Cooling Load Analysis in Asrama Kinanti 1 UGM Using Building Performance Simulation

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Abstract. Indonesia is predicted to increase energy needs by 4.1 GW each year until the year 2030. These energy needs are using fossil fuels, which will harm the environment because of air pollution. Based on that fact, the reduction of energy consumption in Indonesia is a must. One of the highest energy demands is in the building sector. The building for both residential and commercial consumes 61.5% of national total energy consumption. Moreover, in the building sector, almost 60% is consumed for air conditioning (AC) systems, and one-third of the total energy consumption is for other electrical equipment. Nevertheless, to maintain thermal comfort in a building, the AC system is crucial, and the intention to remove it reduces occupants' comfort significantly. The AC system that has a lot of energy consumption depends on the cooling load. However, because of the complexity in the calculation, several heat gains in cooling load (namely, people, equipment, lighting, solar, and ventilation) need to simulate. In this study, the simulation software is IES-VE software. Furthermore, a research object in this study is Asrama Kinanti 1 that is known as a kind of residential building in Universitas Gadjah Mada, operating 24 hours a day. The results show that the external heat gains (solar and ventilation) can be minimized during 8:00 A.M. to 3:30 P.M. Meanwhile, the internal heat gains (lighting, people, and equipment) can be reduced during the rest of the day.

1. Introduction

Building construction plays an essential role in energy savings because most of our activities are done in indoor. Those activities require electric appliances. Thus, it will increase energy demand. Our daily activities that need electrical equipment will increase electrical demand. For Indonesia, the majority of power generation is supplied by fossil fuels [1]. As a consequence, it will create a negative impact on our environment.

In energy consumption management for buildings, it is a necessary to understand the air conditioning (AC) effect during the energy analysis. In a tropical country like Indonesia, a cooling load analysis is critical to design an efficient air conditioning system for an energy-efficient building. However, the affected cooling load parameters, for instance, people, equipment, lighting, solar, and ventilation, cannot be calculated because of its complexity. One can fix these problems by using Building Performance Simulation (BPS) software [2]. A kind of complete-featured software to do BPS is Integrated Environmental Simulation – Virtual Environment (IES-VE) [3].

This research aims to estimate the cooling load of a university dormitory in UGM (Asrama Kinanti 1) using IES-VE software and to find out the most significant source of the heat gain components. The
analysis uses modeling of annual building operational hours and a daily base usage. This case studied was selected since dormitories are buildings where activities of the occupants are continuously happening as compared to other facilities on the campus that have certain operational hours. Following that, it consumed energy higher than other buildings in UGM. One of the benefits of knowing the daily energy consumption is that we can give different priorities for the recommendation to minimize energy consumption for daytime and at night.

2. Cooling Load
Cooling load is the heat removal rate that is needed to maintain the desired room temperature [4]. It comprised of internal heat gain and external heat gain. Internal heat gain consists of lighting, equipment, and people's heat gain. Heat gain from the lighting system and the use of electronic devices is determined by the total electrical input power and fraction heat that is emitted into the room. The energy used for lighting and electronic equipment is considered as either heat that is released directly (convection) and indirectly (radiation) into the room. All surfaces will absorb radiation that penetrates from the sun before finally release the heat into the room through convection.

In many conditions, daylighting is complemented with artificial lighting to obtain visual comfort, where the index value for electricity consumption also varies in each country. This value is called LPD (lighting power density), and Indonesia uses the LPD value required in SNI 03-6197-2000 [5]. Meanwhile, there is no fixed requirement in Indonesian standards regarding the use of electrical devices inside a building. However, CIBSE Guide A suggests some typical electrical density power in any kind of room function [6]. Following the heat gain due to the lighting system is the heat gain produced by the human body. It relates to the type of activity and the number of occupants inside the room. People with activities will radiate different amounts of sensible and latent heat. Peraturan Gubernur DKI Jakarta 28/2012 provides a list of the amount of heat released by the occupant for different indoor activities [7].

