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A BIM-BASED STUDY ON THE EFFECT OF WINDOW-TO-WALL RATIO (WWR) ON ELECTRICAL ENERGY EFFICIENCY

Gabrilia Dewi Narwastuti[1*], Aurora Cahya Adisa[1], Yuni Azizah[1]

[1] *Department of Architecture and Planning, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia*

ABSTRACT

The construction sector's reliance on non-renewable energy sources affects the sustainability of the world's energy supply. Household electrical energy consumption is one of the main factors contributing to Indonesia's electricity consumption; hence, the residential typology is researched for energy efficiency. This study aims to analyze the variations of window-to-wall ratio (WWR) effect on electrical energy consumption in developing type 55 houses in Sleman, DIY. Several WWR percentage scenarios were created to determine the most effective value for improving building energy efficiency. This research was conducted with the quantitative method using the Building Information Modeling (BIM) simulation through Autodesk Revit software and the Green Building Studio (GBS) plugin. According to the research, WWR impacts buildings' electrical energy usage, particularly for HVAC systems, with a range of around 41% to 52% usage. Alternative scenarios with lower WWR can reduce annual electrical energy consumption and specific energy use intensity (EUI) values. In addition, a 5.8% savings in electricity costs can be obtained with the lowest WWR scenario. Thus, it can be concluded that variations of WWR affect electrical energy consumption and costs in residential buildings.

[*]Corresponding Author

Gabrilia Dewi Narwastuti*,
Universitas Gadjah Mada
Email:
gabriliadewinarwastuti@mail.ugm.ac.id

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Building Energy Efficiency, Electricity Cost, Energy Use Intensity, Green Building Studio, Housing, Window-to-Wall Ratio

1. Introduction

According to the International Energy Agency, the construction sectors account for approximately 35% of the global cumulative energy consumption, presenting a significant challenge to worldwide sustainability (Duarte et al., 2021). In addition, buildings have a significant environmental impact due to their dependence on non-renewable energy sources (Jadhav & Minde, 2024). In response to this issue, building design and construction solutions are needed to minimize the negative environmental impact caused by buildings. However, it cannot be denied that energy consumption in buildings will always be necessary to support various human activities. Hence, the solution that needs to be considered is energy efficiency strategies to reduce energy consumption without disrupting activities within the building (Duarte et al., 2021).

To achieve a significant global impact from energy efficiency strategies, it is not enough to apply them to a single building; it is more effective if the strategy can be implemented collectively. The implementation of the housing strategies offers excellent potential to make a significant contribution, as it encompasses many buildings with typical designs. Moreover, in Indonesia, it is expected that the demand for residential housing will continue to grow over time. This further strengthens the argument that applying energy efficiency strategies in housing has excellent potential to play a role in overall energy efficiency efforts.

Controlling the amount of solar radiation that enters a building is one way to increase energy efficiency and achieve indoor comfort (Bulbaai & Halman, 2021). The building envelope is crucial in regulating this amount. It is a complex system of environmental barriers and filters that can regulate the flow of heat, solar radiation, and airflow and convert radiation into energy (heat and electricity) (Rabani et al., 2021).

Windows are an essential building envelope component that can influence how much radiation enters a structure, mainly because they generally have transparent parts. This study aims to see how the ratio between window openings and walls of a building, more commonly known as the Windows-to-Wall Ratio (WWR), can influence efforts to increase electrical energy efficiency in residential houses.

In this study, researchers used a type 55 house (development version) as the research object. Type 55 houses are one of Indonesia's most popular houses because they are relatively affordable. Type 55 houses are commonly inhabited by small families (a couple of parents with two children) and can be expanded to accommodate growing space needs. Some housing developers include an alternative development plan in the offering brochure to help buyers visualize how their houses can be expanded to accommodate future needs. One of the housing estates that offers this is Puri Larasati Kalasan in Sleman, DIY. Therefore, this study used the alternative development design version of a type 55 house from this housing estate (provided in the offering brochure) as the focus of the research.

