Conference Paper

Eco House Design: A House Design to Reducing Carbon Dioxide Emission

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Abstract

Until 2016, fossil fuels as primary energy are included in the top three most widely used. The process of combustion of fossil fuels causes the release of tremendous amounts of carbon to the atmosphere. In the atmosphere, carbon turns into carbon dioxide (CO_2) or often called greenhouse gas. Greenhouse gas has a negative impact on the environment: direct effects like acid rains, and indirect effects like global warming. In Indonesia, the buildings used 37.8 percent of the total national energy consumption and are directly responsible for 37.8 percent of CO_2 emission. This study aims to discuss the impact of reducing energy consumption used by the household on the risk of greenhouse gases. A computer simulation was used to calculate energy consumption in buildings. A conversion method from building energy consumption to the amount of CO_2 emission was used to determine the level of reduction of greenhouse gas risk. Some parameters were evaluated, such as building's material (e.g., roof, wall) and building geometry. It was found that the energy consumption savings were around 66.1 percent and operational CO_2 savings were obtained 923 kg/year.

Keywords: carbon dioxide, design criteria, eco house, energy saving, greenhouse gas

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1. Introduction

Greenhouse gas (GHG) emission has now become everybody's concern. This is because greenhouse gases in the atmosphere increase the temperature of the Earth [1, 2]. Therefore, greenhouse gases are a significant contributor to climate change. According to Kyoto Protocol, GHG consist of CO_2, methane (CH_4), nitrogen oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulfur hexafluoride (SF_6) [3, 4]. Among these GHG, CO_2 is the most critical anthropogenic gas, accounting for nearly 80 percent of the enhancement of the global warming effect [5]. One very obvious way to contribute to the fight against greenhouse gas emission is to reduce CO_2emission.

CO_2 emissions associated with energy can come from a range of fuel types. According to the Handbook of Energy and Economic Statistics of Indonesia, building use 37.8

percent of the total national energy consumption and are directly responsible for 37.8 percent of national emissions. It was shared the most significant part of CO_2 emissions, followed by transportation sector (30.3 percent), industry (25.5 percent), commercial sectors (4.1 percent) and other sectors (19.4 percent) [6]. Efforts are gearing up towards reducing annual CO_2 emissions in building through the use of suitable materials.

Klufallah et al. [7] found that choosing environmental – friendly material in the building would help to reduce CO_2 emissions by 16.17 percent. A study of three terraced houses in Spain by Gonzalez and Navarro [8] have also demonstrated that the use of materials has a significant impact on carbon dioxide emissions, influencing both the embodied and operational energy of the buildings. In another study, Ganguly et al. [9] showed that the correct selection of materials saved 8 percent of the energy that directly would reduce CO_2 emissions by 8 percent [9].

From the previous studies, it is evident that one of the factors affecting energy consumption and annual CO_2 emission in the building is material. The primary objective of this paper is to identify and determine the energy consumption and CO_2 emission of construction material and geometry of building from selected models. Furthermore, this study aims to identify the correlation between construction material and building's geometry and its energy consumption and carbon emission. Eventually, this study proposes some option for designing eco house design based on the simulation result.

2. Methods and Case Study

2.1. Computer simulation

The building is complex physical objects. Physical objects in buildings such as envelope component (e.g., walls, windows, roofs) strongly correlated to the performance of buildings. In recent years, the variables affecting energy use have increased manifold, and computer simulation to predicting energy performance in the building have been developed [10]. By using computer simulation tool, energy performance analysis can be obtained in a short time and calculated by hourly frequency. One of the shortcomings of computer simulation is not immune to GIGO (Garbage In, Garbage Out). This means that the simulation result depends on the value entered. So, all the input parameters must be appropriately defined.

By weighing the performance of computer simulation tool, a computer simulation was performed in this study to calculate and simulate the energy consumption and annual CO_2emission of the building. Nowadays, there are many building performance simulations with different user interfaces and various simulation engines that are capable of these analyses, and one of them is EnergyPlus. EnergyPlus is free of use and can be downloaded from the official website provided by the U.S. Department of Energy [11]. EnergyPlus simulation is mainly based on input from a text file of building geometry, material and weather conditions — those input files created by using Google Sketch Up 3D drawing program and Open Studio Plug-in. The data input shown in Figures 1 and two are created using Sketch Up then converted to IDF file and the material used is defined using Open Studio Plug-in.

