Conference Paper

Potential of Energy Saving through Modification of Low Energy Housing Models

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Abstract

Globally, building sector currently consumes around of 40 percent of total energy and it is predicted to further rapidly increasing up to 80 percent by 2040. This study aims to investigate some design options to achieve thermal comfort and reduce energy consumption. In Indonesia, building sector consumes around of 37.8 percent of the total nationwide energy consumption. Computer simulations using EDGE and EnergyPlus were performed in this study to obtain embodied energy value and obtain operative temperature respectively. EDGE uses monthly quasi-steady-state calculation method based on the European CEN5 and ISO 13790 standards while EnergyPlus uses dynamic simulation model based on hour-by-hour (or higher resolution) outputs. A single storey building with 12 different parameters and design configurations including one base model were developed for this simulation. Some parameters were evaluated such as wall materials, roof materials, Window to Wall Ratio (WWR), window shading, ventilation opening, solar PV and ceiling fan. The simulation results showed that modification of U-value of wall and roof, increased WWR value, presence of window shading, additional rooster above windows with WWR of 9 percent and additional ceiling fans would optimize the embodied energy saving of building by 20.2 percent. Under these circumstances, final embodied energy saving of building was around of 63,939 MJ. This result was 10,837 MJ higher than that of the base model. Simulation results showed that the operative temperature mostly did not exceed the upper comfortable limits.

Keywords: EDGE, EnergyPlus, energy-saving, housing, low energy, simulation

1. Introduction

Currently, building sector consumed around of 40 percent of worldwide energy consumption and it is predicted to rapidly increasing up to 80 percent in 2040 [1]. Based on its percentage, most of energy consumed in the building were used for lighting, cooling, and other electronic equipment such as washing machine, dispenser, and so on. In Indonesia, household sector was shared the largest part of energy consumption due to the fact that they used 378,046 Barrel Oil Equivalent (BOE), or 37.8 percent of

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the total nationwide energy consumption, followed by transportation sector (303,307 BOE), industry and commercial sectors (255,814 BOE and 41,452 BOE, respectively) and other sectors (19,440 BOE) [2].

The energy consumption strongly correlated to the economic growth and environment impact particularly to the global warming. A number of researches were carried out to improve efficiency of energy consumption in buildings [3, 4]. In the residential buildings, ceiling height and the building materials were found to be the most important parameter in reducing energy consumption [5]. Relative average disaggregated end uses and losses of energy in buildings due to the wall is 8 percent and the floor is 7 percent [6, 7]. Particularly in the tropics area, the use of reverse brick veneer R15 instead of brick concrete plaster as wall material saved 8 percent of energy. Nevertheless, several factors should be considered in the selection of wall materials such as U-value, heat admittance and the thickness [8]. Meanwhile, potential of energy saving through modification of roof materials was presented by Ganguly et al. [9]. In their study, U-value significantly affected energy consumption since it directly related to heat transfer characteristic of materials. Heat transfer through material with high U-value was larger than that with the smaller U-value. In other studies, window was found to be one of the fundamental building element in energy saving design of building. Relative average disaggregated end uses and losses of energy in buildings due to the window, ventilation opening and shading is 11 percent [6, 7]. Yang et al. found that the total energy consumption increased when the WWR increased [10]. Nonetheless, the use of shading device as passive control system could save energy by 0.03-13.14 percent [11].

It is common that home appliances contributed to the increased energy consumption of building. In particular, air conditioning system significantly contributed to the residential electricity consumption. It is reported that AC system consumed about 17 percent of total energy in household sector, and followed by ceiling fans (10 percent) [12]. However, using ceiling fan as a substitute for air conditioning is expected to reduce energy consumption without sacrificing thermal comfort through creating air motion in the residences. Furthermore, application of renewable energy sources such as solar panel could be one of the strategies for improving energy consumption toward sustainable buildings. As reported, 21 MW of energy per month were saved in Cairo by utilizing 560 solar panels in 70 units of residential houses [13].

From the previous studies, it is evident that many factors affecting the energy consumption in buildings such as wall and roof materials, Window to Wall Ratio (WWR), window shading, ventilation openings, solar PV and ceiling fans. This paper extends the previous researches with the main objective to find the correlation of the combination of aforementioned parameters to the energy performance of residential buildings. Eventually, this study proposes some options for designing low-energy houses based on the simulation results.