Figure 1. Case Study: Type 55 House (Development Version)
Source: Author's Analysis (2024)

2. Literature Review

2.1 Windows and WWR as Indicators for Building Energy Efficiency

Windows are a typically transparent component of the building envelope, which can act as a climate filter between the building's interior and exterior environments, influencing the energy consumption needed for lighting and air conditioning equipment (Elghamry & Hassan, 2019). Increasing the energy efficiency of building components like windows is crucial to lowering overall energy consumption and mitigating the consequences of climate change in the broader framework of global environmental challenges (Pekdogan et al., 2024). In addition, the external wall as the building envelope also affects the building cost requirements, energy consumption efficiency, and indoor environmental quality (Elghamry & Hassan, 2019; Bachrun et al., 2021).

One of the critical indicators for calculating the energy load from window usage is the window-to-wall ratio (WWR). The concept of WWR is utilized in the fields of design and construction, representing the ratio of functional space available within each façade (window) as perceived from an external vantage point (Pekdogan et al., 2024). According to previous research by Mehaoued & Lartigue in 2019, increasing the WWR in hot and humid areas increases the need for more cooling since the reflection of heat flow raises the surrounding temperature, which in turn increases the building's energy consumption (Mehaoued & Lartigue, 2019). Therefore, proper utilization of WWR in the building envelope will help to control the internal climate of the building with natural light control, and architects require WWR optimization to design energy-efficient building-oriented designs (Purwoko & Purwanto, 2022).

2.2 The Use of BIM in Enhancing the Energy Efficiency

One of the rapidly growing solutions to make buildings more environmentally friendly is the use of BIM (Building Information Modeling) as an engineering analysis method for simulation (Jadhav & Minde, 2024), including for small-scale (home) construction (Waqar et al., 2023). BIM provides a process to prepare, control, and measure the effects on the environment of a design and construction project through virtual modeling/visualization technology (Waas, 2022). BIM is also important in material selection, encouraging environmentally friendly decisions (Waqar et al., 2023). BIM (Building Information Modeling) can be used in all design and construction stages. In the context of energy efficiency, one of the crucial stages in building construction is the early design stage. The early design stage is essential because most decisions in the building design process are made at this stage (Ouldja, 2024). Most of a building's energy use occurs during operation (Salgude et al., 2024); hence, making detailed and appropriate design decisions early on can minimize energy consumption and make buildings more efficient and cost-effective (Bataineh, 2021). This can be accomplished by considering several options in the pre-construction stage (Salgude et al., 2024).

2.3 Simulation Software: Autodesk Revit 2018 and Green Building Studio Plugin

Autodesk Revit 2018 is one of the BIM applications that allows users to design buildings, structures, and their components in 3D/4D models. More than just designing models with BIM, linking models created with decision-making tools and sustainability indicators assists in making more informed decisions in the preliminary stages of the design project. It enables detailed sustainability comparison analysis using actual project data (Waas, 2022). This approach also helps designers look at various greener options, which can save energy and resource use while considering project costs. The software that is often used for BIM-based sustainability analysis is Autodesk Green Building Studio (GBS) (Azhar, Brown, & Sattineni, 2010).

Green Building Studio constitutes a cloud-based framework that permits users to conduct building performance simulations to enhance energy efficiency and minimize carbon emissions from the preliminary design phase. Numerous simulations about energy consumption within architectural structures can be executed utilizing Green Building Studio. Prior studies indicate that Autodesk Revit 2018, in conjunction with Green Building Studio, facilitates the evaluation of energy efficiency and associated costs of buildings (Pekdogan et al., 2024). Green

Building Studio supports building design development with much less time and cost than conventional methods (Luziani & Paramita, 2019). Autodesk Revit and Green Building Studio have been utilized to determine the most appropriate building component materials that improve the operational efficiency of structures, thereby reducing the extraneous expenses related to energy use throughout the lifespan of the edifices (Alithman & Khrisnaraj, 2021).

