The effect of wall material on energy cost reduction in building

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**ABSTRACT**

To reduce the energy consumption of buildings, walls have an important role to conserve energy costs of the AC. The choice of appropriate material for walls can significantly reduce the energy consumption of the AC. In this research, a new composite material was developed to design the walls of buildings. Due to high thermal resistance, there are possibilities for Styrofoam and soil as a principal bonding material to produce an innovative CLC brick. The aim of this research is to investigate the effect of wall materials on energy cost reduction. There are two kinds of building investigated, such as building-1 using a traditional CLC brick and building-2 with using innovative CLC bricks to manufacture the wall. To investigate the energy costs, an economic mathematical model was developed to calculate the optimal cost of AC according to climate change during the hot season in Barru South Sulawesi-Indonesia. The investigation revealed that due to the $Q$ factor, a building using a traditional wall material has a higher energy cost for the AC (IDR 34,109) than if using an innovative wall material (IDR 28,346). Consequently, the ECR was IDR 5763 (16.89%).

1. Introduction

As a developing country, Indonesia faces serious problems from an anticipated increase in population. The current population of Indonesia in 2019 is around 2,669,536,000 [1]. Annually, the population increases around 1.07% [1]. Consequently, it has created a big environmental problem around demand and consumption of energy. According to Ref. [2] household energy consumption for electricity sector accounts for approximately 49.12% of Indonesia’s total energy consumption in 2018. In addition, energy for buildings is responsible for 28% of energy savings related to CO2 emissions [3].

As a material designed for walls of buildings, CLC brick has an important role to conserve energy consumption in building construction. Similar to the previous research [4], studies on wall design to improve performance and reduce heat transfer can be categorized into three groups: developing new types/models walls; construction of wall materials that have different properties and characteristics and optimizing of combinations for some materials to construct walls.

Firstly, some research has been developed for new types/model of walls. Author in Ref. [5] argues that using shear walls and appropriate materials could avoid heavy damage because of earthquakes in Turkey. The kinds of materials and shear walls are based on the Turkish Seismic code 2007. To perform reinforcement towards shear wall, carbon fiber reinforced polymer was applied to investigate the seismic behavior of the shear wall [6]. Another model was developed by Ref. [7] to investigate the properties of cavity walls for sound insulation. By increasing the wall’s width cavity and applying sound-absorbing material for this model, it is appropriate to reduce the load acting on the ceiling structure and as sound insulation. In addition, applying partition wall model was developed by Ref. [8] to investigate the seismic performance of non-structural lightweight steel drywall building components.
Secondly, other studies have discussed the construction of wall materials that have different properties and characteristics. For example [9]: investigates reinforced concrete blocks for seismic resistant low-and mid-rise building in North America. In this research, there are eight different models that have been developed to analyze the maximum displacement capacity of reinforced concrete blocks. One of these models was selected to further investigate the effect of altering the characteristics of the wall. As a result, the influences of the axial load and vertical reinforcement bar spacing on wall drift capacities are higher than other models. Other study has been developed by Ref. [10] to investigate veneer as alternative material for wall. This paper presents the main characteristic, summarizes the different types of brick veneer walls, different type of analysis (experimental and numerical) and different types of loading. Based on the results, the contribution of brick veneer has been significant to respond to the resisting system in case of structural system. In addition, the author in Ref. [11] developed wood as construction of wall material which have different characteristics than previous materials. This study developed a model to define the load resistance of wooden-framed walls. The finite element model was developed to characterize the response of a wooden-framed wall under both in plane and out-of-plane wind load. The study reported that performing rigorous finite element analyses to address the influence of some variables and proposes modification factors to be used in the developed parametric models.

Thirdly, optimizing of combinations for some materials to construct walls of buildings. For example: selecting appropriate materials to create a new wall to increase the performance of building [12,13]. Author in Ref. [14] develops zero energy building with combining some materials of external walls according to climate change in the Mediterranean. This method applied a technology of light multi-layer walls considering the low density of material, thermal insulation, width, low specific weight, low mass accumulation, to achieve very low steady thermal transmittance. As a result, lighter and thinner walls are a possible solution to obtain high performance of buildings [15]. Revealed optimisation of insulation thickness to achieve energy saving in Turkey. This is because in almost buildings without insulation and the energy price for heating was expensive. In this research, the optimum insulation was conducted for different insulation material such as: expanded polystyrene and rock wool, considering, five different energy sources, namely: coal, LPG, fuel oil, natural gas and electricity. Based on the results, the energy saving and payback period were 14.09 $/m² and 1.43 years, respectively. In addition, optimize the design of envelope for new residential houses according to climate change in Southern Italy. For example: walls, slab-on ground floor, roof, shading, windows and internal heat load. Under dynamic simulation software, the prototype of the building has been modelled to achieved a high efficient building [16].