There is no single criterion for low-energy housing because each country has different standards for it. In Germany for instance, low-energy is defined as the housing that has energy consumption up to 50 kWh/m^2 per year for space heating. In the US, to achieve the ENERGY STAR certification, a building must use at least 15 percent lesser energy than that of standard houses [14]. This paper uses the low-energy housing parameters as defined by EDGE. To comply its standard, building must demonstrate a 20 percent reduction in operational energy consumption, water use and embodied energy of materials as compared to the typical local practices (or baseline).

2. Methods

2.1. Computer simulation

Computer simulation was performed in this study to calculate and simulate the embodied energy and operative temperature of the model. Computer simulation is generally used to solve complex mathematical calculations in an easier way. However, if there is a bug in the simulation tool, the accuracy will be affected. In addition, the simulation will be more complex when it used non-dynamic mode [15]. Over the past 50 years, hundreds of building energy programs have been developed, enhanced and are in use, and some of them were reviewed by [16].

EDGE is one of those computer simulation programs. In addition to simulating building energy performance (i.e. embodied energy), EDGE also used to simulate water consumption and the emission of greenhouse gases including carbon dioxide (CO_2) produced by households. EDGE, abbreviation for Excellence in Design for Greater Efficiencies), is a quick and cheaper energy simulation tool provided by International Finance Corporation (IFC). It combines simplicity of empirical models and provide better accuracy than that of steady state models. The simulation is based on the physical description of the building (e.g. material, WWR, ventilation, dimension), heating and cooling systems, and the building location. But EDGE does not take account of the dynamics of building response and Not suitable for detailed analysis of complex building forms [17].

EDGE uses the 'Cradle to Gate' calculation method as defined in European Standard EN: 15804:2012 to obtain the embodied energy value [17]. Embodied energy is the total energy consumed during processing, manufacturing and delivering building materials to construct a building unit. Since energy consumption during construction processes would give environmental impact, thus increasing embodied energy saving significantly reduce the overall environmental impact.

Consistency and reliability of the EDGE results were evaluated by validating and comparing its results with the results of other computer simulation programs (e.g. Energyplus, eQuest, IES) [17]. In India, EDGE was validated using eQuest in four cities representing different climate zones (i.e. hot-humid, warm-humid, temperate and composite) and involved various building types such as apartment, office, hospital, retail and hotel. The comparison results indicate that in terms of energy use (kWh/m^2/year), the discrepancies between the EDGE results and eQuest results in the non-residential building were around of -5 to +10 percent while those in the residential building were around of -4 to +18 percent [17]. These results clearly indicated that the EDGE results met the consistency requirements for simulation and its results are reliable to explain the energy consumption patterns of the building.

Since the operative temperature for EDGE has not been validated yet, EnergyPlus was employed to simulate the indoor operative temperature of the building. EnergyPlus has its root in both the BLAST (Building Loads Analysis and System Thermodynamics) and DOE-2 programs. The advantages of this software are lied in its precision level, easiness for obtaining detailed simulation results due to its hourly resolution and its thermal condition-based simulation. However, using EnergyPlus requires high technical skill in building simulation [18].

2.2. Description of the base building models

For the simulation purpose, the building models were developed reflecting the actual simple detached residential housing as stipulated in the Decree of Ministry and Public Works (No. 403/KPTS/M/2002). **Figure 1** illustrates the building model for the simulation. The building models were situated in Jakarta so that climatic condition input in the simulation used weather conditions of Jakarta. Jakarta is the largest city in Indonesia with a population of 9.2 million. Jakarta contributes 16 percent of Indonesia’s total income, and has annual Gross Domestic Product (GDP) per person of USD7,600. It makes Jakarta become the richest city in Indonesia even it still amongst the other lower income cities according to the Asian Green City Index [19].

The models were typical single storey residential housing with the total area of 32m^2. These buildings typically consist of one living room, two bedrooms, one bathroom, and one kitchen. Relatively small verandas were put on the both sides of building (i.e. front-side and back-side). **Table 1** summarizes the description of the building models.