2.4 Residential House as a Research Object

Residential houses are a building typology that needs to be investigated for energy efficiency strategies, particularly using BIM (Building Information Modeling) as a tool. There are several reasons for this, the first being that small-scale construction projects have not made significant progress in integrating BIM and green building practices compared to projects (Ferdosi et al., 2023), and the second being that households account for 39.4% of Indonesia's total electrical energy consumption in 2013-2019 (Svendsen & Schultz, 2022). Due to limited resources, financial constraints, and a lack of knowledge about the benefits of green building, small projects occasionally require assistance in implementing sustainable practices. These problems might make it challenging for them to implement sustainable practices, even though they have significantly contributed to the construction sector (Waqar et al., 2023). The growing number of households, which is anticipated to reach 70.6 million by 2025 and 80 million by 2050, will impact the quantity of household energy demand (Svendsen & Schultz, 2022). Implementing energy efficiency strategies in households (especially electrical energy) is expected to significantly impact national electrical energy consumption. Therefore, research on improving the sustainability of housing typology is required to respond to this challenge.

3. Research Method

First, researchers conducted a literature review of some selected articles to find gaps in the previous studies that had not been explored. The Keywords used to find the articles are BIM, energy efficiency, energy use intensity, and window-to-wall ratio. Then the researcher determines the research goals and collects the required data related to the site and the existing building. The case study the researcher used was in the form of alternative designs for the development version of type 55 houses obtained from the Puri Larasati Kalasan housing brochure. After receiving the data, researchers modeled the existing building using Autodesk Revit 2018 software and calculated the Windows-to-Wall Ratio (WWR) percentage from the initial design. The data about the site and the building that researchers get are as mentioned in Table 1:

Table 1. Location and Existing Building Data

Site Data and Existing Building Data	
Location	Puri Larasati, Sleman, DIY
Typology	Type 55 House (development version)
Building Orientation	North
Total Building Area	74 m ^{2}
Total Land Area	110 m ^{2}
Building Height	6,78 m ^{2}

Source: Author's Analysis (2024)

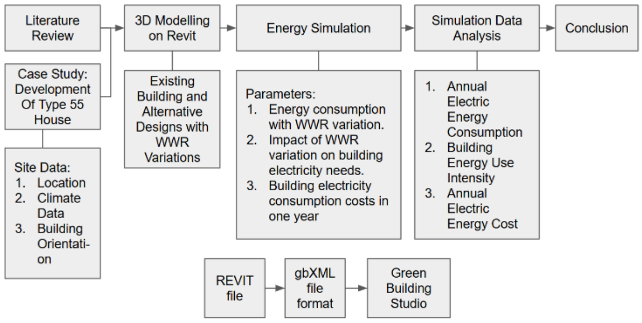


Figure 2. Research Methods
Source: Author's Analysis (2024)

Climate significantly influences architectural design, especially when simulating building models. The shape of the building, such as window dimensions and shape, as a determinant of building energy efficiency, is also influenced by the climatic conditions on the selected site. Therefore, researchers took some climate-related data on the building site to be input into modeling and simulation software as analysis data. Climate aspects focused on as a simulation requirement in this research are temperature and radiation, because both will affect the need for electrical energy in this case study. As shown in Figure 3a and 3b, the selected site, Puri Larasati, Sleman, is located in an area that has a tropical climate, with a monthly temperature range of 20°C to 35°C (BPS-Statistics Indonesia Sleman Regency, 2024). Here are some illustrated diagrams that represent the information on climate data for the location that researchers used in the simulation process:

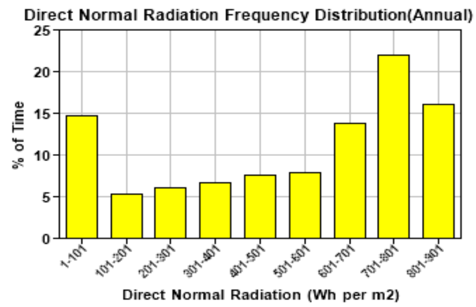


Figure 3a. Direct Normal Radiation Frequency Distribution
Source: Climate Data on Green Building Studio (2024)

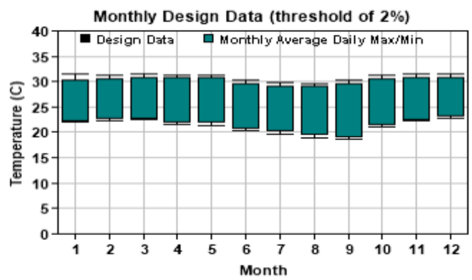


Figure 3b. Direct Normal Radiation Frequency Distribution
Source: Climate Data on Green Building Studio (2024)

