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Simulation-Based Exploration with Energyplus as an Energy Efficiency Strategy

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A B S T R A C T

In countries with tropical or subtropical climates, such as Indonesia, the use of air conditioning is becoming increasingly important for comfort and productivity. However, high energy use in air conditioning systems has significant environmental and economic impacts, including increased greenhouse gas emissions and high operational costs. This research aims to analyze the Energy Consumption Index (ECI) in the Joint Lecture Building, State University of Malang using EnergyPlus software simulation. Research data consists of building data, weather data, building construction data, operating schedules, equipment specifications, and energy usage data. Furthermore, the data analysis technique used ECI calculations based on EnergyPlus software simulation. The research results show that based on the Energy Consumption Index value it is 201,943 kWh/m^2/year, but with a savings scenario it becomes 161,964 kWh/m^2/year (an increase of 19,797%) so it is classified as efficient. The energy-saving scenario implemented is to replace the Constant Air Volume (CAV) air conditioning system with Variable Air Volume (VAV) and the types of luminaires that were originally fluorescent will be replaced with Light Emitting Diodes (LEDs). The comparison results obtained an energy-saving value of 19,797%. The research results show that using VAV and LEDs technology can increase energy efficiency in the Joint Lecture Building, State University of Malang. The scenario attempts to reduce environmental impact through energy efficiency in commercial buildings and shows that the EnergyPlus simulation method is an effective approach for designing energy savings strategies.

1. Introduction

Energy consumption plays an important role as a source of life for all activities carried out in a building. Energy consumption occurs in various sectors of life, including the building sector [1]. It is also said that energy consumption is in line with population growth, economic growth, and industrial development [2]. Aspects of energy consumption in buildings include

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several things, such as geographical location, operating schedule, construction materials, energy supplier tariffs, air conditioning systems, lighting, and external weather conditions as input parameters [3]. Buildings consume around 40% of the world's energy, especially in Indonesia. This sector is responsible for 50% of all energy expenditure, as well as more than 70% of electricity consumption [4]. The large amount of energy used by buildings in nature will certainly result in the condition of natural resources, especially non-renewable sources, becoming increasingly difficult to access in the next few years [5].

Malang State University (UM) is one of the best universities in Malang. The UM Joint Lecture Building (GKB UM) is a facility to support learning and teaching activities by the entire Malang State University academic community. UM always tries to provide the best services and infrastructure for all academic communities. The construction of lecture buildings increases the effectiveness of teaching and learning activities [6]. The UM Joint Lecture Building includes two buildings with similar characteristics on nine floors. The nine-building floors include 1 and 2 for car parking, laboratories, lecturers, and lecture rooms. Meanwhile, 3 to 7 are used as classrooms, seminar rooms, lecturer's rooms, libraries, and even common space areas. 8 to 9 are used as auditoriums, multifunction, seminars, testing centers, and language laboratories. This twin tower has a garden, amphitheater, powerhouse, rainwater channels, river crossing, parking area for 2 and 4 wheels, and a pedestrian. When viewed physically, the GKB UM building envelope has a translucent facade that is wider than the opaque material. This of course affects energy consumption in the building envelope. On the other hand, the building envelope at GKB UM has many vertical fins which will influence the use of lights and will directly influence the artificial lighting aspects listed in the Green Building Council Indonesia's Greenship Rating Tools. Apart from that, GKB UM which covers 9 floors will of course use energy in the form of a vertical transportation system whose energy consumption also needs to be reviewed.

Green Building is a building that optimizes energy savings, preserves the environment, minimizes pollution, maintains health, uses space efficiently and is in harmony with nature in its life cycle [7][8][9]. According to Green Building Council Indonesia's Greenship Rating Tools, a green building is a building from the design, construction, and operation to maintenance operations that shows aspects of conserving, minimizing the use of natural resources, maintaining indoor air quality, and paying attention to health, all of which are guided by the principles of sustainable development [10][11][12]. Green buildings focus on the optimization and efficiency of energy consumption, especially in the management of electrical

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energy, ventilation systems, lighting, water resource processing, and material selection [13]. In general, there are ways to save energy expenditure on buildings, which include energy savings with building utility systems, energy savings with building users, and energy savings through architectural design [14][15][16]. Thus, paying attention to environmentally friendly buildings is necessary for building development because they bring opportunities to achieve energy efficiency and a low-carbon society [17].