External heat gain consists of ventilation heat gain and solar heat gain. Every occupied building requires good air quality to suit the occupant's comfort. Installation of an air ventilation system can help to achieve this thermal comfort condition. Once a ventilation system operates, then it uses the temperature difference of the indoor and outdoor temperature to cause air movement, which, in fact, also introduces heat into the room.

The room volume, outdoor weather condition, and type of indoor activity influence the amount of heat gain from air ventilation. The parameter that defines the amount of ventilation needed is Air Change Hour (ACH). It is the amount of air that must be exchanged within one hour. Another way to predict the amount of required air ventilation is by using volume rate per person occupying the conditioned room. The required ACH values are listed in the SNI 03-6572 2001 [8]. Information such as the thermal characteristic of the building envelope is needed to analyze the building performance. Two essential variables are U-value and SHGC. The U-value is the parameter that determines the amount of heat that can enter the building through the building envelope. Meanwhile, the SHGC is the value that indicates the amount of sunlight radiation that enters the building through transparent surfaces. The ASHRAE 90.1 regulates the maximum values of the U-value and SHGC [9].

Cooling load estimation involves either conduction, convection, and radiation calculation of three kinds of heat balance, namely outdoor heat balance, indoor heat balance, and air heat balance. Heat Balance Method (HBM) directly solves the problem without using a transformation procedure. The benefits of this procedure are that it does not have an arbitrary parameter, and there is a hidden process within the observation [4]. A computer could do the calculation.

| No | Parameter                | Category                  | Source                  |
|----|--------------------------|---------------------------|-------------------------|
| 1  | Ventilation Rate         | Room Thermal Data         | SNI 03-6572 2001        |
| 2  | Occupancy                | Room Thermal Data         | Pergub DKI 38/2012      |
| 3  | Lighting Maximum Power   | Room Thermal Data         | SNI 03-6197-2000        |
3. Methods

There are three main phases, as described in Figure 1. The data was collected are weather data as external conditions, activity data as internal conditions, and standard and building geometry as boundary conditions. The weather data was collected from other tools called Meteonorm software [10]. It generated weather data of Yogyakarta, Indonesia, by using the interpolating technique. The most related variable of weather data with the heat balance process in terms of heat gain calculation is dry-bulb temperature, direct solar radiation, and diffuse solar radiation.

Predicting the entire activity of a building is not easy. Therefore, the maximum values related to the cooling load variables based on the occupant's activity are approached using standards (table 1). Some schedules were assumed using information that was collected from an interview with the building manager.

The boundary conditions are defined by the building geometry and the thermal properties of the building envelope. The building geometry model was developed from the blueprint collected from the building manager. Unfortunately, the information about the materials used in the existing building is limited. It is a common problem of most buildings in Indonesia, especially for conducting a simulation. Furthermore, cooling load calculation requires U-values for a solid and transparent surface of envelope and SHGC for transparent surface. These values should not exceed the ASHRAE standards for zone 1A, which is a standard value for Indonesia's location. Table 2 provides the list. The second stage is the simulation stage which a thermal dynamics simulation was performed in IES-VE software. After the simulation, documentation was conducted, and the data were analyzed.

3.1. Simulation Model of the Asrama Kinanti 1

An analysis was conducted on the previously collected data. Detailed engineering design was verified with an observation of the actual conditions so that the 3D model could be created, and the zone function could be obtained. The Asrama Kinanti 1, which is the building studied in this paper, is a student dormitory with seven stories. It is located in Yogyakarta, Indonesia. The 3D geometrical model by IES-VE can be seen in Fig. 2.
Weather data that was used for this research is Yogyakarta's weather data from the Meteonorm software. The average dry bulb temperature and solar radiation are shown in Fig 3. From the figure, we can see that Yogyakarta has a hot climate since the average dry-bulb temperature is around 25.94 until 27.9 degrees Celsius. May is the month with the highest average temperature, while February has the lowest average temperature. Furthermore, May also has the highest total solar radiation compared to other months.