Second, researchers created several scenarios of the house model by giving different percentages of Windows-to-Wall Ratio (WWR) in each design scenario. At this stage, researchers have done modeling using Autodesk Revit software. The calculated results of the window-to-wall ratio percentage in the existing building were obtained at 13%. The variation in the percentage of WWR in the alternative design iteration is done by increasing or decreasing the window area while maintaining the shape module and materials used. The researchers created 4 (four) alternative design scenarios, with details of 2 (two) alternatives using a lower WWR percentage than the initial design (7% and 11%), and 2 (two) other options using a higher WWR percentage than the initial design in an existing building (22% and 30%) to obtain a significant energy efficiency simulation result. Researchers gave the same treatment to building materials, window materials, and frames in each alternative design as control variables. The diagram in Figure 3 below shows the comparison of the percentage variation of Window-to-Wall Ratio (WWR) values in each alternative design scenario:

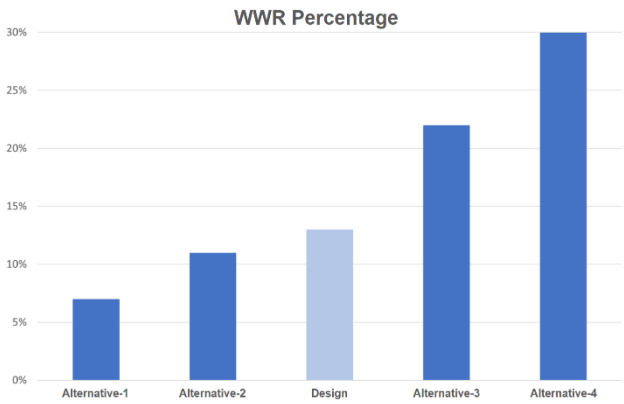


Figure 4. Comparison Diagram of WWR Percentage on Alternative Scenario
Source: Author's Analysis (2024)

Third, researchers simulated the five designs (4 alternative scenarios and one initial design) to calculate the annual electrical energy building consumption and building energy use intensity. This simulation used Autodesk Revit software and Green Building Studio as an additional plugin. The researcher inputs the data location for simulation purposes using Autodesk Revit software. The simulation was arranged to have the same energy settings in Revit (as shown in Table 2) before being exported to the Green Building Studio (GBS) plugin. Researchers conducted the energy analysis in Revit for every design scenario after establishing the energy and developing the energy model. The Green Building XML (gbXML) file type is then used to export this data from Autodesk Revit, which is then imported into Green Building Studio for energy efficiency and electrical energy consumption calculations. This open-schema format was developed to facilitate the transfer of building data from Building Information Models (BIM) to engineering analysis tools. In Green Building Studio, the same location data was re-input. The settings of each alternative design scenario are made on the same template so that the simulation results between the existing building and the 4 four alternative design scenarios obtained are accurate.

Table 2. Energy Setting in Revit

Energy Setting	
Analysis Model	Conceptual Mass and Building Element
Export Complexity	Simple with Shading Surface
Building Operating Schedule	Default
Building Services	Split System(s) with Mechanical Ventilation
Building Type	Single-Family
HVAC System	Residential 17 SEER/9.6 HSPF Split HP <5.5 tons
Export Category	Rooms

Source: Author's Analysis (2024)

Fourth, from this simulation, researchers obtained data results from annual electrical energy consumption, energy use intensity, and the calculation of the annual electricity costs required for each design scenario. The annual electrical energy consumption data is also accompanied by a percentage of the allocation of electricity use, so specific data is also obtained in addition to receiving the yearly energy consumption result. The standard electricity components used in residential projects are detailed in Green Building Studio (GBS) and consist of HVAC (Heating, Ventilation, and Air Conditioning), artificial lighting, and miscellaneous equipment. After obtaining the data from the simulation results, researchers analyzed the data. The energy consumption indicator used to analyze the data obtained is Energy Use Intensity (EUI). The level of energy utilization in a building can be measured using the Energy Usage Intensity value (Wanimbo & Amiruddin, 2019). Another method used for measuring a building's energy efficiency and consumption level is to use Energy Use Intensity, which can be calculated using several standards as follows:

According to SNI regulation No. 03-0196: 2010, the classification of the Energy Use Intensity (EUI) value in air-conditioned buildings is as mentioned in Table 3:

Table 3. EUI Value Classification

Criteria	EUI (kWh/m^2/month)
Very Wasteful	23,75 – 37,5
Wasteful	19,2 – 23,75
Somewhat Wasteful	14,58 – 19,2
Moderately Efficient	12,08 – 14,58
Efficient	7,93 – 12,08
Highly Efficient	4,17 – 7,93

Source: SNI No. 03-0196 (2010)

Meanwhile, PERMEN of ESDM No.03/2012 classifies Energy Use Intensity (EUI) more specifically on building electrical energy consumption with the following assessment described in Table 4:

Table 4. Classification of Specific EUI Values

Criteria	EUI (kWh/m^2/month)
Highly Efficient	EUI < 8,5
Efficient	8,5 < EUI < 14
Moderately Efficient	14 < EUI < 18,5
Wasteful	18,5 < EUI

Source: Permen ESDM No.03 (2012)

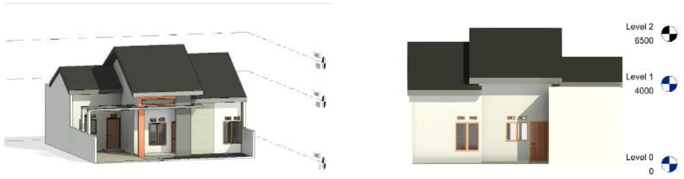
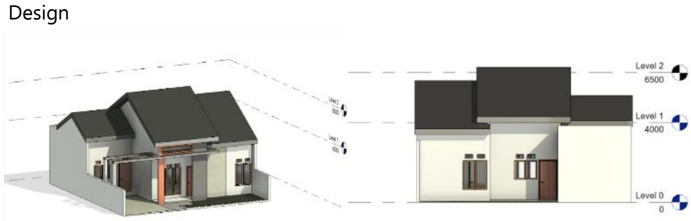
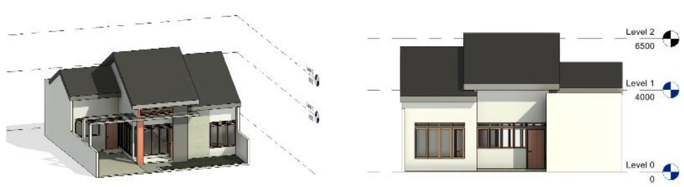
This research focuses on analyzing the impact of the relationship between the Window-to-Wall Ratio (WWR) and energy efficiency in small-scale building construction (residential houses), where the use of energy in small-scale buildings is dominated by electricity. Therefore, to analyze the collected data and evaluate electrical energy usage, researchers use the Energy Use Intensity (EUI) classification in PERMEN ESDM no.03 2012 (as shown in Table 4).

4. Results and Discussions

4.1 Simulation Result of WWR Variations on Annual Electrical Energy Consumption

The researcher's approach to modifying the four alternative scenario designs has been described in the second phase of the research methods section. The addition and subtraction of window modules in developing type 55 houses was carried out at the front and back sides of the building envelope, as illustrated in Table 5. This modification is predicated on compatibility with its current function to avoid interfering with user activities within the interior space. Table 5 shows the outcomes that were attained by researchers using simulations with four distinct variations in the Window-to-Wall Ratio (WWR) percentage in Autodesk Revit 2018 software and the Green Building Studio (GBS) plugin to analyze the impact on annual electric energy consumption in the case study.

