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Passive Design Strategies for Achieving Net Zero Energy Targets in Middle-Income Dwellings in Greater Jakarta

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Abstract **- Greenhouse gas (GHG) emissions from fossil fuel combustion have been identified as a significant contributing factor to the worsening of climate change in recent decades, increasing the Earth's average temperature. The residential building sector in Jakarta, Indonesia, exhibits a higher energy consumption rate than their commercial counterparts. Net zero energy houses are widely recognized as highly effective in energy efficiency. However, there are no net zero energy houses built in Indonesia. Using appropriate passive design strategies can significantly reduce the energy consumption of net zero energy dwellings. As per the research findings, architects, engineers, and housing developers can utilize the net zero energy house model. The study used an experimental approach to identify the most effective passive design components for energy conservation. It is crucial to consider factors such as building orientation, shading devices, and window-to-wall ratio (WWR) at an early stage. This study guides architects and engineers on using fundamental passive design principles in designing net zero energy dwellings.**

Index Terms **– House, Net Zero Energy, Passive Design, Window-to-Wall Ratio**.

INTRODUCTION

This century's most significant environmental issue is climate change, increasing the earth's average temperature, which has become a serious environmental problem and has recently shown worsening symptoms. The United Nations (UN) has issued a Paris Agreement (COP21) resolution, which limits the increase of the temperature below two degrees Celcius in the year 2100 and achieves net zero emissions conditions in the years 2050 – 2100 [1].

Net zero energy buildings will be a solid and significant contribution to this worldwide environmental issue because they significantly reduce fossil fuel use and use clean and renewable energy. Therefore, there is a need to implement a solution to overcome the trend of climate change, which has gotten worse in the last few decades.

The residential and commercial sectors consume energy 21% and 9%, respectively. In addition to the buildings and construction industry, the number tops at 34% in 2021, even more alarming than the industrial and transportation sectors [2]. In Indonesia, residential and commercial sectors consumed 13% and 4% of energy in 2019 [3].

Especially in Indonesia, most electrical energy sources come from power plants that use fossil energy, such as coal. While energy conservation in the housing sector has a substantial effect on mitigating the impact of climate change, the regional rules of energy savings in the housing sector need to be more effectively enforced.

The notion of net zero energy dwellings is remarkably efficient and an imperative approach for addressing and diminishing the consequences of climate change. Consequently, it is crucial to advocate for energy-efficient dwellings and renewable energy sources to foster consciousness, augment comprehension, and expedite the adoption of net zero energy residences.

From the research problems, it can be derived two research questions which are:

- Can passive design reduce energy significantly to achieve the target of a net zero energy house?
- What passive design variables have the most significant impact on energy consumption?

Those research questions will be answered in the conclusion of this research.

The research objective is to create net zero energy house guidelines that consider every aspect of optimal architectural passive designs to improve a significant amount of energy savings. These guidelines then can be a house model that can guide the development of a net zero energy house in Indonesia, especially in the greater Jakarta area.

LITERATURE REVIEW

I. Net zero energy buildings

The Net Zero Energy Buildings (NZEB) is a concept proposed by Torcellini to describe a residential or commercial building that utilizes energy efficiency to reduce energy consumption significantly and balance the remaining energy from fossil fuels by offsetting it with renewable energy. Net zero energy buildings use an on-grid system to return excess electricity production to the electricity network, thus reducing electricity bills. The theory of net zero energy entails the utilization of the power grid to determine the overall energy usage while also incorporating the integration of renewable energy resources; therefore, this definition does not include independent network systems such as off-grid networks. Using an off-grid system will pose challenges due to the need for extensive energy storage technology, and the cost of implementing this particular installation system is the highest compared to other available solar panel installation systems [4].

Net zero energy buildings are buildings with high energy efficiency, resulting in low consumption of fossil fuels. To offset its energy consumption, NZEB can produce equivalent or even greater renewable energy than its energy usage [5].

Net zero energy can be defined and categorized into two concepts. First, the net is the definition that may still use fossil fuels, and the production of renewable energy is the same or more than the use of fossil energy annually. The second concept refers to an operational goal that calculates the building's energy consumption over one year of building operation, including variations in weather changes [6].

The definition of energy efficiency refers to increasing the energy output of a process by reducing energy input and minimizing waste energy during the process [7].

The main principle in achieving energy efficiency starts with good design to reduce energy requirements, improve building operations, use renewable energy sources, and minimize fossil fuel consumption [8].

