Operational Energy Analysis of an Educational Building Design; A Case Study of Center of Excellent (CoE) Building at Universitas Pendidikan Indonesia (UPI)

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Abstract. Operational energy contributes significantly to the most energy consumption of a building’s life cycle. Analysis of operational energy is usually conducted when a building is being operated. However, we can compare and predict the operational energy of a building’s designs to obtain the best design alternative low energy building. The objective of this study is to simulate the operational energy of the design of the Centre of Excellent (CoE) building at Universitas Pendidikan Indonesia (UPI). Rhinoceros and Grasshopper with Ladybug and Honeybee are selected as the software simulation due to the comprehensive features of energy simulation. This modern building will be constructed for five floors with an area of about 5000 m² per level facing south and north sides. Analysis of operational energy calculated three main factors of cooling, lighting, and other equipment. The result shows that the annual operational energy contributes to about 586 kWh/m² per year. This value is far from the basic standard for educational building, with about 240 kWh/m² per year from ASEAN. The cooling system of the building is recorded as the highest amount of energy use. Further, evaluating the building’s operational devices and the strategy to reduce the energy loads will be proposed to accommodate a modern school building’s main issue that harms operating energy.

1. Introduction

In recent years, many people have been paying attention to the life cycle of energy (LCA) from the building. It upfront the production of the building material and home appliances is upfront to be advanced technology in low energy consumption. The global goal of this is to reduce the energy consumption for the building sector. Buildings consume about 40% of all energy consumption in the world [7]. In Indonesia, this sector is responsible for 50% of total energy expenditure and more than 70% of overall electricity consumption [7]. Of a large amount of energy use, the building sector contributes to 30% of Greenhouse Gas (GHG) emissions in Indonesia.

Operational energy is a respective amount of energy from household appliances by their usage and electric capacity. This energy is required during the entire service life of a structure, such as lighting, heating, cooling, and ventilating systems; and operating building appliances [13]. The annual energy is calculated by multiplying the number of appliances, the energy intensity, and time usage.

In the early stage of the planning process, architects decide to respond to the natural condition to obtain the optimal design to reduce energy and determine what equipment should be used for the building. The lighting equipment, cooling/heating, and ventilation (HVAC) are the electrical devices
that use energy to operate. In the tropical climate, the building orientation and envelopes impact the use of HVAC devices. For example, a room with a window on the east side would expose sunlight in the morning until midday. If the window ratio is large, it will affect the room temperature, and then occupants will use an active strategy such as an air conditioner to balance the temperature to their comfort condition. The rise of energy use takes account of the room with no windows facing outside to obtain the sunlight. Space will use artificial light to accommodate the lighting level. The devices, such as air conditioners and artificial lighting, use electricity to switch on.

The public facility, such as educational buildings, has consent to deliver a comfortable zone to the occupant. The academic building has maximum occupancy in the daytime. In this period, the building should accommodate the comfort of the students by the temperature. There are three strategies to provide thermal comfort for the building, i.e., active cooling, passive cooling, and hybrid. Active cooling means the room temperature is controlled by an electrical device such as the air conditioner. Passive cooling is the well-turned strategy to maximize the natural elements to control the room temperature. This strategy usually uses the opening to obtain lighting and airflow to the room. The last, hybrid, means controlling the room temperature can use both active and passive strategies.

This research was conducted to evaluate the Centre of Excellent (CoE) as educational buildings’ design products at the Universitas Pendidikan Indonesia (UPI) by simulating energy use. This study aimed to determine the level of operational energy use based on the cooling, lighting, and other equipment used by the CoE building. The results of this study are expected to provide input on design products to be able to control operational energy use before the building is built.