In addition to simulating building energy performance (i.e., energy consumption), EnergyPlus also used to affect thermal comfort (indexed by Predicted Mean Vote and Predicted Percentage Dissatisfied), and amount of atmospheric pollution (e.g., CO_2, SOx, NOx, CO), produced by household [11]. In this study, the output parameters used from the simulation are the total energy consumption and annual CO_2 emission. Energy consumption is the total energy used at home. This value is obtained from the total energy consumption of electric light, electric equipment, heating, and cooling system, used by the household. Meanwhile, annual CO_2 emission in EnergyPlus was obtained using Equation (1).

$$CO_2 = \text{Total energy consumption} \times 66.0233 \frac{g}{MJ} \tag{1}$$

EnergyPlus has been used in other studies as a source of consumption. Rallapalli used EnergyPlus [10] for analysis of energy consumption compared to eQuest and actual condition. The comparison results indicate that in term of energy consumption (kWh), the discrepancies between the EnergyPlus and the eQuest result were around of 4 percent, while comparison between EnergyPlus and actual condition were around of 5 percent [10]. The U.S. Department of Energy has been validated the EnergyPlus simulation result with ANSI/ASHRAE Standard 140-2011 and International Energy Agency Solar Heating and Cooling Program BesTest (Building Energy Simulation Test) methods. From the results of the study [10], and high acceptance levels by the building energy analysis community on EnergyPlus, it can be concluded that EnergyPlus is feasible to be used for energy performance analysis.

2.2. Description of the base building models

The base building to be simulated is house model according to the regulation decree of Ministry and Public Works (No. 403/KPTS/M/2007). Figure 1 illustrates the base building model for the simulation. The house's geometry was created with Google Sketch Up based on the house plan and then converted to an EnergyPlus input file using Open

Studio plugin. The house is located at Bandung – Indonesia, so that climatic condition input in the simulation used weather condition of Bandung. The house has one floor with a total area of 36 m^2. It is composed of one living room, two bedrooms, one bathroom, and one kitchen. The walls are made of brick, and the roof is made of metal without insulation. Table 1 summarizes the description of the building models.

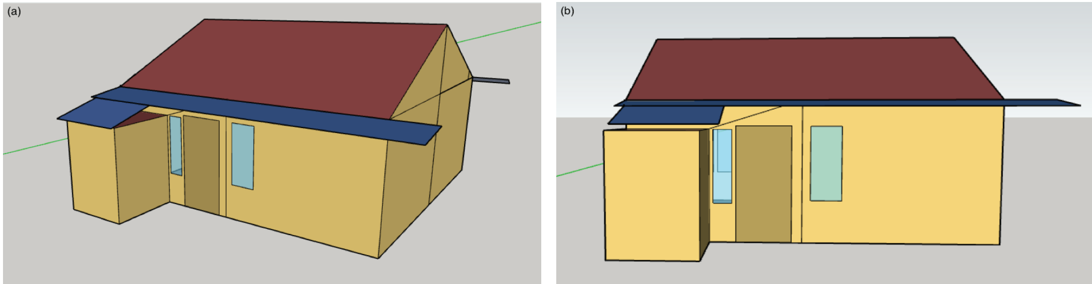

Figure 1: Design object of the base case – Type 1, (a) Isometric view; (b) Front view.

Table 1: Description of the base model – Type 1.

Component	**Information**
House area [m^2]	36
Window Wall Ratio (%)	0.05
Ceiling height [m]	2.5
U-value of glass[W/m^2K]	5.894
U-value of roof	2.15
U-value of wall	2.08
Glass SHGC	0.862
Roof type	Gable
Building type	Use AC