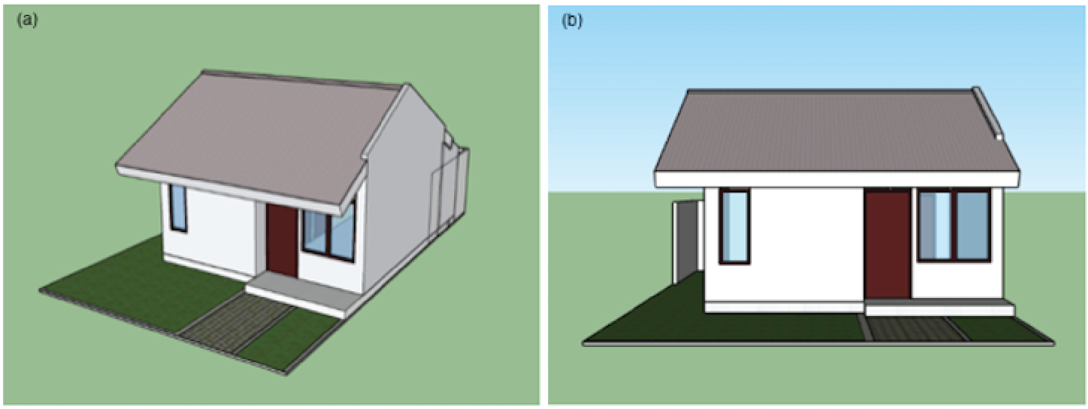

Figure 1: Design object of this study, (a) Isometric view; (b) Front view.

TABLE 1: Description of the base model.

Parameter	Information
Area [m^2]	32
Wall material	Brick
Roof material	Metal roof
Window to Wall Ratio [%]	0.05
Type of roof	Gable roof
Ceiling height [m]	2.5
Building type	Use AC

TABLE 2: Physical conditions of the base model.

Component	Information
Energy sources for hot water	Electric resistance
Energy ources for space heating	Electricity
CO$_2$ emission factor of electricity [g/kWh]	754.57
Window to Wall Ratio [%]	0.05
Solar reflectivity for wall paint	0.40
Solar reflectivity for roof paint	0.30
Efficiency of Hot water boiler	0.80
U-value of Roof [W/m^{2}K]	2.15
U-value of wall [W/m^{2}K]	2.08
U-value of glazing [W/m^{2}K]	5.80
SHGC of glazing	0.80
Coefficient of Performance (CoP) AC system	2.70
Income Category	Low

For simulation, some initial values were put into the model as boundary conditions. Those parameters including physical conditions of building (see **Table 1**), energy sources for home appliances, etc. Furthermore, some initial values of thermal properties of some materials such as U-values, Solar Heat Gain Coefficient (SHGC) were also put as the input. **Table 2** shows the initial conditions of some parameters for simulation of the base models. As indicated, some parameters would change due to the change of simulation test cases. For instance, U-values of would change as the roof materials change from roof metal to the roof metal with 25mm insulation.

2.3. Simulation test cases

As previously described, one building with 12 parameters models including base model were developed for the simulation to investigate optimum design for low-energy housing model. Simulation were conducted by varying several parameters on the single building model. The simulations mainly focused on wall and roof materials, Window to Wall Ratio (WWR), window shading, ventilation opening, solar PV installment and ceiling fan application. **Tables** 3-4 show the detailed information of the parameters and simulation test cases. 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 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. It should be noted that EDGE and EnergyPlus requires U-value as input parameter rather than building material type.

Table 3: List of simulated parameters.

	Base Case	**A**	**B**
Wall Material	Brick	Aerated lightweight concrete (ALC)	Timber
Roof Material	Metal Roof	Concrete Tile Roof	Metal Roof with 25mm insulation
Window to Wall Ratio	0.05	0.09	0.15
Window Shading	No Window Shading	Additional window shading	
Ventilation Opening	Only openable windows	RV9%	R9%
Solar PV	None	0.6 KWp	0.9 KWp
Ceiling Fan	None	Ceiling fans	

Note :
RV9% : Roster below windows + ventilation grill above + increased 9%WWR
R9% : Roster above windows + 9% WWR

3. Result and Discussion

Table 4: Simulation test cases.

Building model	Wall material	Roof material	WWR	Window shading	Ventilation opening	Solar PV	Ceiling fan
Base	Brick	Metal	0.05	N/A	Openable	N/A	N/A
Model 1	ALC	Metal	0.05	N/A	Openable	N/A	N/A
Model 2	Timber	Metal	0.05	N/A	Openable	N/A	N/A
Model 3	Brick	Concrete tile	0.05	N/A	Openable	N/A	N/A
Model 4	Brick	Metal with 25mm insulation	0.05	N/A	Openable	N/A	N/A
Model 5	Brick	Metal	0.09	N/A	Openable	N/A	N/A
Model 6	Brick	Metal	0.15	N/A	Openable	N/A	N/A
Model 7	Brick	Metal	0.05	Additional	Openable	N/A	N/A
Model 8	Brick	Metal	0.05	N/A	RV9%	N/A	N/A
Model 9	Brick	Metal	0.05	N/A	R9%	N/A	N/A
Model 10	Brick	Metal	0.05	N/A	Openable	0.6 Kwp	N/A
Model 11	Brick	Metal	0.05	N/A	Openable	0.9 Kwp	N/A
Model 12	Brick	Metal	0.05	N/A	Openable	N/A	Additional