2. Method
This research is descriptive quantitative research, which explains the calculation results of the use of operative energy used in a building with several parameters. The total energy usage calculation uses the simulation software Rhinoceros and Grasshopper with the Ladybug and Honeybee plugins. Ladybug is an effort to support the full range of environmental analysis in a single parametric platform and provide energy and daylighting modeling by using validated simulation engines such as EnergyPlus (U.S. Department of Energy), RADIANCE [7], and Daysim [10] [11]. Ladybug is an open-source environmental plugin for Grasshopper3D that helps architects and engineers create an environmentally-visualization for architectural design. Ladybug imports EnergyPlus Weather files (.EPW) and provides various 2D and 3D interactive graphics to support the design process.
This research requires a digital geometric model created in Grasshopper using a formula. The building geometry is adjusted based on the dimensions and volume of the CoE building plan drawing. Overall sizes are made from ground floor to top floor with floor height based on working drawings. In the simulation, each arrangement must be made for each room. This is done because each function room has a different use of equipment. For example, classrooms require more lighting than service rooms, such as toilets and storage rooms for tools. Rhinoceros and Grasshopper with Ladybud and Honeybee plugin have their own settings for the type of building that will be simulated using energy. In this case, the type of building used is a school building.

2.1. Data Requirement for Simulation
The data used in this simulation are technical drawings and a 3d model of the CoE UPI building design complete with technical specifications. Technical drawings and 3d models are used for modeling into the software to fit dimensions and volume. Also, the need for this document is to determine the points of existing openings. Furthermore, technical specification documents are used to determine the type of electrical components used to calculate the amount of power in each lighting point used.

Figure 3. CoE UPI is located in the UPI campus site in northern Bandung city.

Figure 4. Perspective view of CoE UPI building

The UPI CoE building itself is located in the central UPI campus area in the city of Bandung. This building will be built to meet the need for education facilities on a city and national scale. This building
will be one of the prominent buildings belonging to the UPI campus, so it is expected that the recommendations from the results of this study can help the building operation better.

2.2. Simulation Parameters
The UPI CoE building is planned to have an area of approximately 5000 m2 consisting of five floors. The status of this building is an educational building that is included in the category of public buildings. This building will later follow the working hours from 08:00 am to 04:00 pm and active in the weekdays period. This operation time is the variable used in this simulation.

Table 1. Simulation parameters.

| Distance (m)                      | Data                         |
|----------------------------------|------------------------------|
| Building area                    | 5000 m2                      |
| Building program                 | School Building              |
| Zone Classification              | Public, Service              |
| Opening construction             | Glazing windows              |
| Working hours                    | 08:00 am to 04:00 pm         |
| Working days                     | Weekdays                     |

In addition to using parameters related to the building’s function and operating time, the use of other parameters related to the model object needs to be determined in the simulation. There are several stages in the simulation starting from creating a 3d model in Rhinoceros, determining the Honeybee zone, determining the dimensions of the opening, inputting weather data, dividing the typical floor, entering natural and artificial (mechanical) ventilation data, entering lighting components, simulating total energy use, and breakdown the entire energy data.

Table 2. Several simulation steps, parameters, and values are used.

| Parameters                  | Value                               |
|-----------------------------|-------------------------------------|
| 3d model and zone program   | zoneProgram_(_bldgPrograms)         |
| Determine zoning and openings| _glzRatio                           |
|                            | BreakUpDist_                        |
|                            | windowHeight_                       |
|                            | sillHeight_                         |
| Weather data               | EPW                                 |
| Typical plan               | Type 1 (ground floor) and Type 2 (2-5 floor) |
| Natural and mechanical ventilation | _HBZones                           |
|                            | Classroom, Corridor, and Service    |

Table 2 shows the simulation stages starting from modeling to entering natural and artificial (mechanical) ventilation values. Each of these stages has parameters that are used in the formation of the simulation object. The building program used is a Secondary School, a parameter used to simulate higher education buildings. Then in the building plan, almost the entire building envelope uses glass
material. Therefore, the use of glass material and openings that are adjusted more or less resemble the dimensions used.