This research focuses on the third category. Today, some research studies optimize certain wall materials to improve the performance of buildings, such as: bricks [17], wood [18], glass [19] and timber [20]. These materials were used to create and develop new types/models of walls with different functions. For example: lightweight [21], strength [22] and soundproofing [23] constructions. None of these studies developed a new model that can be used to reduce energy consumption of buildings [24]. analyzed the energy performance of an office building with a ventilated composite Trombe wall for winter heating application. They designed a new composite Trombe wall located in Kitakyushu, Fukuoka, Japan, that is oriented on the southern side of the office building and designed
pipes with a fan to control thermo-circulation. As a result, the composite Trombe wall could minimize energy costs by up to 3.7% annually. However, they investigated only the optimized ventilation of a Trombe wall.

The proposed model designs a new CLC brick to create walls for buildings. The materials contain: soil, Styrofoam, calcium carbonate, iron and water. Soil and Styrofoam were chosen as the main and bonding materials to manufacture CLC brick as it is inexpensive and easy to obtain. In addition, Styrofoam has a high thermal insulation and it can protect the environment from waste Styrofoam pollution. Moreover, waste from Styrofoam contributes greatly as detrimental waste that can pollute water sources either directly or indirectly. In contrast, the materials of traditional design contain only: cement, foam, sand and water. These materials were expensive and have no significant impact on the environment. Therefore, manufacturing CLC brick using Styrofoam is an appropriate solution from an environmental and economic perspective.

According to Ref. [25] Styrofoam, also known by the generic term "extruded polystyrene foam", is one of the most widely used types of plastic for various purposes and makes it easy to use for many industries and applications. For example: coffee cups, plates, bowls, packing material, craft materials and thermal insulation. Styrofoam is made of plastic polystyrene, a non-metallic solid with low thermal conductivity. The physical properties of Styrofoam are thermoplastic. Its material is solid when at room temperature, but it can be a liquid when heated to a specific point. Therefore, it can be molded in fine detail.

This paper is systematized into five sections, as follows: section 1 is the introduction; section 2 is method; section 3 is result and discussion, section 4 is conclusion and section 5 is references.

2. Methods

2.1. Description of the problem

To implement energy saving for buildings, particularly in residential homes during the hot season. The Indonesian government conducted some trials to prevent increasing electricity bills for building caused by air conditioning. According to Ref. [26] the electricity demand increased due to residential air conditioner loads. Indeed, the electricity demand reached the maximum level during the hot season. Therefore, it’s important to design an innovative wall material to replace traditional brick to meet energy savings goals. On the other hand, using non-recycling material can keep the environment free from polluting waste. It is also inexpensive and easy for engineers to apply in practice.

2.2. Description of building

In this research there are two kinds of buildings that were investigated: The first building uses traditional CLC brick as wall material. The second building uses an innovative CLC brick as wall material. To manufacture an innovative CLC break required selected soil, Styrofoam, calcium carbonate, iron and water. In contrast, to manufacture traditional CLC bricks only required cement, fly ash, water and foam [27–29].

Fig. 1 illustrates the physical model of building description and wall design. The total thickness of wall design is 15 cm with inside and outside insulation being 2.5 cm. In simple terms, the thermophysical properties of the inside and outside wall insulation for both designs are equal. Consequently, thermal conductivity of these insulations for both designs was similar. However, due to the differences of materials, the characteristics of both CLC bricks were different.

In this research the characteristics of the buildings were illustrated in the following parameters: Q of both building, namely 1.5 W/m²°C and 1.1 W/m²°C for building-1 and building-2, respectively. A of building-1 and building-2 are equal to 15 m². B for building-1 and building-2 is 450 W. X for building-1 and building-2 is 10 h. Permitted T maximum and minimum were 24 °C and 20 °C, respectively; the To was 33 °C; S for both building is 900 W; P is IDR/kWh 1352.
2.3. Outside temperature

Fig. 2 illustrates an example of outside temperature in Barru South Sulawesi. Similar to other places, the outside temperature during in the morning and night time lowest to low level. According to the climate change on Barru, the minimum and maximum temperatures were 15 °C and 33 °C were recorded at 00:00 a.m. and 13:00 p.m., respectively. The high temperature only increased to the maximum level occurred on 11:00 a.m. to 16:00 p.m., such as: 31 °C in 11:00 a.m., 32 °C in 12:00 p.m., 33 °C in 13:00, 32.5 °C in 14:00 p.m., 31 °C in 15:00 p.m. and 30 °C in 16:00 p.m. In contrast, the temperature of less than 30 °C was conducted from 00:00 a.m. to 10:00 a.m. and from 17:00 p.m. to 23:00 p.m.

