The Comparison of Energy Usage of Modular Housing using Sefaira®

Achmad Faizal Sidik, Beta Paramita, Tjahyani Busono
Department of Architectural Education, Indonesian University of Education (UPI)
betaparamita@upi.edu

Abstract. As the fourth largest population in the world with 52% urban inhabitant, housing as
the most primer need, Indonesia has a significant impact on urban energy consumption. The
backlog of housing in the urban area is known as much as 8%. The government tries to fulfill
those needs by supplying an affordable house that requires not more than 36m2 and less than
IDR 121 million The need for affordable housing occupies the largest ratio in urban areas. This
is related to the middle-class family's income structure that 21% of the total population of
Indonesia. The complexity in modular affordable house design that derives from the building
material, construction cost, as well as the energy consumption, later becomes the urgency of this
study. This paper aims to compare simulating several modular houses with 36m2 total ground
floor area, namely: 6m x 6m, 4m x 9m, and 3m x 12m module houses using metal wall cladding
and Glassfibre Reinforced Cement (GRC). From these comparisons will be found modular house
designs and material that have optimal energy efficiency. This paper presents modular house
design. The modular house design will recommend which modules and materials will best
optimize the building's performance, thus optimizing energy efficiency based on the simulation
results. Based on each material's U-Value, a house with a GRC wall has lower energy
consumption than a house with metal wall cladding because GRC has a lower U-Value.

Keywords: Modular Housing, Energy Efficiency, Sefaira®

1. Introduction
Indonesia is the fourth most populous country after China, India, and the United States, with
260,580,739 people based on Central Intelligence Agency (CIA) data released in July 2017 [1]. The
majority of Indonesia's population occupies urban areas. Based on data from Worldometers 2019, the
projection of Indonesia's population in urban areas in 2025 is 59.3% [2]. One of the most populous cities
in Indonesia is Bandung, with the Bandung Kulon as the most populous sub-district in the city. As the
population increases, the need for housing also increases. In meeting human needs, the house is one of
the primary needs. Through identity, security, and home stimuli, it is related to its residents' social and
economic needs [3]. As a result, a large number of people have an impact on the environment. A lot of
energy consumption will affect the environment [4]. Not all of the population can meet these needs.
Low-income people have problems in financing the ability to participate in housing procurement. The
high need for habitable housing (backlog) in Indonesia reached 11.56 million units or 17.42% of national
households' total number in 2016 [5]. Some of the obstacles in housing construction for low-income
people are that some low-income people do not have enough income each month to get a mortgage loan from the State Savings Bank. Besides, the view is that house’ construction for low-income communities does not generate large profits because the occupants have limited costs. This makes low-income people, especially those in urban areas, have limited options to meet decent housing needs. As a result, to meet the housing needs of low-income people building self-help houses that can become slum neighbourhoods in several parts of the city [6].

The government strives to meet these needs by providing affordable housing, which requires no more than 36m2 and less than IDR 121 million. Modular housing can be a residential solution for a little cost, but a modular home has several complexities in its application. One of the complexities of affordable modular home designs that comes from building materials, construction costs, and energy consumption becomes the urgency of this research. To make a house liveable is in terms of the comfort factor. Some of the factors that make a home comfortable are lighting, cooling, and heating that use electricity. 90% of electricity customers come from the residential sector [7]. Wall material has an impact on cooling and heating needed in buildings because it has different thermal transmittance values (U-Value). The U-Value affects the amount of heat flow that enters the building. The higher the U-Value, the greater the heat entering the building [8]. Some lightweight materials used as walls are Glassfiber Reinforced Cement (GRC) and metal wall cladding.