2.3. Simulation test cases

In this study, 18 building models include a base case model was developed for the simulation to obtain the optimum design for eco house design (indexed by the annual CO_2 emission). 18 building models consist of nine models with the geometry of building type 1 (see Figure 1) and nine models with the geometry of building type 2 (see Figure 2). Building type 1 and 2 have differences in geometry and roof shape. Building type 1 has a gable roof while type 2 has a shed roof. However, both of them have the same parameters of total house area, Window to Wall Ratio (WWR), and glass type. In a previous study conducted by PUSKIM, the simulation result using Ecotect showed that shed roof type reduces the temperature value of 3°C from the base case. The cost directly reduces energy use by household. So, in this study using type 2 as a comparison of energy performance with type 1 using EnergyPlus. The simulation mainly focused on wall and roof material, and the house's geometry. As indicated, three types of wall materials were used, they are brick, Aerated Lightweight Concrete (ALC) and timber with the respective U-values are 2.08W/m^{2}K, 1.41 W/m^{2}K, and 0.45 W/m^{2}K. Meanwhile, the U-values for a metal roof, concrete tile roof and metal roof with 25mm insulation are 2.15 W/m^{2}K, 0.664 W/m^{2}K, and 0.26 W/m^{2}K, respectively. Table 2 shows the physical condition of building type 2; meanwhile, Table 3 shows the detailed information of input parameters and simulation test cases.

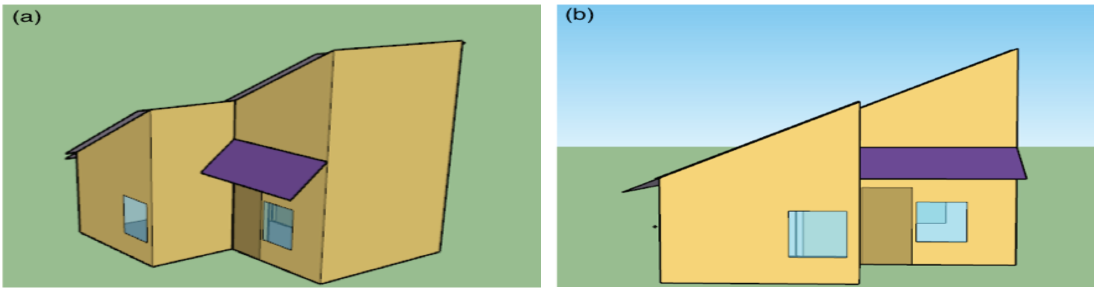

Figure 2: Variation design - Type 2, (a) Isometric view; (b) Front view.

Table 2: Description of variation design – Type 2.

Component	Information
House area [m^2]	36
Window Wall Ratio (%)	0.05
Ceiling height [m]	2.5 – 6
U-value of glass[W/m^{2}K]	5.894
Glass SHGC	0.862
Roof type	Shed
Building type	Use AC

3. Result and Discussion

A comparison of the simulation result of energy consumption is shown in Figure 3, and annual CO_2 emission for the various models is shown in Figure 4. The energy consumption is obtained from the total energy consumption of electric light, electric equipment, heating, and cooling system, used by the household for one year. As illustrated in Figure 3, the energy consumption of the base case model was around 21.14 GJ/year.

The effect of roof materials was analyzed by comparing Base Model and Model 1-5, Model 6-11, and Model 12-17. By using brick as wall material in Base Model and Model 1-5,

Table 3: List of simulated parameters.

	Wall Material	Roof Material	Design object
Base	Brick	Metal	1
Model 1	Brick	Metal	2
Model 2	Brick	Metal & insulation 25mm	1
Model 3	Brick	Metal & insulation 25mm	2
Model 4	Brick	Concrete Tile Roof	1
Model 5	Brick	Concrete Tile Roof	2
Model 6	Timber	Metal	1
Model 7	Timber	Metal	2
Model 8	Timber	Metal & insulation 25mm	1
Model 9	Timber	Metal & insulation 25mm	2
Model 10	Timber	Concrete Tile Roof	1
Model 11	Timber	Concrete Tile Roof	2
Model 12	ALC	Metal	1
Model 13	ALC	Metal	2
Model 14	ALC	Metal & insulation 25mm	1
Model 15	ALC	Metal & insulation 25mm	2
Model 16	ALC	Concrete Tile Roof	1
Model 17	ALC	Concrete Tile Roof	2