Table 5. Simulation Result of WWR Variations with Alternative Scenarios

Building Model	WWR (%)	Annual Electric Energy Consumption (kWh)
Alternative 1 	7	6.810
Alternative 2 	11	6.995
Design 	13	7.226
Alternative 3 	22	7.725
Alternative 4 	30	8.447

Based on the data from the simulation results in Table 5, each alternative design scenario has a different annual electrical energy consumption value. This means that window-to-wall energy influences building energy consumption. As shown in the diagram illustrated in Figure 5, researchers compare the annual electrical energy consumption figures of the building design and alternative scenarios in terms of understanding how the values differ:

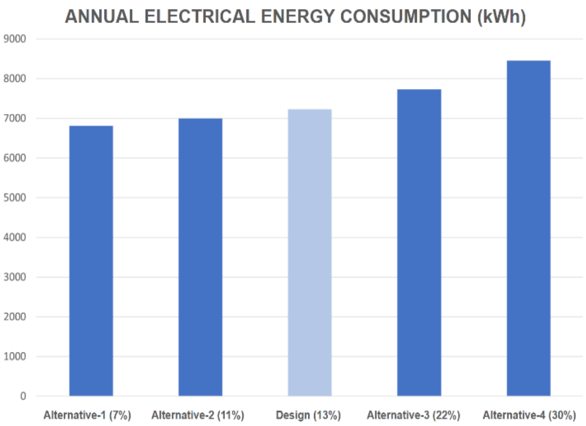


Figure 5. Annual Electrical Energy Consumption
Source: Author's Analysis (2024)

The compared result illustrated in Figure 5 shows that as the percentage of Window-to-Wall Ratio (WWR) increases, the annual electrical energy consumption figure also increases. Alternative design scenarios with larger WWR significantly increase results, approximately 500-1220 kWh. On the contrary, alternative design scenarios with a reduced window-to-wall ratio (WWR) result in decreased energy consumption estimates. The deviation between the existing design and the lowest WWR percentage reduces approximately 416 kWh on the overall value of annual electrical energy consumption. These comparisons explain that the building's window-to-wall ratio and yearly electrical energy consumption are directly proportional.

For residential house cases, several components of electricity consumption needs are used. Based on the simulation results using Green Building Studio (GBS), this annual electrical energy consumption can be broken down in more detail for HVAC, artificial lighting, and miscellaneous equipment. The miscellaneous equipment in this GBS simulation refers to some household electrical appliances such as hot water, electric stoves, and pumps. The result of annual electric energy consumption and the details of each component are presented in the table and diagram below:

Table 6. Simulation Result of WWR Variations on Annual Electrical Energy Consumption

Alternative	Annual Electrical Energy Consumption	HVAC	Lighting	Miscellaneous Equipment
1	6,810 kWh	41 %	29,5 %	29,5 %
2	6,995 kWh	42,5 %	28,7 %	28,7 %
Design	7,226 kWh	44,4 %	27,8 %	27,8 %
3	7,725 kWh	48 %	26 %	26 %
4	8,447 kWh	52,4 %	23,8 %	23,8 %

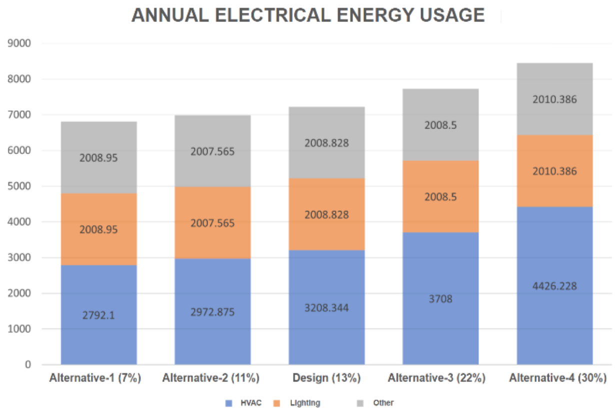


Figure 6. Annual Electrical Energy Usage (HVAC, Lighting, and Others)
Source: Author's Analysis (2024)

The table and diagram of simulation results in Green Building Studio (GBS) presented in Table 6 and Figure 6 show that the greater the percentage of WWR, the greater the percentage of electricity consumption for Heating, Ventilation, and Air Conditioning (HVAC) purposes, as well as the lighting and miscellaneous equipment. The greater the percentage of WWR, the greater the solar radiation energy that enters the building; hence,the building's thermal mass also increases (Kurniawan et al., 2023).