Due to the worsening effects of climate change, relying solely on the green building movement is insufficient. Therefore, there is a need for the development of highly energy-efficient buildings, often commonly known as nearly zero energy or zero-ready buildings. Highly energy-efficient buildings have more significant energy savings of over 40%, exceeding green buildings in energy efficiency [9].

In summary, there are two mandatory requirements that Net Zero Energy Buildings must attain, which are significant energy savings and renewable energy production that can balance the remaining fossil fuel energy. This research focuses on how house design can achieve substantial energy savings.

II. Passive design

Indonesia is in an area with a humid tropical climate. One of the characteristics of this climate is Indonesia gets a lot of sun exposure throughout the year and high rainfalls.

The climate comprises various components: solar radiation, air temperature, precipitation, humidity, sky conditions, wind patterns, distinctive environmental attributes, and vegetation. Architects must consider these components as they significantly impact the functionality of the building and the comfort of its occupants. By analyzing climatic data and presenting findings, architects can discern potential future issues and disruptions encountered by building occupants [10].

Passive design refers to a design approach that minimizes the impact of the external environment on a building by employing strategies well-suited to the local climate. It utilizes natural resources and elements to enhance the comfort of building occupants (climate balance). Architecturally unified stages are needed: climate data, biological evaluation, engineering solutions, and architectural applications [11].

For tropical countries such as Indonesia, we must know about the heat transfer from solar radiation through the building envelope. We must also incorporate passive solar-responsive design principles, including heat rejection and avoidance. Examples of heat rejection include shading devices, high-reflectance roofs, and insulation. Meanwhile, heat avoidance refers to placing a building in north and south orientation and its window size and placement. Several initiatives in solar responsive design considered low-hanging fruit, focusing on window orientation, placement, and size. These initiatives are easily implementable and yield significant benefits [12].

Passive design strategies for tropical climates encompass two primary approaches: heat exclusion strategies, which entail the utilization of extensive shading, reflective thermal insulation, and avoidance of east and west orientation, and heat dissipation strategies, which involve the implementation of ample natural ventilation and appropriate building massing [13].

The combination of WWR and shading devices can reduce energy consumption, optimize daylight, and improve the aesthetics of buildings [14]. There are two things related to the orientation of the building, which are the amount of exposure to sunlight that the building receives and the pattern of wind direction. These two aspects will determine the size of the window opening, its placement, and the creation of a natural ventilation pattern [15]. Increasing the WWR ratio is not a good strategy as opposed to achieving the NZE target; a better approach is to position the window in a favorable orientation [16].

The Window to Wall Ratio (WWR) is a metric that quantifies the proportion of window area to the total area of the building facade for a specific orientation. (Figure 1).

The larger amount of WWR will give more daylight into the building and the heat of solar radiation, so it needs to be considered heat transfer when designing window glazing [12]. To keep WWR enough to give daylight and natural ventilation, it can put large window openings to avoid window placement at the west and east orientations due to large amounts of solar radiation and put enough shading devices in each window opening.

FIGURE 1 WINDOW TO WALL RATIO (WWR)

Shading devices (overhangs) are architectural elements that prevent solar radiation from entering the interior of the building and can be a tool for reducing the glare from sunlight (Figure 2). Shading devices consist of horizontal, vertical, or egg crates (a combination of horizontal and vertical overhangs) [12].

Building orientation is the direction of the main direction the building is facing (Figure 3), and it will affect the amount of solar radiation and natural ventilation due to its air pattern [15].

FIGURE 2 SHADING DEVICES OF A BUILDING

With a good passive design, significant energy savings can be achieved, and solar panel needs can be optimized. Furthermore, implementing this technology allows a building to attain the objective of net zero energy buildings successfully.

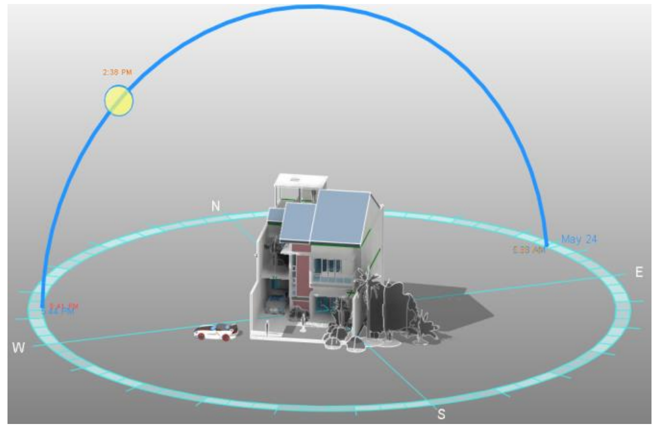


FIGURE 3 BUILDING ORIENTATION

MATERIALS AND METHODS

We studied middle-income housing types in four locations in the Greater Jakarta Area. Middle-income housing because it is the most favorable house type and the possibility of improving the net zero energy house target. The typical type we chose for the experiment is a two-story built landed house, 8 m wide, and used for a family with four occupants. The details of the four object studies are below.