The material properties are provided in ASHRAE Standard 90.1, SNI 03-6572 2001, SNI 03-6197-2000, Pergub DKI 38/2012, and CIBSE Guide A. Among them; several data were selected using an algorithm provided within the standard. The selected data were considered ready to be inputted for the simulation process. Table 2 is the list of the selected materials with their U-values and SHGC values. The column with the heading "Max Value" is the list of the U-values that are allowed by the standards. Therefore, the value assigned in the simulation for the selected materials should be less than the "Max Value" mentioned previously. Table 2 will affect the external heat gain results. As for the internal heat gain, several input data must be assigned before the simulation, which is listed in Table 3. The values in Table 3 are taken from SNI 03-6572 2001, SNI 03-6197-2000, Pergub DKI 38/2012, and CIBSE Guide A. Each zone represents a unique activity so that the internal heat gain parameter will be varied according to the zone function. Asrama Kinanti 1 has 372 zones. To simplify the case, we categorized it as a dormitory, corridor, and lobby.

| No | Element       | Sub-element   | Max Value | Assigned Value |
|----|---------------|---------------|-----------|----------------|
|    |               |               | U-value (W/m²K) | SHGC | U-value (W/m²K) | SHGC |
| 1  | Roofs         | Attic and Others | 0,192     | 0,192          |
| 2  | Walls         | Mass          | 3,293     | 3,284          |
| 3  | Floors        | Mass          | 1,825     | 1,824          |
| 4  | Vertical Glazing |            | 6,81      | 0,25           | 6,005 | 0,248 |

Table 2. Building envelope data
Table 3. Internal heat gain data

| Zone         | Function | Occupancy Heat (W) | Natural Ventilation (ACH) | Lighting Heat Density (W/m²) | Radiant Fraction | Equipment Heat Density (W/m²) | Radiant Fraction |
|--------------|----------|--------------------|---------------------------|-------------------------------|------------------|-------------------------------|------------------|
| Corridor     |          | 73                 | 10                        | 6                             | 5                | 0,45                          | 10               |
| Lobby        |          | 73                 | 50                        | 0.3 m³/min/room               | 12               | 0,45                          | 10               |
| Dormitory    |          | 72                 | 2                         | 0.3 m³/min/room               | 12               | 0,45                          | 10               |

The schedule consists of lighting, equipment, corridor, and ventilation. The schedule model was created from the information that was collected when interviewing with the building manager. Every category of the room has its schedule shown in figure 4. The corridor is used as a circulation area. There is no utilization of equipment in the corridor. People and ventilation operate at 6.00 A.M. to 9 P.M. at 25% of maximum value. While the corridor lighting operates entirely from 5.00 A.M. to 9.30 A.M. and 3.30 P.M. to 9.30 P.M.. The lighting then turned off from 10.00 A.M. to 3.00 P.M. because the natural lighting is enough to light up the corridor.

The dormitory is fully occupied at night and empty during daytime since occupants are doing activities outside the building, such as attending the class. At night during sleeping hours, the equipment is just operated by 25%, assuming that some of the students are still awake using electricity for their equipment. The lobby is a co-working space. The peak time is around 6.00 P.M. to 9.00 P.M., where some visitors that are non-occupant are using the facility to do group assignments.

![Corridor Scheduling](a)

![Dormitory Scheduling](b)

![Lobby Scheduling](c)

Figure 4. Scheduling for corridor (a), dormitory (b), and lobby (c)
3.2. Simulation Process

After the simulation model is created, the next step is to run the simulation. In the IES-VE software, simulations are carried out with a thermal dynamic software calculator named ApacheSim. This simulation is done within a 10 minutes interval between each step, and the data interval is presented every 60 minutes. In total, the simulation process takes 8760 hours to cover the annual cooling load demand.