Note :
RV9% : Roster below windows + ventilation grill above window + increased 9%WWR
R9% : Roster above windows + 9% WWR

3.1. Simulation results

Evaluation of thermal comfort of simulation result was carried out by using Indonesia National Standard (SNI) [6310-2011] and adaptive comfort equation (ACE), which was developed for the use in hot-humid climatic regions [20]. **Figures 2** illustrate the evaluation results of indoor thermal comfort in the respective models (from Base Model to Model 9) on the hottest day of the year, i.e. 29 - 31 October. Models 10-12 were excluded in this analysis because EnergyPlus and EGDE cannot find the value of operative temperature and embodied energy of those parameters (i.e. solar PV and ceiling fan).

As illustrated in **Figure 2**, during the daytime, almost all the cases exceeded upper comfortable limit according to the SNI and adaptive comfort equations (ACE). The effects of wall materials were analyzed by comparing Base Model and Models 1-2 (see **Figure 2**(a)). It is showed that Model 2 obtained the highest percentage of comfortable limit compared to the other models (55.5 percent), followed by Model 1 (52.7 percent) and Base Model (51.38 percent). Theoretically, the results were in accordance to the principle of heat transfer through material that the material with the higher U-value would obtain more heat gain than that with the smaller U-value. The same phenomena also could be seen in the case of different roof materials (i.e. metal roof of Base Model, concrete tile roof of Model 3 and metal with insulation of Model 4) (see **Figure 2**(b)). Model 4 obtained the highest percentage of comfortable limit compared to the other models (65.2 percent), followed by Model 3 (56.9 percent) and Base Model (51.38 percent).