Previous research on using the Energy Consumption Index (ECI) as a parameter to measure the energy performance of a building generally relies on the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 13 of 2012, ECO ECI, and the Energy Efficiency Index (EEI) [21] [22][23]. This indicates that previous research has yet to utilize EnergyPlus software simulations, even though EnergyPlus software has advantages over other energy simulation software [24]. A similar opinion states that the most comprehensive EnergyPlus software simulation is used to analyze or provide a deeper understanding of energy efficiency [25]. EnergyPlus can also model the energy consumption of buildings' heating, cooling, ventilation, lighting, and water use processes [24]. This shows that the application of EnergyPlus Software simulation is still relatively new. This approach provides a more detailed understanding of energy consumption and overall building performance, allowing for developing more appropriate strategies for designing and managing green buildings. These latest breakthroughs in energy simulation technology, such as EnergyPlus, allow researchers to model buildings more accurately and evaluate the impact of various design strategies on energy consumption. Currently, no one has researched the energy consumption index (ECI) of the GKB UM building using EnergyPlus software. ECI is needed to develop sustainable buildings that are more energy-efficient and environmentally friendly.

This research aims to analyze the Energy Consumption Index (ECI) at the GKB UM using EnergyPlus software simulation. This is to support government programs regarding energy conservation and efficiency, especially for buildings [26]. The results of this research will significantly contribute to sustainable building development energy efficiency and can be the basis for government policy in encouraging the development of sustainable buildings in the future, as well as contributing to global efforts to reduce carbon emissions.

2. Research Method

This research will adopt a quantitative approach to analyze the application of the Green Building concept in the Joint Lecture Building, State University of Malang (GKB UM). This

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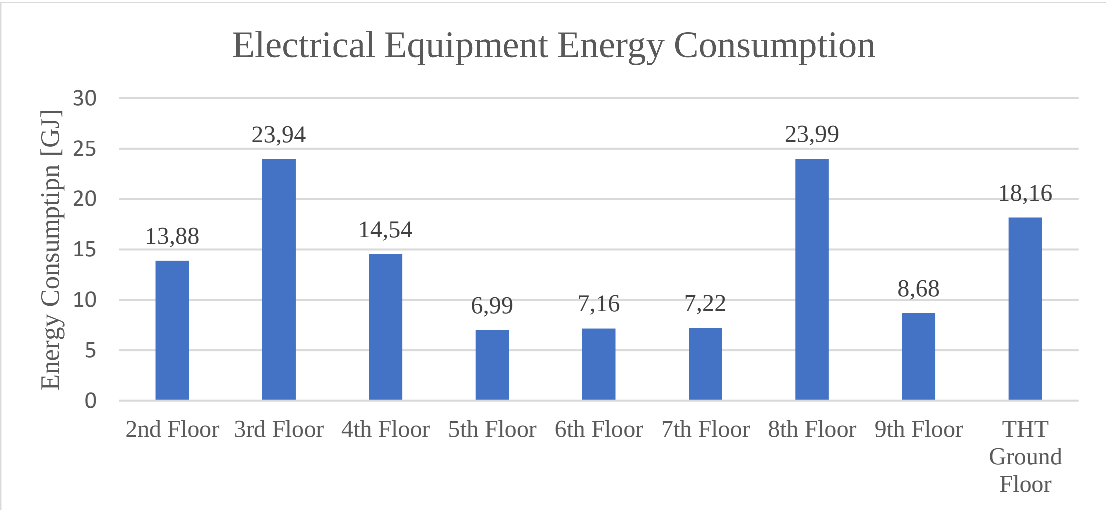
approach allows measurable data collection and in-depth statistical analysis to evaluate the effectiveness of Green Building concepts in reducing energy consumption. Conduct a literature review to understand the Green Building concept, energy consumption index (ECI), and simulation methodology using EnergyPlus software.

