 Position graph of optimal energy building model (W1) with or without panels (W1WP)

III.4 Application block

Walls of 8 cm thickness were found to be optimal. For that, we need to make a sample block that has a thickness of 8 cm. The resulting block has a soil weight composition of 50% by weight of paper while the cement composition is 20% of the total weight. Soil used in accordance for a soil block should contain 45% sand [10]. The shape of the block is made with a thickness of 8 cm width of 30 cm and length of 50 cm, with a weight of 10–12 kg. The resulting block density is 850–1000 kg / m^3. Both outer and inner sides of the block are coated with 2 mm thick calcium silicate boards. As a comparison, red brick has a density of 1700 kg/m3, while soil block's density is 2050 kg/m3. A typical soil-paper block can be seen in Figures 9 and 10.

Figure 9 Soil-paper block with calcium silicate panels

Figure 10 Soil-paper blocks without calcium silicate panels (WP)

Sample temperature measurements were made by constructing a room model of the block arrangement as high as 30 cm. The data logger analysed pairs of outside and indoor models. Field measurements of temperatures inside and outside the model are given in Figure 11. In the morning, inside temperatures are generally higher than those outside while during the day, indoor temperatures tend to be lower. Temperatures at night are higher than those outside. The ideal temperature conditions are during the day, so that the walls can reduce heat. But in the afternoon, the room temperature is higher than the outside temperature. The wall is therefore more optimal during the day. Indoor temperature models without Calcium Silicat panels in the noon and afternoon are lower than the models with Calcium Silicat panels. This shows that the Calcium Silicat model without panels is better than the model with the Calcium Silicat panels.

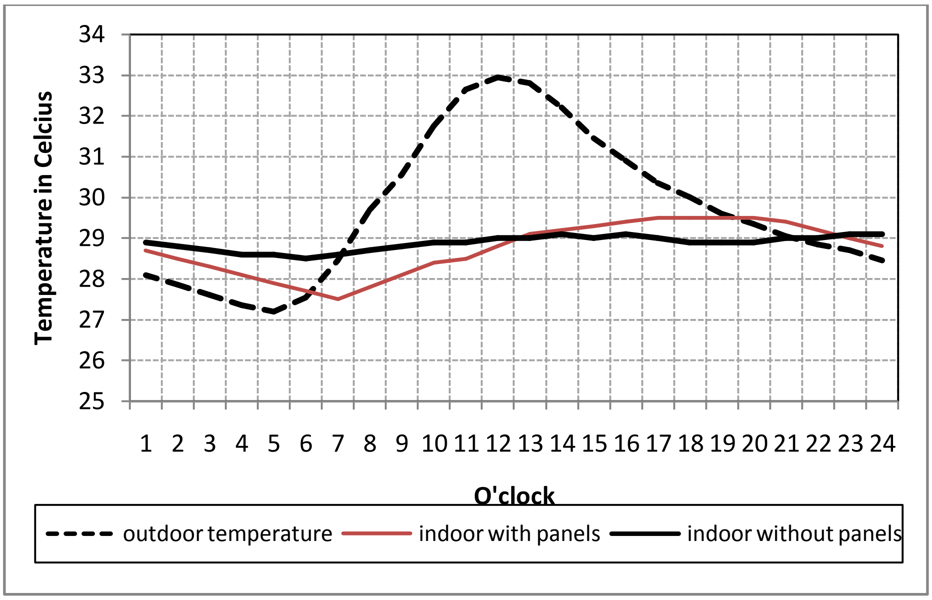


Figure 11outdoor and Indoor temperature condition models

CONCLUSIONS

Soil-paper block walls with calcium silicate board with an cooling energy and embodied energy are optimal when they are of 8 cm thickness. Soil-paper block samples are lighter than compressed earth block (CEB) and red bricks because the former have lower densities than CEB and red bricks.

The use of 8 cm calcium silicate boards for a simple house leads to indoor temperatures at night being warmer than without such boards. This result shows that the use of calcium silicate boards is not necessary and they are probably more suitable as protection from rainwater or as a substitute for wall plastering. But on thicker walls, calcium silicate boards have an effect on the indoor temperature of the building.

The disadvantage of using a calcium silicate board on soil-paper wall in a low income house is that it interferes with the aesthetic appearance of soil-paper walls. The use of such boards on walls also causes an increase in the embodied energy of the walls.

In this study, the process of drying soil-paper blocks was found to require a relatively long time due to the characteristics of the pulp paper, which takes a long time to dry. Hence, the determination of soil-paper block length and width must also be considered.

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