I. Type Nara, Paramount

The location of the house is in Tangerang with coordinate 6°16'32.1"S 106°37'12.0"E

FIGURE 4 TYPE NARA, PARAMOUNT

II. Type Allegro, Summarecon

The location of the house is in Tangerang with coordinate. 6°16'19.5"S 106°36'48.5"E

FIGURE 5 TYPE ALLEGRO, SUMMARECON

III. Type Alton, Bintaro

The location of the house is in Tangerang with coordinate. 6°16'11.3"S 106°41'44.2"E

FIGURE 6 TYPE ALTON, BINTARO

IV. Type Ubud, Daan Mogot

The location of the house is in Daan Mogot, with coordinate. 6°09'07.4"S 106°42'34.6"E

FIGURE 7 TYPE UBUD, DAAN MOGOT

V. Methods

This study was conducted in four steps.

First, we collect the geometry data of each landed house in the Greater Jakarta area, such as window size, length of shading device, orientation, building materials, and electrical equipment data used, such as lamps, air conditioners, and occupants.

Second, for each type of house, we make modeling to replicate actual building conditions and make input data such as geometry data, light, AC, occupant, and materials so it can be analyzed using the Energy Plus software to get results on the energy use per year (kWh/year).

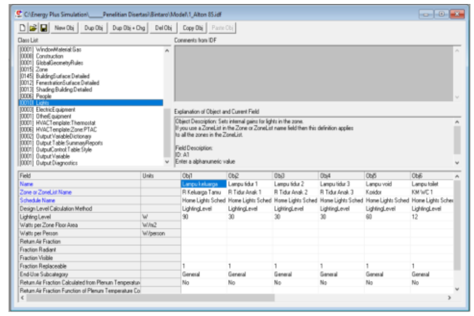


FIGURE 5 INPUT DATA IN ENERGY PLUS

Third, we do the simulation with Energy Plus analysis consisting of altering the size of window size, length of shading element, and orientations.

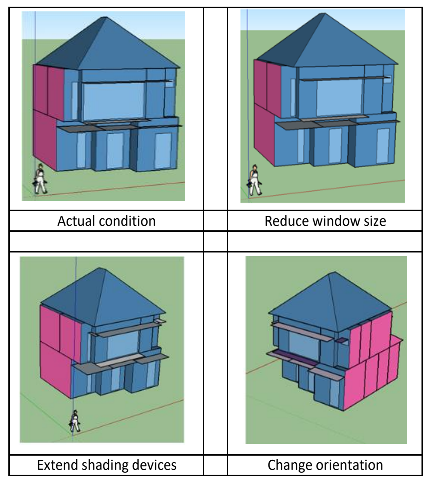


FIGURE 6 EXPERIMENTS OF PASSIVE DESIGN ELEMENTS

For roof and wall materials, use typical materials used in middle-income housing. Every type of house we did experiment for those alter 64 experiments. So, we had 256 experiments in total, four types of houses.

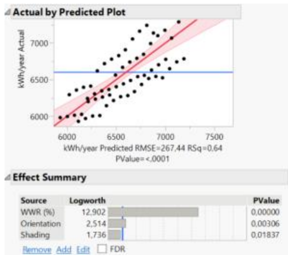
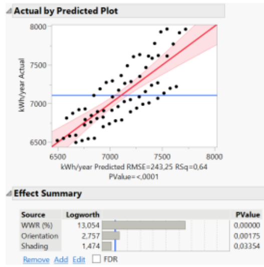
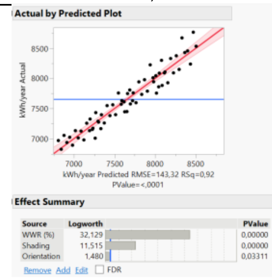
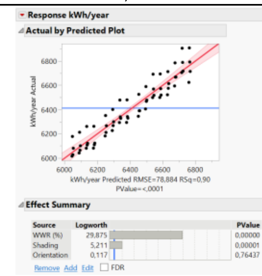
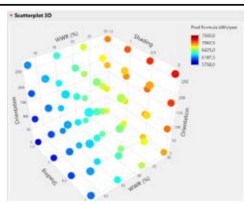
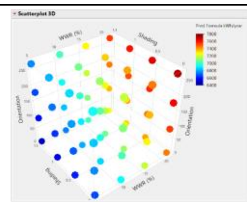
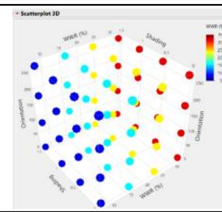
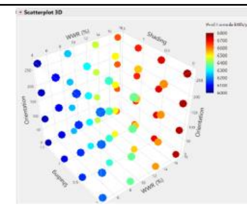
This experiment aims to evaluate the impact of passive design elements on energy consumption.