The processing and use of software follow the research flow, starting from the literature study stage, data collection stage, building modeling with Google SketchUp, Open Studio Plugin, Input Data to EnergyPlus, EnergyPlus Simulation, analysis and discussion of simulation results, and the conclusion stage. The research data or aspects observed consist of building data, weather data, building construction data, operation schedules, equipment specifications, and energy usage data. The data analysis technique uses the ECI calculation based on the EnergyPlus software simulation, and then the simulation results refer to the Guidelines for Energy Saving in Government Buildings in line with the Minister of Energy and Mineral Resources Regulation No. 13 Yrs. 2012 regarding savings in electricity use in the ECI value of air-conditioned buildings.

3. Results and Discussions

3.1 Energy Consumption of Electrical Equipment for Each Floor

The Joint Lecture Building, State University of Malang found that the largest energy consumption on the 3rd and 8th floors was 23,990 GJ, while the lowest energy consumption occurs on the 5th floor at 6,990 GJ. The simulation results show that the total electrical energy consumption of the equipment is 124,560 GJ. Details of the electrical energy consumption of electrical equipment are shown in **Figure 1**.



Source: Research Document Results

Figure 1 Electrical Energy Consumption of Electrical Equipment for Each Floor

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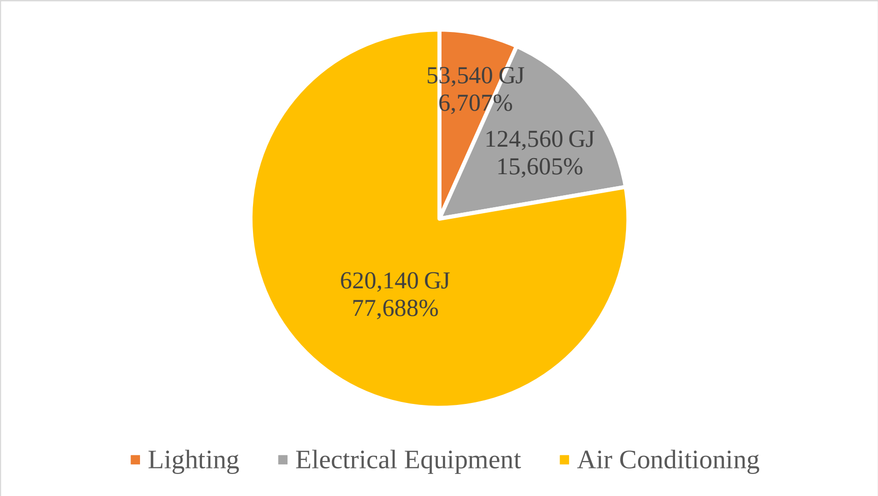
The ground floor is used for a car parking area and laboratories, while floors 3 to 7 are used for classrooms, seminar rooms, reading rooms, faculty rooms, a library, and a common area. Meanwhile, floors 8 and 9 are used for an auditorium, a multipurpose room, seminar rooms, a testing centre, and a language laboratory. The electrical appliances that consume the most electricity are air conditioners (AC). Air conditioning (AC) is one of several aspects of energy consumption in buildings, alongside other factors such as geographical location, operating schedules, construction materials, energy supplier rates, lighting, and weather conditions [3]. Among these aspects, air conditioning is one of the electrical appliances that consumes the most electricity. Therefore, increased energy consumption in buildings is usually caused by air conditioning.

3.2 Electrical Energy Consumption of the Entire Building

Based on the simulation results using EnergyPlus, it can be seen that the highest energy consumption occurs in the air conditioning system, reaching 77,688%, while the lowest energy consumption occurs in electrical equipment, only 6,707%. This shows that the air conditioning system requires significant energy consumption, while the energy consumption of electrical equipment is relatively lower. Details of the overall energy consumption of the building are shown in **Figure 2**.



