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Energy Efficiency Optimization on Sustainable Housing Modelling in Tegaldowo, Pekalongan, Central Java

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ABSTRACT
House is a place for human activities that has certain requirements to provide comfort for the occupants and have no significant impacts to the environment in order to achieve sustainability. Reducing annual energy consumption is one of the strategies to achieve the principle of sustainability in the housing model. Annual climatic conditions in Pekalongan Regency are classified as fluctuating due to geographical location in coastal areas with temperatures of 25°C at night and 31°-33°C during the day with fluctuations of air humidity ranging from 70-90%. Geographical conditions of Pekalongan Regency require comfort that have the potential to cause high energy use. The purpose of this research is to provide housing model that has efficient energy use in suburb area in Tegaldowo, Pekalongan, Central Java. The applied strategy is to optimization the potential of the local climate to provide comfort through passive designs such as building shape, openings, and orientation. Quantitative method is used by performing simulation on Sefaira based on ASHRAE standards in zone 2 (hot humid climate). Based on the simulation results, modifications made to the direction of the roof slope, building orientation, and openings in the facade have a significant impact in increasing the effectiveness of annual energy use in housing modeling in Tegaldowo.

Keywords: *Sustainable housing, Energy efficiency, Simulation.*

1. INTRODUCTION

Pekalongan is located on the north coast of Java Island. Tegaldowo Village was chosen as the study site. Coastal community life affected by coastal disasters such as flood caused by tidal conditions and rainfall. Society of coastal area suffered losses due to flooding is trying to adapt to the environment. Adaptation made both by community and as an individual [1]. One of individual adaptation done by the people is increasing the height of the floor without raising the ceiling causing low ceiling height and some windows cannot be opened [2]. Geographical conditions of Pekalongan and individual adaptation made by people require comfort that have the potential to cause high energy use.

The comfort needed causing energy consumption of household reached the second largest after industry sector approximately 37.5% of total energy consumption in 2011 [3]. It shows that many countries with hot humid climate consumes electrical energy mostly for air conditioning [4]. The high air temperature and humidity in tropical climate causes the effectivity of natural ventilation. Therefore, several researches conclude that tropical country has high possibility achieving thermal comfort by applying purely natural ventilation [5,6].

To confirm that the adaptation built by Tegaldowo people has high energy use, simulation was conducted for housing model on Sefaira and the result shows that existing housing model consume 189 kWh/m^2/year caused by cooling system and lack of daylighting (Figure 1 and 2). Because of the high energy use, a more sustainable housing model is needed.

Figure 1 Existing house in Tegaldowo.

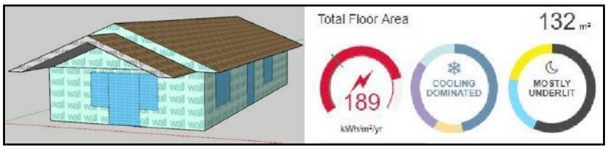


Figure 2 Energy use of existing house.

This research is about designing housing model which utilize the attic room to be a storage when annual flood occurs that is energy efficient by accommodating passive cooling and daylighting.

The purpose of the study is to find sustainable housing design model that is energy efficient in Tegaldowo, Pekalongan by conducting simulations in Sefaira based on ASHRAE 55 zone 2 (hot humid climate) standards to optimize passive design to provide thermal and visual comfort.

2. MATERIALS AND METHODS

2.1. Location and Climate Type

As a region with hot humid tropical climate, annual climatic conditions in Pekalongan are classified as fluctuating due to geographical condition on coastal area with temperatures of 24°-25°C at night and 31°-33°C during the day with fluctuations of air humidity ranging from 70-90% [7].

2.2. Study Framework

Most of several studies focused on analyzing the building and system design to show the relationship between building elements and building performance [8]. In this case, simulations are conducted on Sefaira both in sketch up and web to find the optimum roof slope, orientation and openings. Sefaira simulation uses energy plus engine developed by US Department of Energy. This simulation conducted as a theoretical analysis for the study based on heat balance method recommended by American Society of Heating Refrigerating and Air-conditioning Engineer (ASHRAE 55) in zone 2 (hot- humid climate) [9].

2.3. Modelling and Simulation

Data needed are location, building orientation, opening ratio & daylighting, and energy use.