This paper aims to compare simulating several modular houses with 36m2 total ground floor area, namely: 6mx6m, 4mx9m, and 3mx12m module houses using metal wall cladding and GRC. Each material is applied to each building module with a design with the same orientation. By simulating the design into Sefaira with Thermal transmittance in mind, which is calculated based on the ASHRAE 90.1 - 2013 standard. The result is a design recommendation for low-income community housing in Bandung Kulon, Bandung, Indonesia. This research was conducted as a development of previous research entitled "Ansmittance / Conductance of Building Elements (Roof, Wall, and Floor) Based on The Different Building Materials Used in Famagusta." [9] This study focuses on the effects of two types of building materials and shapes on energy consumption.

2. Method
The method used in this study is simulating several modular houses with 36m2 total ground floor area, namely: 6mx6m, 4mx9m, and 3mx12m module houses using GRC material and metal wall cladding into Sefaira. Sefaira is software, which can simulate buildings using several variables. The U-Value and the building's shape will become the main focus variables, and the two variables will differentiate the energy assumption data that will be generated. After obtaining data on the recapitulation of the assumptions of energy requirements and the Intensity of Energy Usage of each modular house design for one year, a comparison will be made to determine the design of a modular house with wall materials with low energy consumption.

2.1 Modular House
Modular design is one of the applications produced by industrial fabrication. The manufacturer produces several modules that will be applied to a building. Producers can directly focus on the building's designation to be produced so that the development process becomes faster [10]. Modular development is a development process that uses pre-fabricated components of the site. It can be said that the modular construction process on the site has been 60% - 80% completed [11]. Based on this definition, a modular home is a house design mass-produced by factories to speed up the construction process by minimizing construction costs.

2.2 The Effect of Building Material on Energy Consumption
The choice of material will impact the energy use of a building, materials with different heat transfer coefficients so that the building's ventilation requirements are determined by the materials applied to the building. According to Marwan, a simulation was carried out between two buildings with different materials. The result is that a building with a smaller heat transfer coefficient consumes less energy [12].
2.3 Thermal Transmittance (U-Value)
Each material has different thermal transmittance. Thermal Transmittance (U-Value) is thermal transmission in every surface of the building elements of the unity of time when the temperature difference between outside and inside the building. The unit of U-Value is W/m²K [13]. The formula for finding a U-Value if it is known that R-Value is \( U-\text{Value} = \frac{1}{r-\text{Val}} \). R-Value is the value of a material with a certain thickness to conduct heat, to find the R-Value, the value of thermal conductivity (\( \lambda \)), and the thickness of the material (d), it is necessary to know so that it has a formula (R-Value = \( \frac{d}{\lambda} \)) [14]. GRC, which has a thickness of 10 mm with a conductivity level of 0.18 W/mK - 0.21 W/mK has a U-Value of 4.35 W/m²K [15]. Metal wall cladding materials made from aluminium it has a high conductivity. Aluminium is 237 W/mK, and Zincronum is 25.2 W/mK so that the U-Value, which is owned by metal wall cladding with a thickness of 0.4 mm, is 5.56 W/m²K. U-Value differences occur because of differences in each material's conductivity. The higher the conductivity of the material, the higher the U-Value. In addition to the conductivity value, the material's thickness also affects the U-Value. The thicker the material, the longer the heat transfer process takes place. Measurements using the U-Value calculator that can be accessed on http://Vesma.com by inputting the type of material with its thickness, based on these data, the U-Value is obtained.

2.4 Sefaira
To see the energy consumption consumed by the building model used by Sefaira as an application to simulate energy. Sefaira is a software plug-in for SketchUp and Revit, which functions on the assumption of the overall energy consumed. Sefaira was accessible at https://sefaira.com/ [16]. Analysis of the energy generated based on the influence of climate on the building envelope, and its shape is designed [17]. The simulation on Sefaira uses the ASHRAE 90.1-2013 standard, which becomes a guideline for analysing building energy with several variables [18].