This simulation assumes that the higher solar radiation will increase the electricity demand for type 55 development houses. The concept of this Green Building Studio energy simulation was that larger windows indicated that a building would necessitate increased air conditioning and reduced lighting, thereby delivering a higher value of annual electrical energy consumption.

In hot and humid climate conditions, a high WWR ratio will increase the cooling load while decreasing the indoor heating load (Shaeri et al., 2019). The annual electricity consumption usage range for HVAC equipment was from 41% to 52.6%, indicating that the percentage increased by approximately 11% or 1.634 kWh from the lowest to the highest WWR percentage design scenario. This shows that in a small-scale building like a residential house, the annual electrical energy consumption is most affected by WWR for HVAC purposes. According to the Green Building Studio, the lighting and miscellaneous equipment components have the same percentage ratio. The result demonstrates that, compared to the lowest and the highest WWR percentages, the number decreased by almost 6%, or 2 kWh, on each component. Therefore, it can be concluded that in small-scale buildings, annual electrical energy consumption for detailed components such as HVAC, artificial lighting, and miscellaneous equipment is influenced by variations of WWR in this simulation.

4.2 Specific Energy Use Intensity

A housing's predicted total Energy Use Intensity (EUI) can be calculated by dividing the total value of energy used by the building (kWh/year) by the building's floor area (m^2) (Wingrove et al., 2024). In this research, researchers analyze the Energy Use Intensity as a specific EUI on electrical energy needs for the development version of the type 55 house. The following data in Table 7 are the simulation results gained from the Green Building Studio (GBS) on the Specific EUI score between the existing design and each alternative design scenario made by the researchers:

Table 7. Simulation Result of WWR Variations on Specific Energy Use Intensity

Alternative	Annual Electrical Energy Consumption (kWh)	Specific Energy Use Intensity (kWh/m²/month)
1	6,810	9,95614
2	6,995	10,22661
Design	7,226	10,56433
3	7,725	11,29386
4	8,447	12,34942

Meanwhile, the diagram in Figure 7 presents a comparison of specific energy use intensity values based on the classification of PERMEN of ESDM No.03/2012 as stated in Table 4:

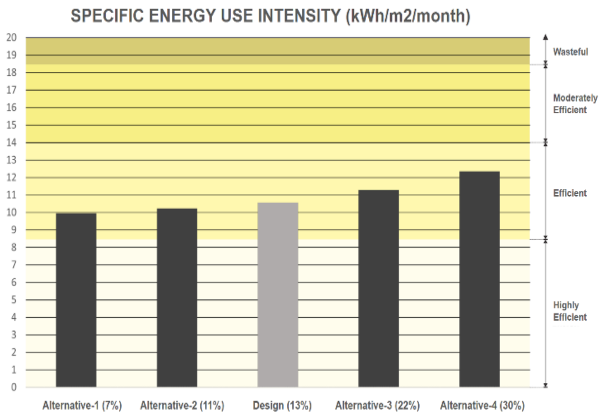


Figure 7. Comparison Diagram of WWR Variation Simulation against Specific EUI Assessment
Source: Author's Analysis (2024)

From the comparison diagram illustrated in Figure 7, the variations in the WWR value between the existing design and the four alternative design scenarios demonstrate how the specific Energy Use Intensity (EUI) score changed. The diagram shows that alternative design 1 and alternative design 2, which have a smaller WWR value, could decrease the specific EUI score. By reducing the WWR value by 2-6% from the existing building, the EUI score in the development version of the type 55 house model has reached a more efficient value. The deviation from the existing design and the lowest WWR percentage was approximately 0,61 kWh/m2/month. While the alternative design three and alternative design 4, with a value of WWR, are higher than the existing building, which affects a higher score of specific EUI. The increase in yield ranges from 0.73 to 1.78 kWh/m2/month, making buildings even more wasteful.

A prior study conducted by Shi (2021), which uses container dwellings simulations, demonstrated that variations in window-to-wall ratio (WWR) could affect the EUI score. According to the study, higher WWR percentages result in increased EUI values, with the dominant usage for HVAC equipment. To provide more significant results of specific EUI values, the simulations conducted in the research need to consider several other variables that affect the heat intensity received by the building, such as building orientation (Shi, 2021, Dagiyan et al., 2024, Jadhav & Minde, 2024), insulation thickness (Altun, 2022), window type and material selection (Jadhav & Minde, 2024), and more.