Source: Research Document Results

Figure 2. Electrical Energy Consumption of the Entire Building

Based on these results, it is necessary to make significant savings related to air conditioning. The ECI value for the simulated GKB UM building is 201,943 kWh/m²/year. This value is derived from the value of the overall electric energy consumption of GKB UM which is worth 798,240 GJ or 221733,333 kWh divided by 1098 m^2 floor area. Its shows that using AC increases the building's electrical energy consumption. The cost of electrical energy for an AC

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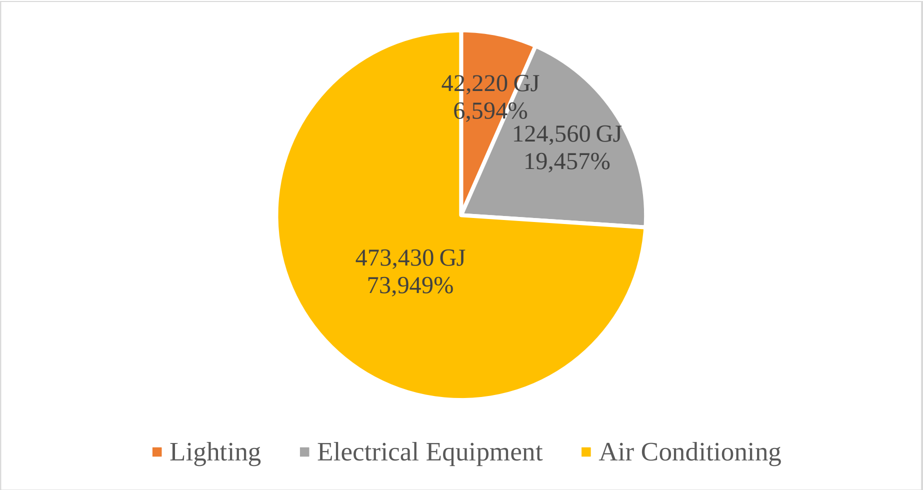
system can reach 50%-80% of all electrical energy consumption in a building. Previous research proposed air conditioning savings using a Trombe wall system which is planned to provide thermal comfort, where the outer wall is a Trombe wall and allows light to enter while blocking direct light [29]. The same research results also show that AC's large contribution to electricity consumption requires a solution to reduce electrical energy consumption. An alternative to producing air that can save electrical energy is to use a thermal energy storage system to minimize the thermal load in the room in a building [28]. It was also stated that the AC system is usually used to condition the air in the room so that it matches the room's thermal comfort temperature [28].

3.3 Energy Conservation Scheme

Through EnergyPlus, to save energy in the GKB UM, the scheme that can be implemented is to replace the Heating, Ventilation, and Air Conditioning (HVAC) system and the type of luminaires used. The HVAC system which was originally a Constant Air Volume (CAV) will be replaced with a Variable Air Volume (VAV). This VAV system can provide constant variations in air volume to meet changes in room cooling load [30]. In addition, the types of luminaires that were originally fluorescent will be replaced with light emitting diodes (LEDs), which are more energy efficient. This step aims to increase building energy efficiency by utilizing more efficient and environmentally friendly technology.

Electrical energy consumption values for the simulation of the application of the VAV system and the use of LEDs type luminaires, with the simulation results using EnergyPlus are presented in the **Figure 3**.



Source: Research Document Results

Figure 3. Electrical Energy Consumption of the Entire Building for the scenario of implementing a Variable Air Volume (VAV) system and using LEDs type luminaires

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After carrying out a simulation using EnergyPlus regarding energy conservation, the largest energy consumption is still in the air conditioning system, even with the implementation of Variable Air Volume (VAV) which reaches 473,430 GJ. The energy consumption of the lighting system using LEDs reaches 42,220 GJ. Energy consumption for electrical equipment is still the same as before, namely 124,560 GJ. The overall energy consumption after the energy conservation scenario is 640,210 GJ. The ECI value after energy conservation is 161,964 kWh/m²/year.