- Building envelope materials used are template from Sefaira with building façade faces south direction. The main building elements simulated are roof slope, its orientation and openings ratio.
- The data collected by making 3d modeling, changing the layer of entities such as roof, floor, and wall, then conducting simulation on Sefaira sketch up and web.
- To process the data, simulation result comparison to the existing was done. If it still indicates high energy use, new model is made by changing roof orientation and opening to lower the energy use.
- Analysis instruments used are thermal comfort based on ASHRAE 55 standard, daylighting ratio and 2030 energy challenge for 38 kWh/m²/yr. First analysis is about daylighting target to reach 75% well-lit of total area. The second one is about optimizing thermal comfort and comparing to 2030 energy challenge.

Thermal indicators used to identify thermal comfort are dry bulb temperature of 98% occupied hour, operative temperature range between 25°-27° C, and PMV general comfort range for occupant with -0.5 to +0.5 [8]. Operative temperature used is classified as warm comfortable criteria provided by SNI 03-6572-2001 raging between 25.8°-27.1° C [10].

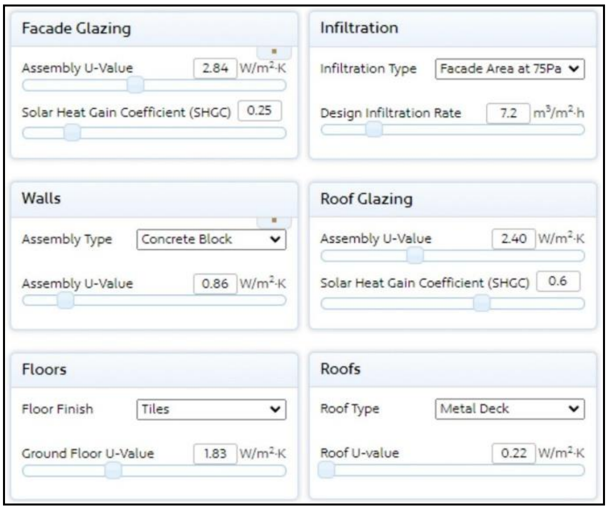


Figure 3 Materials setting in Sefaira.

To purely find the optimum roof slope, roof orientation and openings, materials specifications in Sefaira is not changed as details on Figure 3.

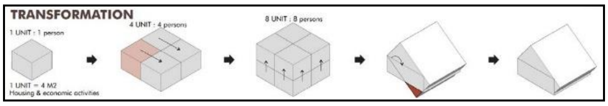
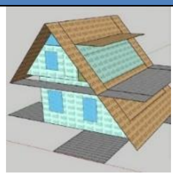


Figure 4 Design transformation.

Mass transformation adjusts the occupants' need of space to live and work. Assumed that one person needs 16m², one housing accommodates eight people, total space needed is 128m² with 3.5m ceiling height. The attic room provided as a storage room when annual flooding occurs. Housing orientation faces south direction maintaining the orientation of community houses facing Tegaldowo street (Figure 4). Gabble roof is maintained to symbolize local architectural style of kampong housing.

Table 1. Building elements

Model 1	Model 2
 ↑U	 ↑U
Roof: gabble roof **Roof slope and orientation**: East: 45º, West: 45º **Openings**: 30% with shading	**Roof**: gabble roof **Roof slope and orientation**: East: 30º, West: 60º **Openings**: 2 x 15% with light shelves

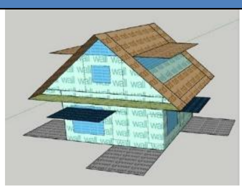
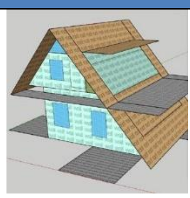
Both models roof shape is gabble roof with different orientation (Table 1). First model roof orientation is symmetrical with slope both 45o from east and west side. Openings ratio on each direction is 30%. Second model was made with different roof slope of 30o from east and 60o from west. The intention is to reduce direct sunlight from west direction.

3. RESULTS AND ANALYSIS

Main aspects that are considered to analyze the model in Sefaira are daylighting, energy use, and thermal comfort. Giving optimal openings ratio up to 30% on each direction can reduce energy use because this passive design strategy allows natural air flow circulating inside the house and causes cross ventilation and daylighting.