| Tabel 1. ASHRAE 90.1 – 2013 Baseline |
|--------------------------------------|
| ASHRAE Climate Zone                  | 1.4                                  |
| Wall Insulation                      | 2. 0.59 W/m².K                      |
| Floor Insulation                     | 3. 0.32 W/m².K                      |
| Roof Insulation                      | 4. 0.2 W/m².K                       |
| Glazing U-Factor                     | 5. 1.99 W/m².K                      |
| Visible Light Transmittance          | 6. 0.41                              |
| Solar Heat Gain Coefficient           | 7. 0.4 SHGC                         |
| Infiltration Rate                    | 8. 7.2 m³/m².h                      |
| Ventilation Rate                     | 9. 15 L/s.person                     |
| Equipment                            | 10. 25 W/m²                         |
| Lighting                             | 11. 10 W/m²                         |

2.5 Location
Based on the Bandung City statistical center agency data, the sub-district with the most population is Bandung Kulon district, with a figure of 22.43 thousand people/km². Location data is entered into Sefaira to determine climatic conditions.
3. Findings and Discussion

3.1 Modular House Design
Each modular house design is made with two different materials, namely GRC and metal wall cladding. All designs will be compared to determine the design with the lowest energy consumption. All buildings have the same area with a ground floor area of 36m² and an attic area of 9m² with a total area of 45m².

![Figure 1. (a) 3x12 module house design](image1)
![Figure 1. (b) 4x9 module house design](image2)
![Figure 1. (c) 6x6 module house design](image3)

3.2 Building Orientation
Because this paper will compare two materials in several module designs so the orientation of each building is the same.

![Figure 2. Building Orientation 6x6, 4x9, and 3x12 Design Modules](image4)
3.3 Energy Comparison

![3x12 module house design](image)

**Figure 3. 3x12 module house design**

| Energy Segments | 3x12 House (GRC) | 3x12 House (metal wall cladding) |
|-----------------|------------------|----------------------------------|
| Heating (kWh/year) | AHU 0 0 | AHU 0 0 |
|                  | Humidification 0 0 | Humidification 0 0 |
|                  | Zones 165 194 | Zones 165 194 |
| Cooling (kWh/year) | AHU 137 136 | AHU 137 136 |
|                  | Heat Rejection 62 65 | Heat Rejection 62 65 |
|                  | Zones 604 638 | Zones 604 638 |
| Fans (kWh/year) | AHU 92 92 | AHU 92 92 |
|                  | Zones 155 165 | Zones 155 165 |
| Interior (kWh/year) | Equipment 372 372 | Equipment 372 372 |
|                  | Lighting 744 744 | Lighting 744 744 |
| Pumps (kWh/year) | 194 206 | 194 206 |
| Other (kWh/year) | 0 0 | 0 0 |
| Total (kWh/year) | 2525 2612 | 2525 2612 |

![4x9 module house design](image)

**Figure 4. 4x9 module house design**
Table 3. Energy Segments Usage Comparison on 4x9 Design Module

| Energy Segments | 4x9 House (GRC) | 4x9 House (metal wall cladding) |
|-----------------|-----------------|-------------------------------|
| Heating (kWh/year) | AHU 0 | 0 |
| | Humidification 0 | 0 |
| | Zones 93 | 112 |
| Cooling (kWh/year) | AHU 123 | 122 |
| | Heat Rejection 48 | 50 |
| | Zones 376 | 403 |
| Fans (kWh/year) | AHU 81 | 81 |
| | Zones 102 | 110 |
| Interior (kWh/year) | Equipment 331 | 331 |
| | Lighting 661 | 661 |
| Pumps(kWh/year) | 149 | 157 |
| Other(kWh/year) | 0 | 0 |
| Total(kWh/year) | 1964 | 2027 |