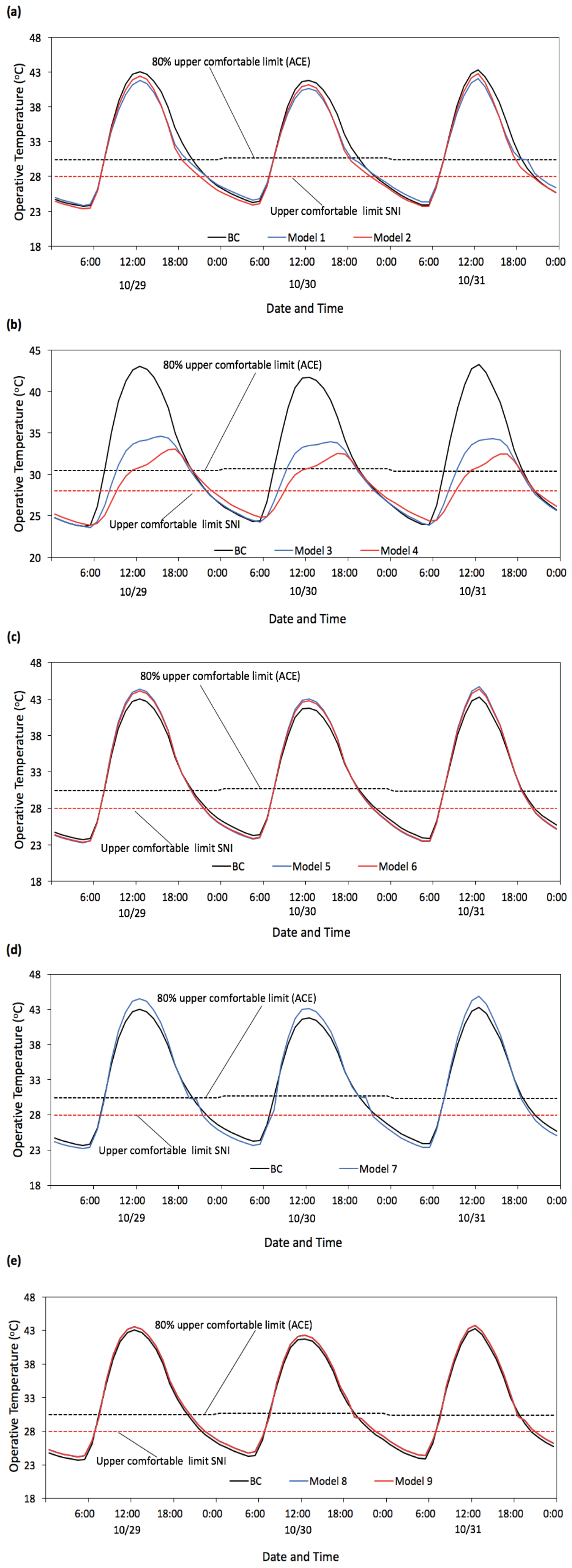

Figure 2: Evaluation of indoor thermal comfort using adaptive comfort equation and SNI 6310-2011, (a) BC, M1, M2; (b) BC, M3, M4; (c) BC, M5.M6; (d) BC, M7; (e) BC, M8, M9.

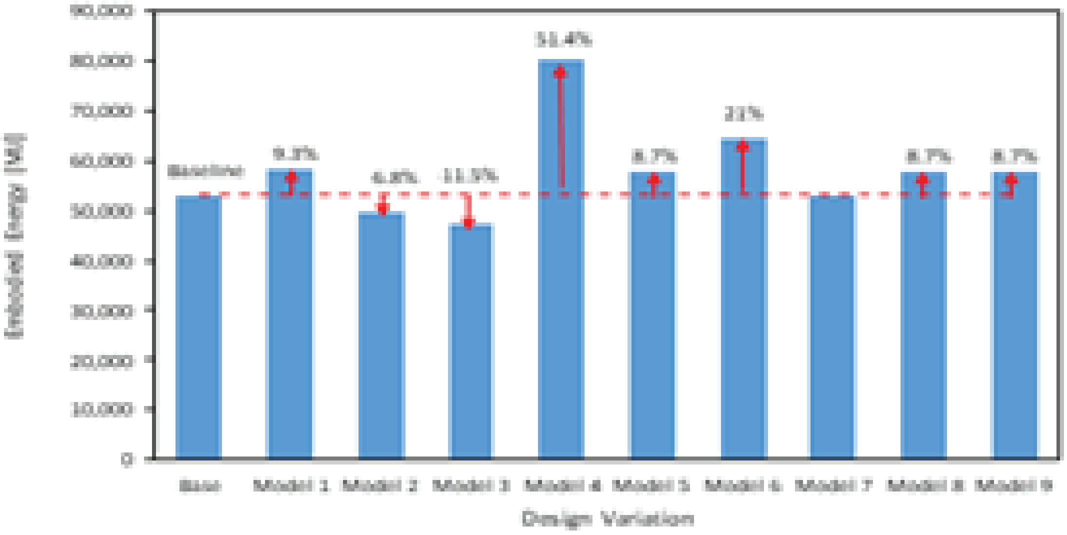

Figure 3: Simulation results of embodied energy saving.

Meanwhile, in the case of change WWR (i.e. Models 5-6), shading devices (i.e. Models 7-8) and ventilation openings (i.e. Models 8-9), there were significant differences on the profile of the operative temperatures. As shown in **Figure 2**(c), increasing WWR to 9 percent and 15 percent lead to increasing of percentage comfortable limit of 50 percent and 48.6 percent respectively. Increasing WWR would increase indoor air temperature due to the air infiltration thus increasing operative temperature. Furthermore, ventilation openings would also increase air infiltration rate so that increased indoor operative temperature as well. But in contrast, the simulation results showed differently see **Figure 2**(e)). The use of ventilation openings did not change the operative temperatures from the Base Model. This is caused by the opening condition window being simulated in a non-ventilated condition. Meanwhile, the presence of shading devices increased the percentage comfortable limit by 4.2 percent (see **Figure 2**(d)). These results can be accepted theoretically, shading devices prevent the excessive solar gain significantly and thus reduce indoor air temperature.