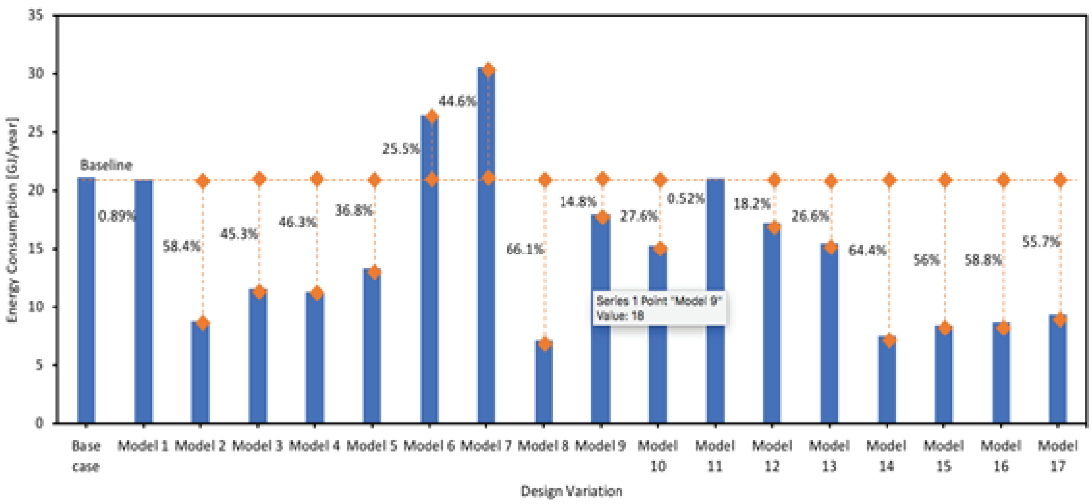

Figure 3: Energy consumption result.

it showed that Model 2 obtained the highest energy saving percentage (58.4 percent), followed by Model 4 (46.3 percent). Meanwhile, by using timber as wall material in Model 6-11, it showed that Model 8 obtained the highest energy saving percentage (66.1 percent), followed by Model 10 (27.6 percent). And simulation result by using ALC as wall material in Model 12-17, it showed that Model 14 obtained the highest energy saving percentage (64.4 percent), followed by Model 16 (58.8 percent). From the simulation result, by using the same wall materials, Models with the highest saving percentage of energy consumption used metal + insulation 25 mm as the roof material. The U-value of material is one of the critical factors in the effective control of heat transfer to the building. Metal roof with 25mm insulation in Model 2, 8 and 14 has the smallest U-value of 0.26 W/m^{2}K compared to other material, while concrete tile roof has a U-value of 0.664 W/m^{2}K and the U-value of metal roof is 2.15 W/m^{2}K. U-value significantly affected energy consumption since it directly related to heat transfer characteristic of materials. Heat transfer through the material with high U-value was more extensive than that with the smaller U-value. Recent studies also have shown the same analysis that among the envelope parameters, the most effective improvement by adding additional insulation to obtain smaller U-value [12–14]. From those data can be concluded that the performance of concrete tile as roof material more efficient than using metal + insulation 25mm as roof material in building type two. This is because of the more important parameter in energy consumption is roof material (6 percent) than roof shape [15].

The same phenomena also could be seen in the case of different roof materials. As illustrated in Figure 3, by using metal as roof material in Base Model, Model 1, 6, 7, 12, 13, it showed that Model 13 obtained the highest saving percentage (26.6 percent), followed by Model 12 (18.2 percent). Meanwhile, by using metal + insulation 25mm as roof material in Model 2, 3, 8, 9, 14 and 15, it showed that Model 8 obtained the highest saving percentage (66.1 percent), followed by Model 14 (64.4 percent). And simulation result, by using the concrete tile as roof material in Model 4, 5, 10, 11, 16 and 17, Model 16 obtained the highest saving percentage (58.8 percent), followed by Model 17 (55.7 percent). From the simulation result, by using metal and concrete tile as roof materials, ALC as wall material obtained the best combination. Similar to the effect of roof materials, in the wall component, the U-value of material also affects energy consumption. The U-value of brick is 2.08 W/m^{2}K, and timber has a U-value of 1.41 W/m^{2}K while ALC had U-value of 0.45 W/m^{2}K which was significantly lower than the other two materials types. Thus, it directly shows that the energy consumption in the material which has high U-value is greater than material that has a small U-value. However, by using metal + insulation 25mm as roof material, the best performance is by using timber as wall. This is probably because U-value of metal + insulation 25mm has a very small value that can cover the performance of timber.