Figure 5. 4x9 module house design

Table 4. Energy Segments Usage Comparison

| Energy Segments | 6x6 House (GRC) | 6x6 House (metal wall cladding) |
|-----------------|-----------------|-------------------------------|
| Heating (kWh/year) | AHU 0 | 0 |
| | Humidification 0 | 0 |
| | Zones 114 | 140 |
| Cooling (kWh/year) | AHU 158 | 158 |
| | Heat Rejection 89 | 93 |
| | Zones 694 | 732 |
| Fans (kWh/year) | AHU 106 | 106 |
| | Zones 187 | 200 |
| Interior (kWh/year) | Equipment 425 | 425 |
| | Lighting 850 | 850 |
| Pumps(kWh/year) | 269 | 283 |
| Other(kWh/year) | 0 | 0 |
| Total(kWh/year) | 2892 | 2987 |
Based on the data generated from the simulation, the design of the housing module that consumes the least energy is the 4x9 module design, with GRC material as a wall covering. The energy consumed by a house with a 4x9 module that uses GRC walls is 1964 kWh/year. Overall, most energy consumption is consumed by the lighting and cooling zone. The 6x6 modular house design with metal wall cladding materials requires the most energy among other modular home designs, with a cooling segment of 732 kWh/year and 850 kW/year lighting segment. The U-Value of each material influences the high energy consumption for cooling zones. The simulation results show that the energy consumption for cooling zones is consumed more by buildings using metal wall cladding material. Metal wall cladding has a higher U-Value than GRC so that heat transfer from the environment can enter the room faster, resulting in higher energy consumption for cooling.

3.4 Energy Use Intensity

| 3x12 House (GRC) | 4x9 House (GRC) | 6x6 House (GRC) |
|------------------|----------------|----------------|
| 3x12 House (Metal wall cladding) | 4x9 House (Metal wall cladding) | 6x6 House (Metal wall cladding) |

EUI (Energy Use Intensity) obtained shows the energy per square meter of the building consumed annually. The EUI is a comparison of the energy consumed in similar buildings with the 2030 Sefaira challenge in a similar climate. In the simulation results, the EUI of each building has not met the EUI 2030 target, which should have EUI 38 Kwh/m/year. The simulation results show the EUI comparison of each modular house. As a result, a modular house design that is close to the EUI 2030 target is a 4m x 9m module house with GRC material as wall coverings, which have EUI 70 Kwh/m/year.

All designs with GRC material and metal wall cladding are still far from the EUI 2030 target. The reason is that the value of wall insulation with GRC material and metal wall cladding is much higher than the ASHRAE 90.1-2013 standard. GRC walls have an insulation of 4.35 W/m²K. Metal wall cladding has an insulation of 5.56 W/m²K. In comparison, the ASHRAE 90.1-2013 standard wall insulation has a value of 0.32 W/m²K, so the EUI of the simulated design is still far from the EUI 2030 target.

4. Conclusion
Thermal transmittance in each material used as a building cover will affect the building's energy consumption performance. The greater the U-Value of material applied to a building, the energy consumption will also increase. Outdoor temperature will quickly enter the room if the U-value is massive, requiring artificial cooling or heating. The conductivity value of a material affects the U-Value. Based on research conducted by simulating several modular houses with 36m² total ground floor area, namely: 6m x 6m, 4m x 9m, and 3m x 12m module houses using GRC material and metal wall cladding, it is stated that the 4m x 9m module house design with GRC wall material consumes the least energy because the level of conductivity of GRC material is lower than metal wall cladding. GRC has a conductivity of 0.18 W/mK - 0.21 W/mK, and metal wall cladding made of aluminum which has a conductivity of 237 W/mK, and Zincronum with a conductivity of 25.2 W/mK, so that heat transfer from the environment into the room is faster in metal wall cladding. The EUI comparison results state that the entire design does not meet the EUI 2030 target because the value of GRC and metal wall cladding insulation are much higher than the ASHRAE 90.1-2013 standard. The 4x9 module housing has the EUI value closest to the target.

In conclusion, the recommended module house design for low-income people is a 4x9 module design with material GRC, which consumed 1964 kWh/year and has EUI 70 kWh/m²/year. The recommendation is to add insulation material to the walls to lower the U-Value so that energy consumption can be more minimized. The design requires improvements in several variables to meet the EUI 2030 target. The design requires improvements in several variables to meet the EUI 2030 target.

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