Figure 3 shows the simulation results for embodied energy saving of respective models except for Models 10-12 for same reason as previously. It should be noted that EDGE requires that embodied energy in the new buildings are at least 20 percent lower compared to the functional buildings in order to match energy saving requirements [16]. As shown, only Models 2-3 received lower embodied energy savings than the Base Model. Amongst all cases, only Models 4 and 6 met the energy saving requirements with the embodied energy saving by 51.4 percent. Comparison of wall materials showed that using ALC (Model 1) would increase embodied energy saving by 9.3 percent, while using timber (Model 2) would decrease it. In the case of wall materials, there is correlation between U-values and the embodied energy saving; the lower U-value, the higher embodied energy saving would be. However, in the case of roof materials, this phenomenon did not occur. As indicated, metal roof with U-value of 2.15 W/m^{2}K obtained higher embodied energy saving compared to that of concrete tile (U value of 0.664 W/m^{2}K). This is probably due to the heat stored in the concrete tile during the daytime emitted to the indoor space during the night-time thus increased cooling load at that time. As shown, metal roof with 25mm insulation had the lowest U-values and therefore obtained the highest embodied energy saving.

Interestingly, providing shading devices did not give any effects on the embodied energy saving while increasing WWR and ventilation openings increased it. It is obtained that embodied energy saving between with and no shading devices (i.e. Base Model and Model 7) were 53,102 MJ, respectively (see Figure 3). The results were also different from the previous research which is claimed that using shading device as passive control system saved 0.03 – 13.14 percent of energy [11]. This inconsistency results probably due to the fact that EDGE does not use geometry as a simulated input. Meanwhile, increasing WWR to 0.09 and 0.15 raised the respective embodied energy saving by 8.7 percent and 21.0 percent. The larger window area may allow more natural light enter into the building and it increase the embodied energy saving. But in other hand, larger WWR may cause uncomfortable thermal condition in building as indoor air temperature increases. Furthermore, air infiltration would increase the cooling load of air-conditioned buildings.

3.2. Optimum design

Optimum design was obtained by simulating all the best results from the previous subchapter with the assumption that combination of best parameters would result optimum design. **Table 5** summarizes the best parameter designs for optimum design simulation. The best parameter variations in terms of embodied energy and operative temperature were combined for Optimum Design 1. In the Optimum Design 2, the ceiling fans were added to the previous Optimum Design 1. Meanwhile, Optimum Design 3, insulated metal roof was changed to concrete tile roof to reduce the cost since insulation materials are expensive, and solar PV 0.6 KWp was added.

Figure 4 shows the thermal comfort evaluation using SNI 6390-2011 and adaptive thermal comfort while **Figure 5** shows the simulation results for embodied energy saving

Table 5: Optimum design component.

Design	Variables	Value
Optimum Design 1	Wall material	ALC walls
	Roof material	Insulated metal roof
	WWR	9%
	Ventilation opening	Roster above windows
Optimum Design 2		Optimum design 1
	Additional variables	Ceiling fans
Optimum Design 3	Wall material	ALC walls
	Roof material	Concrete tile roof
	WWR	9%
	Ventilation opening	Roster above windows
	Additional variables	Ceiling fans
	Additional variables	25% solar PV

of the Optimum Designs. As shown, the Optimum Design 1-2 obtained the highest percentage of comfortable limit in adaptive thermal comfort (100 percent) meanwhile Optimum Design 3 the lowest percentage of comfortable limit compared to other optimum models (75 percent). The same result also shown when SNI is used; Optimum Design 1-2 obtained percentage of comfortable limit by 75 percent, meanwhile Optimum Design 3 only obtained comfortable limit by 51 percent. A relatively lower percentage of comfortable in the Optimum Design 3 most probably because the U-value of concrete tile roof was higher than that of insulated metal roof. Considering the operative temperature, the recommended designs are Optimum Designs 1 and 2. As shown in **Figure 5**, it is found that the Optimum Designs 1 and 2 had the highest embodied energy saving compared to the other optimum designs, which is 63,939 MJ. Meanwhile, the embodied energy saving of the Optimum Design 3 and the Base Model were 56,498 MJ and 53,102 MJ, respectively. This difference is mainly caused by the difference of building materials and physical configurations. These results also concluded that embodied energy saving of the Optimum Designs 1-2 were 20.2 percent higher than that of the Base Model while the embodied energy saving of the Optimum Design 3 only 6,5 percent higher than that of the Base Model. Therefore, only Optimum Designs 1-2 that fit the energy saving requirements. It should be noted that adding ceiling fans will not significantly affected both indoor operative temperatures and embodied energy saving. However, people may be comfortable at under a given air speed and humidity level, so that ceiling fans may improving human comfort. In terms of both categories (i.e. operative temperature and embodied energy saving), the Optimum Design 1-2 were strongly recommended for modification.