2.4. Mathematical formulation

To achieve the goal of research, an economic mathematical model was developed to address the energy costs of building, as illustrated in the following equation:

\[
ECB(t) = \int_{t=1}^{t_n} ((S(t) \cdot P(t) \cdot X(t) \cdot Y(t)) \ dt) \tag{1}
\]

Subject to constraints:

\[
\frac{dT}{dt} = \frac{Q}{A} \cdot \left( T_0 - T(t) \right) - \frac{B \cdot Y(t)}{H} \tag{2}
\]

The ECR is calculated based on the following equation:
Controlling the air conditioning load based on the outside temperature. The control system turned off the AC if the inside room temperature reached the maximum level. In contrast, the AC was turned on if the AC dropped to the minimum permitted temperature. To achieve this objective, an optimisation package such as MATLAB allows the occupant to carry out optimisation within operational constraints such as a permitted temperature range.

3. Result and discussion

3.1. The effects of wall materials without the AC

The following Fig. 3 illustrates the simulation of temperature as a function of day. The outside and inside temperatures are described on July 2019. Local temperature in Barru South Sulawesi was selected as outside temperature. Inside temperature-1 and inside temperature-2 simulates the room temperature for building-1 and building-2, respectively.

Based on Fig. 3, the inside room temperature for building-1 and building-2 varied. In general, the pattern of inside room temperature is based on the outside temperature. The inside room temperature was increased to a high level when the outside temperature increased to the maximum level. For instance: the outside temperature on 22nd July 2019 was 33°C, the inside room temperatures of building-1 and building-2 were increased to 28°C and 25°C, respectively. In contrast, the inside room temperatures of both buildings decreased to the minimum level when the outside temperature dropped to a low level. For example: the outside temperature on 15 July 2019 was 27°C; the inside room temperature of building-1 and building-2 were increased to 25°C and 24°C. As a result, due to the thermal insulation wall of building-2 being higher than building-1, then inside room temperature of building-2 was lower than building-1.

3.2. The effect of wall materials on energy cost reduction

In this research study, simulated energy cost was investigated for a sunny day on Monday, 22nd July 2019 using the AC from 10.00 a.m. to 19.00 p.m. The room temperature is set to 20°C and 24°C for minimum and maximum permitted temperatures. Equation (1) and (2) are used to investigate the energy cost of building-1 and-2, as illustrated in the following Figs. 4 and 5.

As shown in Fig. 4, the control system cycling temperature to calculate the cost of the AC. Under numerical optimisation, the control system defines the minimum cost of the AC. The purpose of this control is to keep inside room temperatures comfortable for the
consumer. In this case, the permitted minimum and maximum temperatures were 20 °C and 24 °C, respectively. In this simulation, starting temperature of 22 °C was chosen from the case study. To calculate the energy costs for the AC, the energy cost was recognized when the inside room temperature decreased to the minimum permitted temperature. For instance, the energy cost was calculated from switch number 1 to switch number 2, when the inside room temperature decreased to the minimum permitted temperature (from 24 °C to 20 °C). In contrast, the energy cost was not recognized when the inside room temperature increased to the permitted maximum temperature. For example: switched number 2 to number 3, when the inside room temperature increased to the maximum permitted temperature (from 20 °C to 24 °C). The form of cycling temperature was continuous until the end of time to operate the AC. The control system setting-up the time to switch the AC on and off according to the characteristics of the building. Due to the heat transfer coefficient factor then the control system dropped the inside room temperature to 20 °C. As a result, the cost of the AC achieved was IDR 34,109.

Fig. 5 illustrates the cycling temperature and energy costs of building-2. Similar to the previous method, to keep the inside room temperature comfortable then the control system only cycles the inside room temperature from minimum to maximum permitted temperature. The permitted maximum and minimum temperatures were 24 °C and 20 °C. The temperature of 22 °C was selected for the starting temperature. In this simulation, the energy cost was calculated when the inside room temperature decreased to the minimum permitted temperature. On the other hand, the energy cost was equal to zero when the cycling temperature status increased to the maximum permitted temperature. Due to the heat transfer coefficient factor that the inside temperature room dropped to above 20 °C, only the switched number 22 dropped to 20 °C. Consequently, the energy cost was IDR 28,346.

Equation (3) is used to define the ECR. The ECR was IDR 5763. Based on Fig. 6 the energy cost of building-2 was cheaper than building-1. This is because the material is used to construct a wall for building-2 has a lower heat transfer coefficient than building-1. Therefore, the consumer paid a cheaper cost if using an innovative CLC brick to design walls for building.

4. Conclusion

In this research, there are two kinds of building was investigation. Building-1 was built from traditional CLC brick and building-2 was built from an innovative CLC brick. The investigation revealed that the heat transfer coefficient of building-1 was higher than building-2. Under an economic mathematical model revealed the energy cost of the AC for building-1 was higher than building-2. In the calculation, the ECB-1 was IDR 34,109 and ECB-2 was IDR 28,346. As a result, the ECR was IDR 5763 (16.89%). In addition, it is recommended to the consumer that the energy cost for building can be minimized when the innovative CLC brick is applied to manufacture a wall.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.csite.2019.100573.
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