Finally, we analyze the results of the experiments with JMP Statistical software to obtain patterns or trends and energy consumption.

RESULT AND DISCUSSION

As a result of the experiment energy use per year from 256 alternative passive design elements in 4 house types, we did a Statistical analysis with JMP software, summarized in Table 1.

TABLE I
SUMMARY OF EFFECT OF PASSIVE DESIGN ELEMENT

	TYPE NARA, PARAMOUNT	TYPE ALLEGRO, SUMMARECON	TYPE ALTON, BINTARO	TYPE UBUD, DAAN MOGOT
Result Actual vs prediction plot				
Scattered Chart 3D				
Maximum Energy (kWh/year)	7618.9 WWR=29.99%, Shading Device=0, Orientation=West	7965.96 WWR=21.35%, Shading Device=0, Orientation=West	8766.95 WWR=32.06%, Shading Device=0, Orientation=North	6907.5 WWR=17.06%, Shading Device=0, Orientation=West
Minimum Energy (kWh/year)	5931.2 WWR=7.50%, Shading Device=1.5 m, Orientation=North	6497.22 WWR=5.27%, Shading Device=1.5 m, Orientation=North	6822.9 WWR=7.98%, Shading Device=1.5 m, Orientation=West	6016.26 WWR=4.33%, Shading Device=1.5 m, Orientation=South
Energy reduction	22%	18%	22%	13%
Rsquare (Rsq)	0.64	0.64	0.92	0.90
Pvalue < 0,05	WWR, Pvalue = 0.00000 Orientation, Pvalue = 0.00306	WWR, Pvalue = 0.00000 Orientation, Pvalue = 0.00175	WWR, Pvalue = 0.00000 Shading device, Pvalue = 0.00000 Orientation, Pvalue = 0.03311	WWR, Pvalue = 0.00000 Shading device, Pvalue = 0.00001
Most significant element	WWR	WWR	WWR	WWR

The most significant energy reduction results are in type Nara and Alton, with 22% savings from the original design. The result from Energy Plus is energy consumption per year (kWh/year). Various combinations of altering of passive design elements can reduce energy consumption significantly. The Window Wall Ratio is the most significant passive design element for reducing energy consumption, which is shown consistently in every house-type experiment.

CONCLUSIONS

The use of passive design principles in the house is crucial for ensuring occupant comfort in various climatic conditions and minimizing energy usage within the home. In meeting the net zero energy target, striving for all aspects that can result in significant energy reduction is necessary. Passive design was the earliest attempt to reduce energy significantly.

The experiments that have been carried out show results that answer the research questions.

- Passive design components that are well implemented have the potential to substantially decrease energy consumption, resulting in a notable reduction of up to 22%. This reduction in energy usage is crucial in attaining the objective of a net zero energy house.
- The most significant passive design variable in reducing energy use is the Window to Wall Ratio.

From the analyzing result data, derived a formula for estimate the Energy consumption/year as (1)

$$E=45.870149282 \times W - 87.461625 \times S + 0.0295076389 \times O + 5977.1700645 \quad (1)$$

Where:

E=Energy consumption per year (kWh/year)
W=Window to Wall Ratio (WWR)
S=Shading devices length
O=Orientation

Shading devices also play an important role, and this is a pair of passive design elements for glass openings. Shading factors can block solar radiation through glass openings.

For orientation, it is necessary to avoid the West direction, which greatly impacts energy use. The placement of windows also needs attention as it can increase energy use when most windows are in the West or East, even if the house orientation is in good orientation.

The net-zero energy model can consider this research's findings, such as minimizing the glass openings and avoiding the placement of large windows in the west and east. Every glass opening needs to have a shading device. Orientation in the south is most favorable for South Latitude.

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