Furthermore, to obtain one optimum design, additional parameters are needed; monthly operational cost and payback in years. Both of these aspects are also presented

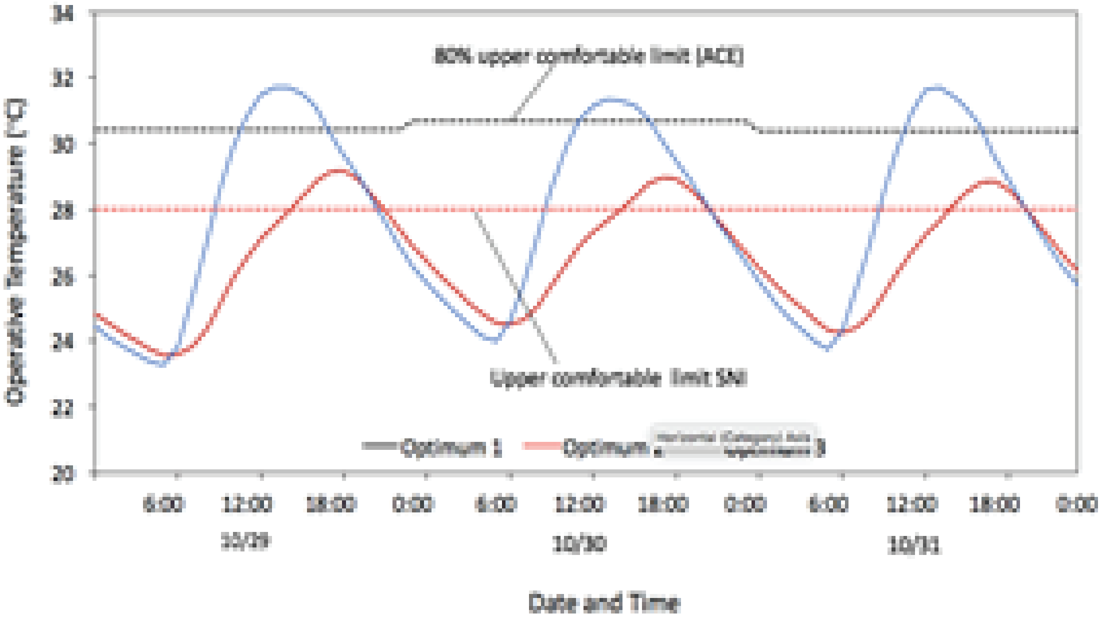

Figure 4: Thermal comfort evaluation in the optimum design using adaptive comfort equation and SNI 6390-2011.

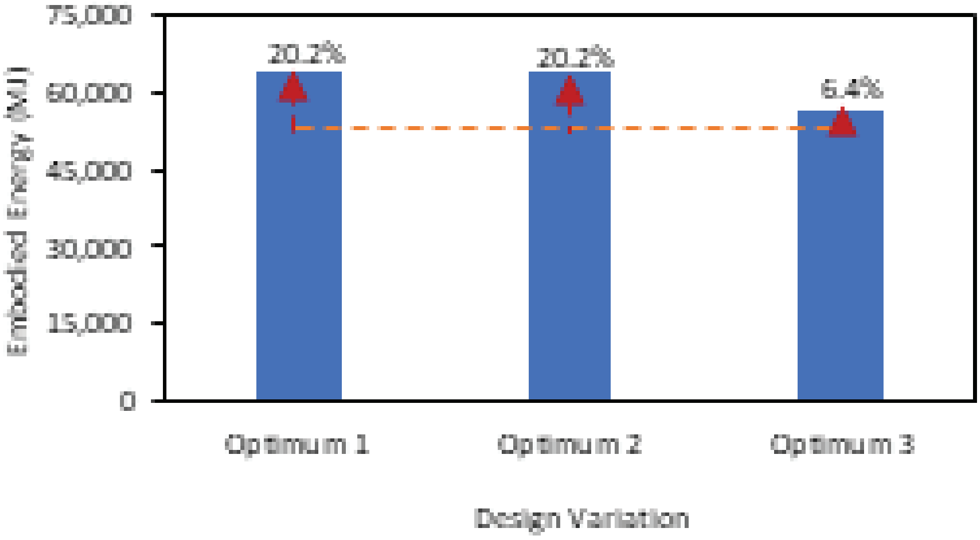

Figure 5: Simulation results for embodied energy saving of the Optimum Designs.