4.3 Annual Electricity Cost

To calculate annual electricity cost, it is necessary to consider the calculation in several aspects, such as kWh charge to cover electricity utilization, base kW charge, and peak kW charge to consider the most significant and lowest monthly demand value (Ye et al., 2022). The Green Building Studio simulation helps to calculate the annual electricity costs automatically. Figure 8 is a comparison of data illustrated in the diagram obtained from the simulation results of Window-to-Wall Ratio (WWR) variations on the annual electricity cost on a development version of a type 55 house:

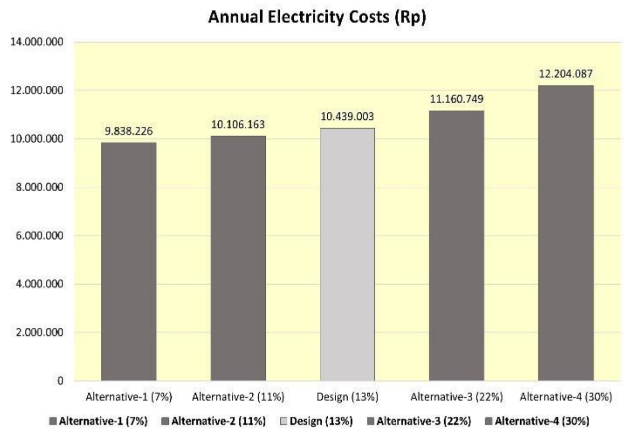


Figure 8. Comparison Diagram of Annual Electricity Costs
Source: Author's Analysis (2024)

The diagram illustrated in Figure 8 shows that alternative design scenarios with different percentages of WWR also affect the results of the calculation of annual electricity costs for type 55 house development. Puri Larasati housing uses 1,300 VA of power in each type of house. Referring to the Minister of Energy and Mineral Resources regulation, the electricity tariff for the R-1/TR class of 1,300 VA power is Rp. 1,444.7 per kWh. Based on the calculation of annual electricity costs illustrated in Figure 7, a cost comparison between the existing building and its alternatives is obtained. The annual electricity cost reaches Rp in the existing building with WWR 11%. 10,439,003. Alternative building 1 with 7% WWR has the lowest annual electricity cost of Rp.9,838,226, while alternative building 4 with 30% WWR has the highest annual electricity cost of Rp.12,204,087.

From these data, if using alternative option 1, the cost savings obtained compared to the existing building is 5.8%.

5. Conclusion

Based on the simulation results and data analysis conducted by researchers, it can be concluded that the windows-to-wall ratio (WWR) affects building annual electrical energy consumption, generated in HVAC, artificial lighting, and miscellaneous equipment. The variations of WWR also affect the calculation result of Energy Use Intensity (EUI). This means that to reduce the overall EUI in buildings, it is necessary to consider other factors that may affect it, such as the selection of window material types, building orientation, insulation thickness, and more (Shi, 2021; Altun, 2022; Dagiyan et al., 2024). Although its effect on electrical energy consumption tends to be insignificant, WWR has been proven to influence the energy efficiency of small-scale buildings (residential houses) based on simulations. The outcome might be different when it is applied to larger-scale construction.

In terms of cost savings, the smaller the WWR value in the alternative design scenario, the lower the annual electricity cost, which is influenced by several other factors, such as air conditioning. Buildings with smaller WWRs generally have lower cooling loads. On the contrary, the larger the WWR value, the higher the cooling load required in a room due to increased heat transfer through windows.

For future studies, researchers suggest providing WWR calculation scenarios in conditions without air conditioning to explore other design alternatives. In this case, optimizing the WWR value to increase electrical energy efficiency can be one of the design strategies in residential buildings. It can consider climatic conditions, building orientation, HVAC systems, and materials used without sacrificing occupant comfort. This research emphasizes the importance of the right design approach, where the WWR factor becomes one of the variables in a more complex system to support the creation of energy-efficient and environmentally friendly buildings.

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