From the description above, after carrying out a simulation using EnergyPlus regarding energy conservation, it turns out that the largest energy consumption is still in the air conditioning system. This is in line with the results of the previous study which explains that the largest electrical energy consumption for AC use is more than 40% of the total power consumption of each building [31]. Likewise, other research results show that most energy consumption in Indonesian buildings is used for air conditioning systems [32]. The energy consumption required for air conditioning systems ranges from 47% to 65% of the total energy requirements of a building. It was also explained in the previous research that 83% of the electrical energy in a campus building at Yogyakarta State University is used as an air conditioning system and the rest is for lighting and instruments to assist the teaching and learning process [32]. This states that the energy consumption required to operate a building's air conditioning system is very large.

3.4 Energy Consumption Index

Savings on electrical energy consumption in the Joint Lecture Building, State University of Malang by implementing the VAV system and LEDs lights are shown in this **Table 1**.

Table 1. Electrical Energy Consumption of the Joint Lecture Building, State University of Malang

<table>
<tr><th></th><th>Before</th><th>After</th><th colspan="2">Savings</th></tr>
<tr><td>Energy Consumption Overall Electricity (GJ)</td><td>798,240</td><td>640,210</td><td>158,030 GJ</td><td rowspan="2">19,797%</td></tr>
<tr><td>Energy Consumption Index (ECI) (kWh/m²/year)</td><td>201,943</td><td>161,964</td><td>39,979 kWh/m²/year</td></tr>
</table>

Source: Research Document Results

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Based on data before and after implementing changes or improvements in energy efficiency, significant energy savings can be seen. Previously, overall electrical energy consumption was 798,240 GJ, but after implementing the changes the number fell to 640,210 GJ. This shows energy savings of 158,030 GJ. In addition, implementing these changes also affects the Energy Consumption Index (ECI), which is a measure of a building's energy efficiency. Previously the ECI was 201,943 kWh/m²/year, and after implementing the changes the ECI value fell to 161,964 kWh/m²/year. This shows a change in ECI of -39,979 kWh/m²/year, indicating an increase in building energy efficiency. Overall, these results reflect the success of efforts to reduce energy consumption and increase the efficiency of energy use in buildings. If you look at the Guidelines for Energy Saving in Government Buildings, they are in line with the Minister of Energy and Mineral Resources Regulation No. 13 Yrs. 2012 regarding savings in electricity use, the ECI value of an air-conditioned building, the ECI value is 161,964 kWh/m2/year. included in the Efficient category (102-168). The Efficient category shows that: 1) maintenance of buildings and energy instruments is carried out based on procedures, and 2) Energy use efficiency can still be developed by utilizing an integrated energy management system.

Referring to energy savings is based on the Energy Saving Guidelines issued by the Ministry of Energy and Mineral Resources No. 13 Th. 2012, as stated by the research results [33] in the Minister of Energy and Mineral Resources Regulation No. 13 Th. 2012, regarding savings in the use of electrical energy, it was stated that all central and regional government offices should carry out programs to save electrical energy in air conditioning systems, lighting, and other supporting instruments. The energy consumption of an office is now very large.

Based on the research results showing that the Energy Consumption Index (ECI) of the GKB UM is considered efficient, it can be said that GKB UM has met the criteria for a green building as it has achieved energy efficiency in its building. As stated in [13] a green building focuses on optimizing and improving energy consumption efficiency, including the management of electrical energy, ventilation systems, lighting management, water resource management, and material selection. However, there is a possibility of further enhancing energy use efficiency. This is in line with other opinion that after efficiency has been achieved it is necessary to identify impact factors so that they can be maintained or improved [31].

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4. Conclusions

The research results show that simulations using EnergyPlus Software show that the existing condition of the Joint Lecture Building, State University of Malang is inefficient with an Energy Consumption Index value of 201,943 kWh/m2/year. However, energy consumption can be further optimized by implementing a VAV system and LED luminaire types, so that savings can reach 161,964 kWh/m2/year (an increase of 19,797%) so that it is classified as efficient. Thus, this research enhances energy efficiency through the proposed solutions, making the building more efficient. The contributions of this study are highly relevant to the sustainable construction industry, significantly impacting the field, especially in the context of developing more energy-efficient and environmentally friendly buildings, reducing carbon footprint, promoting the development of more advanced and environmentally friendly building technologies and systems, increasing public awareness of the importance of sustainable building design and its role in environmental conservation, and reducing operational costs.

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