in the simulation results using EDGE. Figure 6 shows the simulation results for monthly operational cost and payback in years. As shown, the base case had the highest operational cost due to the materials used and physical configuration as well as the low performance as previously discussed. Optimum Design 2 had a higher monthly operational cost compared to Optimum Design 1 because of the use of ceiling fan. In the other hand, Optimum Design 3 has the lowest operational cost because of the additional energy from the use of solar PV. Meanwhile, Optimum Design 2 had

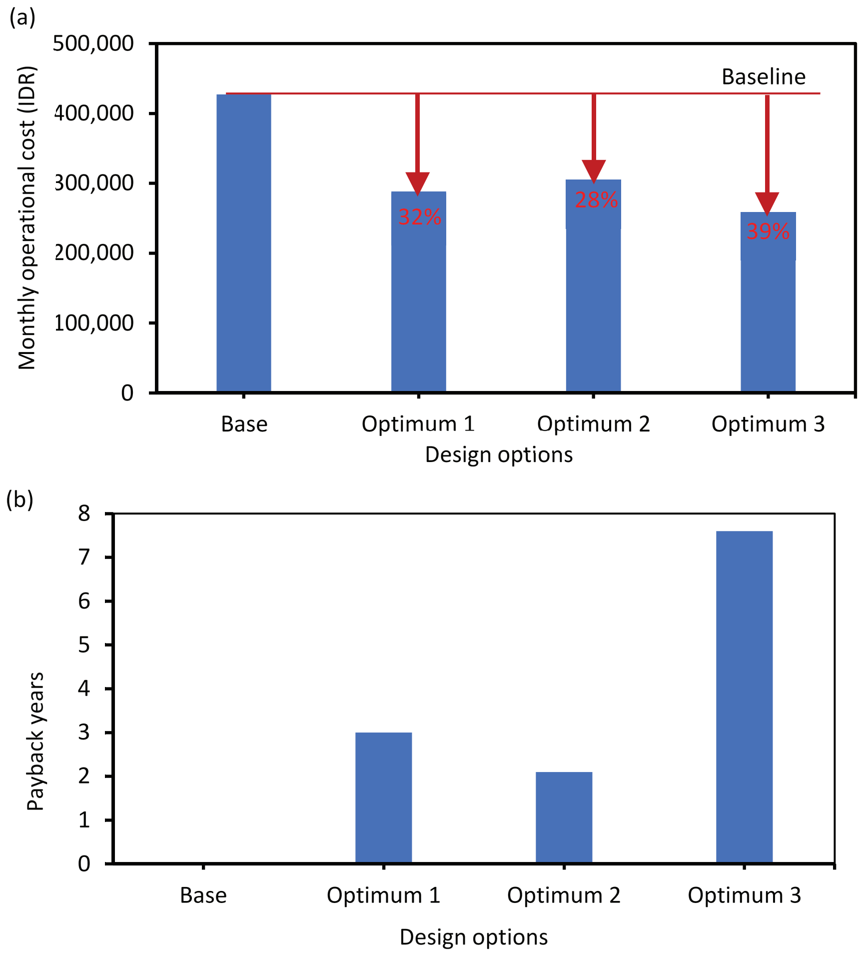

Figure 6: Simulation results for (a) Monthly operational cost; (b) payback in years.

the fastest payback in two years compared to the Optimum Design 1 (three year) and Optimum Design 3 (seven years). Of these four aspects, Optimum Design 2 is preferred design because it has the lowest payback and reasonably better thermal comfort.

4. Conclusions

This paper presents simulation results of some options for designing low-energy house under hot-humid climate of Jakarta, Indonesia. From this paper, it is evidenced that several factors affecting the energy consumption in buildings as well as indoor thermal comfort. Parameters affecting embodied energy saving include envelope material, window wall ratio, window shading, ventilation opening and solar PV. By simulating the variation in each parameter, the highest embodied energy saving is found in the Optimum Design 2, i.e. 63,939 MJ, which is 20.2 percent higher than that of the Base Model (representing current actual housing in Indonesia). Considering EDGE's requirement for energy saving housing, thus Optimum Design 2 complies with the EDGE certification standards. Design parameters for Optimum Design 2 are the use of ALC as wall material, insulated metal as roof, application of 9 percent of WWR and the use of roster above window and additional ceiling fans. By saving embodied energy, the operative temperature obtained is still in a comfortable area based on the adaptive comfort temperature and SNI 6390-2011. However, further study need to be performed particularly related to the physical geometry of buildings in the EDGE simulation such as shading and ventilation.

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