In particular, the building geometry/shape has a significant impact on a building energy performance, as well as impacting on building emission rates [16, 17]. In general, by comparing the same material with different geometry types, it found that type 1's geometry has better performance than type 2's geometry. The discrepancies between

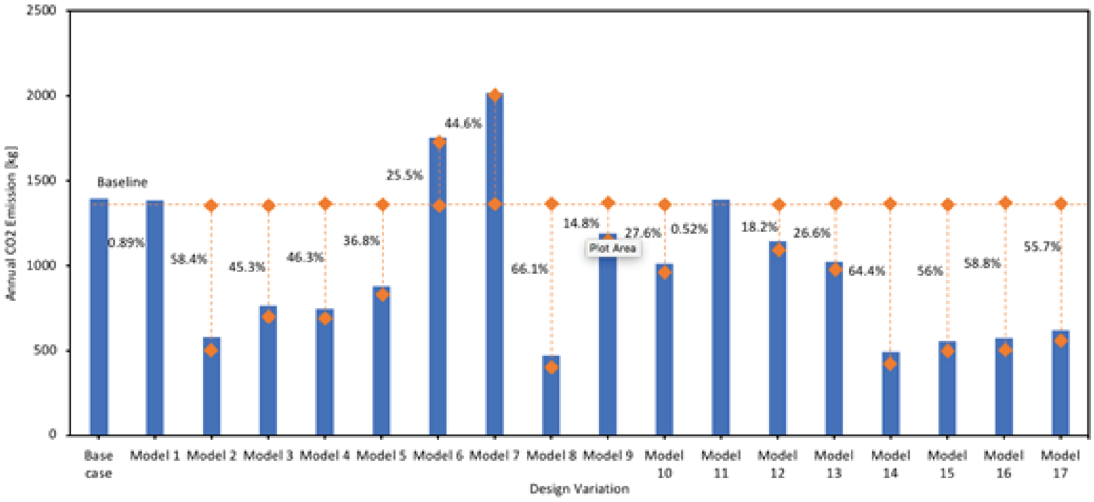

Figure 4: Annual CO_2 emission result.

the type 1 and type 2 performance were around 3.1- 51.3 percent. However, the comparison between the Base Model and Model 1, Models 12 and 13, type 2 has better performance than type 1. The discrepancies between the Base Model and Model 1 were around of 0.89 percent, while the comparison between Model 12 and 13 was about 8.4 percent.

From the simulation results, Model 8 has the best performance with energy consumption savings of 66.1 percent from the baseline. Design parameter for Model 8 is the use of timber as wall material timber, metal + insulation 25mm as roof material, type 1 as building's geometry. They are followed by Model 14 (64.4 percent) and Model 16 (58.8 percent). By reviewing Models 14, 15, 16, and 17 (using ALC as wall materials), those models have an energy consumption savings performance above 50 percent. It shows that the wall material is more influential than the material and the shape of the roof.

Figure 4 shows the annual CO_2 emissions generated by households. The yearly value of CO_2 is proportional to energy consumption; it is shown in Equation (1). Once the energy consumption ofthe models profile was found, the energy metric was converted into its equivalent carbon emission [13]. So, in Figure 4 the percentage reduction of CO_2 equals energy consumption saving. In the Base Model, the CO_2 emitted by the household is about 1395.7 kg/year. Using Model 8, the CO_2 emitted reduces to 472.1 kg/year.

4. Conclusions

This study aims to identify the correlation between construction material and building's geometry and its energy consumption and carbon emission. Furthermore, this study proposes some option for designing eco house design, built in Bandung climate condition based on the simulation result. Eco house design indexed by energy consumption and annual CO_2 emission. The annual value of CO_2 is proportional to energy consumption. Parameters that have an effect on reducing CO_2 emitted by households are wall material, roof material, and building geometry. From the simulation results, Model 8 has the best performance with energy consumption savings of 66.1 percent from the baseline and the CO_2 emitted by household reduces to 472.1 kg/year. Design parameter for Model 8 is the use of timber as wall material timber, metal + insulation 25mm as roof material, type 1 as building's geometry.

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