3.1. Daylighting

Table 2. Building elements

Model 1	Model 2
 ↑U	 ↑U
Daylighting	
Under lit: 13% Well lit: 60% Over lit: 27%	Under lit: 9% Well lit: 78% Over lit: 14%
Openings	
30% with shading	2x15 with light shelves (north & west)

Openings such as windows are providing the connection between indoor and outdoor environment. They are important for user basic human requirements by giving some environmental stimulation and sight to do the task and to see the space around them [11]. Not only daylight provides the condition for good vision, but also the high luminance reflection on display screen and high solar glare causing over lit area [11]. As the building function is housing, high luminance reflection on display screen does not really matter. But, to provide visual comfort for the user, designing the openings that give well-lit area is important.

The result shows (Table 2) that with 30% openings ratio, 2 windows with light shelves provides more visual comfort since the light shelves reduce the energy of solar gain from direct light but still reflect the light to the room.

3.2. Thermal

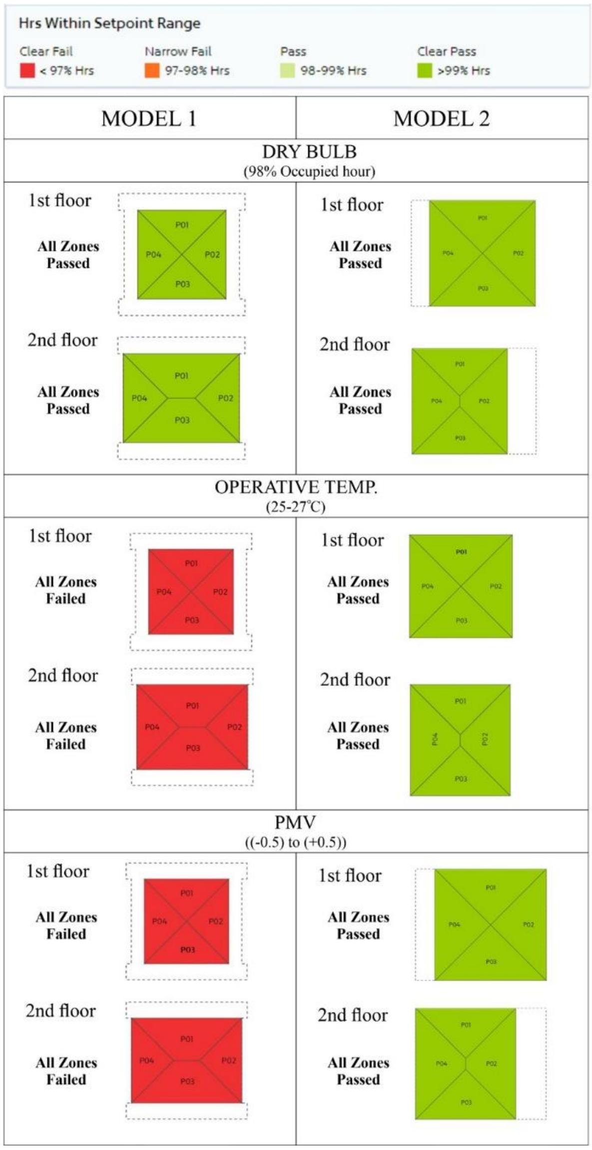


Figure 5 Thermal comfort criteria simulation.

Thermal comfort criteria used to analyze are drybulb temperature of 98% occupied hours, operative temperature range between 25º to 27º C, and PMV criteria based on ASHRAE 55 between -0.5 to 0.5. All the zones of model 1 passed dry bulb but failed to give operative temp. and PMV comfort. Meanwhile, Model 2 zones passed all the thermal comfort criteria (Figure 5).

Thermal comfort for housing model in Tegaldowo is affected by direct light intensity. Housing model with bigger openings causes interior rooms trapped the heat inside and raise the temperature indicated by zone failure to provide comfort based on operative temperature and PMV criteria by ASHRAE. Meanwhile, the 2nd model provides better comfort to occupants by changing roof orientation and exposed less roof surface to the west direction.