4. Simulation Result and Discussion

Based on the simulation results, there is a different result that can be seen from the comparison between the internal (namely, people, equipment, and lighting) and the external (namely, solar and ventilation) heat gains. The simulation results are shown below.

![Comparison of internal and external heat gains](image)

**Figure 5.** The comparison of the internal and the external heat gains in Asrama Kinanti 1 UGM, (a) on 5th of July, and (b) on 19th of November

In Fig. 5, there is a different trend for external heat gain on the 5th of July and the 19th of November. We can see in Fig. 5, the graph declined gradually from 12:30 P.M. to 4:30 P.M. and dropped rapidly to 6:30 P.M.

On the other hand, Fig. 5 (b) showed if the trend decreased slowly from 12:30 P.M. to 6:30 P.M. Based on this trend, on the 5th of July, the external heat gain is longer to expose to the building with higher value compared to on 19th of November.

Fig. 5 also provided information about the range of time when the external or the internal heat dominated in value. On the 5th of July, the external heat gain started from 6:30 A.M. to 6:30 P.M. This range happened on the 19th of November too. It is understood because the highest value of the external gain came from solar radiation. Solar radiation came from Sun exposure. When the sun is gone, so the value also vanished from the calculation. However, the amount of the external heat gain increased in the range of 8:30 P.M. to 10:30 P.M. This trend happened because of the ventilation heat gain effect. As mentioned in SNI 03-65722001, the rate of ventilation depended on the number of people who occupied the building at that time. So, the ventilation heat gain rose as well.

For the internal heat gain, the value always did not reach the lowest value (0 kW). It can be seen from the graph if the internal gain is just lower than the external heat gain in the range of 8:30 A.M. to 3:00 P.M. The peak time of the internal gain happened in the range of 9:00 P.M. to 12:00 P.M. It happened because all parameters that supported the internal gain reached a peak at this time. The comparison of all heat gain parameters is shown in Figure 6.
In Fig. 6., the solar heat gain dominated both on the 5th of July and 19th of November in the range of 6:30 A.M. to 6:30 P.M. Nevertheless, the heat gain value on the 5th of July and 19th of November reached a peak at 12:00 A.M. and 10:00 A.M., respectively. This maximum gain happened because of solar shifting in a year calendar. On the 5th of July, the position of the sun is nearly on the equator, so its location is also near Asrama Kinanti 1 UGM in Yogyakarta, Indonesia. In contrast, on the 19th of November, the Sun position is far away from the equator. Therefore, the peak time is shifting from midday.

For other parameters, both graphs have a similar trend. It occurred because the scheduling time for other settings, excluding the solar heat gain and the ventilation is made similarly. The ventilation is made differently based on standard value. Detail visualizations are shown in Figure 7.

Based on Fig. 7, the charts showed if the most significant heat gain parameter was the lighting (31%). Then, the solar, equipment, people, and ventilation were on the second, the third, the fourth, and the fifth, respectively. These results provided two recommendations for energy efficiency. First is by reducing the amount of energy spend on lighting and equipment, especially during conditions when it is
not in use. Retrofitting the building envelope is another way to achieve energy efficiency, such as by applying window blinds or installing a better window system.

5. Conclusion
From this study, it can be concluded that lighting heat gain is the most significant internal heat gain parameter (31%) for two different days. Therefore, variables that affect lighting heat gain, such as utilization at a particular time, will have the most significant impact on building performance. As for solar heat gain, this variable is the second-largest parameter in this type of building. Then, the third to the last percentage of heat gain in Asrama Kinanti 1 UGM is people, equipment, and ventilation. Knowing these parameter values every hour in a day will help us to design energy conservation strategies more precisely for the type of student residence. As a consequence, we can also estimate the energy consumption reduction more precise for an annual basis.

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