![Figure 5. An input for building program.](image)

![Figure 6. An example of an input process for glazing construction.](image)

The ground floor plan is different from the other plan on the next level floor, so in this simulation, the typical floor grouping is considered to make it easier to input other data per floor. Three measurement zones are also determined on each floor: the class zone, corridor zone, and service zone. This grouping is to adjust the programs that have been provided in the use of electrical components. For example, air conditioners for the class zone will be different from the corridor zone.

![Figure 7. Dry bulb temperature for Bandung per year.](image)

The weather data used is the EPW from onebuildings.com for the city of Bandung. We can see a dry bulb temperature in Figure 6 for one year made using Ladybug from the EPW data. Based on this figure, almost throughout the year, the temperature increases from midday to late afternoon. Nearly every day, the temperature shows a value of around 23-34 °C. There is a significant increase in data around June-July with the highest temperature reaching approximately 40 °C.
The lighting types and their power are included in the formula to calculate the energy. This data comes from a technical specification document that is a technical document used in planning the UPI CoE building. The use of tubular lamps is the most widely used for this building, with 198 units with each light having 2 x 18 watts. There are also 85 downlights of 13 watts. However, the use of electrical energy for simulated lighting on this lighting is carried out at night after working hours are over.

**Table 3. Lighting use per zone.**

| Zone      | Type 1 | Type 2 |
|-----------|--------|--------|
| Classroom | 110    | 76     |
| Service   | 5      | 7      |
| Corridor  | 0      | 0      |
| Classroom | 5      | 1      |
| Service   | 7      | 0      |
| Corridor  | 0      | 0      |

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**Table 3. Lighting use per zone.**

| Zone      | TL 2 x 18 W | DL 7 W | DL 13 W | Emergency |
|-----------|-------------|--------|---------|-----------|
| Classroom | 110         | 6      | 5       | 0         |
| Service   | 5           | 7      | 1       | 8         |
| Corridor  | 0           | 0      | 32      | 0         |
| Classroom | 76          | 1      | 20      | 0         |
| Service   | 7           | 0      | 0       | 6         |
| Corridor  | 0           | 0      | 27      | 0         |

The calculation of the energy used for lighting is a simple calculation by multiplying the number of lights and each floor’s amount of power. In the formula used, the amount of energy is separated based on the space zone per floor. However, this process is conducted to produce a more accurate calculation of the total energy use-value for lighting.

3. Results and Discussion

The results showed that the UPI CoE building had an operative energy intensity of 586 kWh / m² per year. This result is obtained from the simulation based on the three main measurement components: artificial ventilation, artificial lighting, and other equipment. This result calculates all features used for building operations with several previously mentioned variables in the method.
Figure 10. The simulation results for the air conditioning, lighting, and equipment.

In figure 10, we can see that the three measurement elements have different intensities of energy used in one year. The most considerable energy use is mechanical ventilation (air conditioner) with 375 kWh/m², then other equipment requires around 149 kWh/m², and the lighting elements require the least energy with 62 kWh/m². In the UPI CoE building operation, the air conditioning system dominates more than half of the total operating energy use.

Figure 11. Operative temperature for Type 1 floor.       Figure 12. Operative temperature for Type 2 floor

The use of air conditioning in buildings is based on the 12-hour average operative temperature simulation shown in Figure 11 and 12. These results indicate that the room facing east has a maximum opening that implies the high-temperature intensity. Rooms facing south have a smaller temperature than the rooms facing east. The rooms facing north and west have a lower value than rooms facing east and south. This building also has a room in the middle of the building that hardly gets direct sunlight, so that the temperature value is the lowest among other spaces.

Figure 13. Percentage of the energy use intensity
Referring to the ASEAN’s energy use standards, the overall energy use in buildings is around 240 kWh / m² in one year. The simulation results conducted on the CoE UPI building show that the general use of operative energy is more than double the standard. The use of air conditioning is the variable that has the most significant influence on energy use. This is because the air temperature conditions in the UPI CoE building are unbalanced, so residents need mechanical ventilation to balance comfortable conditions.

4. References

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