3.3. Energy

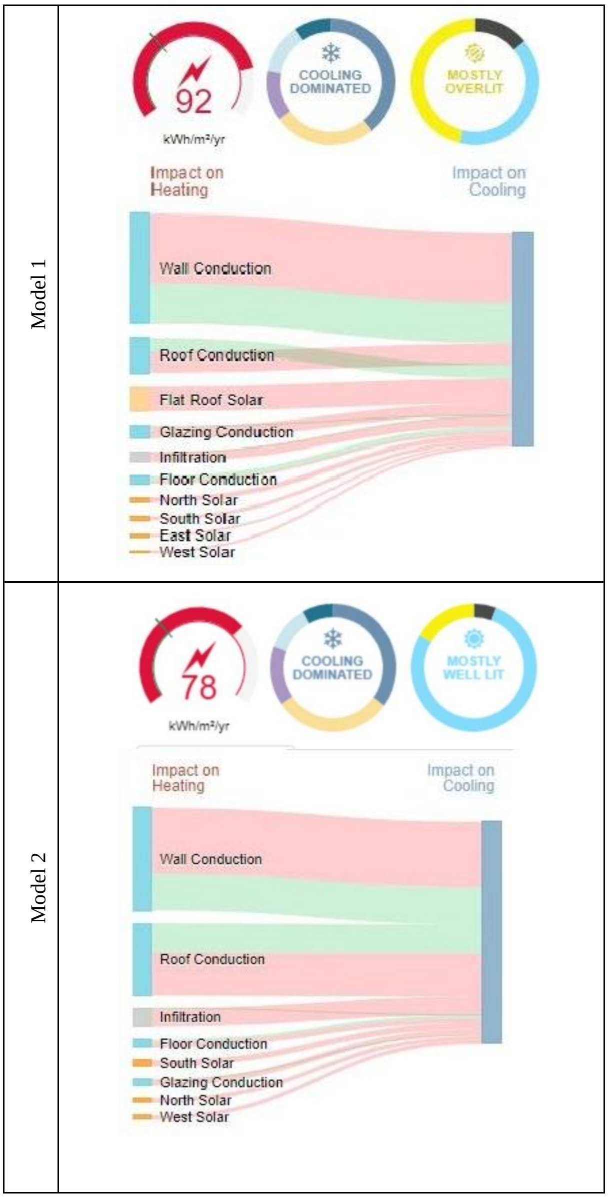


Figure 6 Energy use.

Table 3. Total energy use

Housing Model	Energy Use (kWh/m2/year)
Existing	189
Model 1	92
Model 2	78

From the simulation result in Figure 6 and Table 3, better daylighting has impact for energy efficient housing because lighting electricity is reduced. Since tropical country has high daylight intensity, the direct light increase the cooling load. Cooling load might be reduced in tropical climate because occupants have adaptive thermal comfort in tropical climate that for some cases in UK, India, Iraq, Singapore, and Thailand temperatures range about 30°C in some cases considers comfortable [5,6].

Existing housing in Tegaldowo, Pekalongan indicates high energy use compared to Sefaira 2030 energy challenge 38 kWh/m^2/year. The difference between existing and targeted energy is quite far that new housing models were made. Model 1 and 2 gives better energy efficiency compared to the existing about 51.3% and 61.9%. The result showed from model 1 and model 2 simulations cannot be categorized satisfying as both models do not pass the 2030 energy challenge in Sefaira proposed by ASHRAE.

Further detail simulations and modelling need to be done to find more energy efficient housing that is compatible for housing occupants in Pekalongan coastal area especially Tegaldowo communities who have high thermal and visual adaptability.

4. CONCLUSION

Energy efficient housing in Tegaldowo can be achieved by giving optimal openings with 30% ratio in each side but opening with 2x 15% ratio provides better daylighting. Openings with light shelves provides more comfort because they reduce heat gain from direct light. Gabble roof with orientation 60o from east and 30o from west direction is proven to give better both thermal and visual comfort in gaining less energy use.

Both housing model passes dry bulb comfort criteria but model 1 fails to provide comfort in operative temperature range between 25°-27°C and ASHRAE 55-zone 2 (hot humid climate) while model 2 pass all of comfort criteria. Due to geographical condition of coastal area and tropical climate with high humidity and temperature, both model 1 and 2 failed in achieving 2030 energy challenge in Sefaira by only considering roof slope, its orientation and openings. Building elements in this study (roof slope, its orientation, and openings) give better energy efficiency from the existing model and model 2 reaches the highest energy efficiency about 61.9%. Further detail study and simulation need to be conducted to consider more aspects in order to achieve the 2030 energy target 38 kWh/m2/year.

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