Assessing cooling energy of insulated building built in tropical country

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Abstract. Global warming is a huge issue and has become a global concern lately. The global warming issue is gaining more attention on reducing fossil energy since fossil energy has significantly exacerbated global warming. Since housing sectors are consuming significant fossil fuel energy, reducing housing energy consumption is necessary. One option discussed in this paper is to reduce the load on the air conditioner (AC) by applying insulation to the building. Reducing the AC energy will reduce the total energy consumption in the buildings. Building practice in a mild climate has shown that good insulation can reduce heating or cooling energy in the building. But using insulation in housing is not a common practice in Indonesia's construction sectors. Simulating the use of insulation in housing will show how much energy reduction will be obtained, especially for air conditioning energy. The analysis in this study found that thermal comfort is related to air temperature and relative humidity in the room. This article will study the reliability of using insulation in buildings to reduce energy consumption and provide thermal comfort for the occupant.

1. Introduction

Global warming is the main issue that the world faces now. Fossil fuels have broadly been used worldwide in the past decades and have become the originator of global warming [1]. The primary energy source in Indonesia's electricity company is still using fossil fuels [2]. Any increase in electricity demand on housing will increase fossil fuel uses and will escalate global warming.

One housing main issue in a tropical country is the comfort level with a hot and humid climate. The use of air-conditioning (AC) in the building is mainly to achieve the comfort level. Several air-conditioning options are available on the market at affordable prices, making the use of air-conditioning becomes normal for housing. However, the increase in energy use in buildings due to air conditioning is usually unnoticed.

According to data from the National Development Planning Agency, without any change in energy use, greenhouse gas emissions will increase from 1.5 GT CO2e in 2010 to 1.8 GT CO2e in 2020 and predicted will reach 2.9 GT CO2e in 2030 [3]. The housing sector is one of the most significant contributors to this energy use, accounting for 31% of total energy use in 2017 (Figure 1), and this figure is increasing steadily from 2007 (Figure 2) [4].

Reducing energy use in residential areas is an important aspect to consider to reduce the negative impact of global warming. The use of ventilation in buildings is often not enough to provide comfort in buildings [5]. Creating openings that are not introducing air circulation will not make the room thermally...
comfortable. The heat and humidity will be trapped inside the room, making the occupant inside the room will feel uncomfortable. In making good ventilation, it is necessary to reduce the heat trapped inside the building.

**Figure 1.** Energy consumption in Indonesia in 2017 (including biomass).
(Source: ESDM-RI)

**Figure 2.** The growth of residential energy consumption in Indonesia from 2007 to 2017 (including biomass).
(Source: ESDM-RI)

In this article, the discussion will be on the consequences of using insulation in buildings to reduce cooling energy. The source of this research data comes from data collection of the case study building, which experiments using software by making several changes to the composition of building materials. Two building models built in the software were used to study the building material's performance. The material selection performance was by comparing the building performance of housing using the original material (as the case study) and the housing using insulation.

1.1. Thermal comfort in buildings
According to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the comfortable temperature inside the building is in the range of 25-28°C with a humidity ratio below 0.012 kg/kg [6]. However, in the tropical climate, there will be several factors that can determine a person's comfort, such as: wind speed, clothing, activity, radiation temperature (Figure 3). The hot and humid climate in the tropics has an average temperature ranging from 28°C to 35°C with a humidity ratio between 0.014 kg/kg and 0.02 kg/kg throughout the year [7].

In addition to air temperature, humidity is a significant problem in achieving thermal comfort [8]. Since Indonesia is a tropical country with high relative humidity, thermal comfort is a crucial issue. It is critical to lower the humidity of the room to achieve the desired thermal comfort.

1.2. Air-conditioning in the housing building
Air conditioning usages is increasing every year in Indonesia [9]. High air-conditioning usage occurs because people tend to have a cooler temperature than their environment [10]. Research on buildings that use air-conditioning shows that air conditioning will increase the energy demand of buildings [11].

The building envelope has a critical role in controlling the cooling energy needed to cool the room [12]. So to increase the effectiveness of the use of air conditioning, building envelopes have a significant role. High-performance buildings built in cold climates require about 20% to 30% of the total energy in the building to warm the building, while for hot climates, the potential for cooling energy reductions is about 10% to 40% if you can apply the right building envelope that can reduce the need for air conditioning [12].
2. Research methods
In general, there are three stages used in this research:

1. Site visit, by choosing the case study house, and observe the building material used in the case study house.
2. To monitor the case study house's building performance. The logger was used to record the room temperature and relative humidity.
3. Create a building model in a building energy simulation software and inspect the building performance with changes made on the building envelope.

The analysis in this article using the case studies building's data. The data collection was done by conducting a site visit and using loggers placed on the observed rooms. Material data used in buildings are from direct observation and information obtained from the building owner. Loggers were placed in several rooms in the observed dwelling to record the building's temperature and humidity at the selected time ranges. The measurements are to obtain sufficient data to be able to simulate the model on the existing software.

Every measurement duration is a month, and there are three measurements to get data in different seasons. The measurement for the rainy season is carried out in February, while the summer (dry) seasons measurement was in August and October.

3. Analysis
The selected case study building is a house in a row house. This case study house location is in a housing estate in Cibubur, a satellite city of Jakarta. The case study selected is the most prevalent housing floor areas lie between 50m2 to 69m2 floor area [13]. This case study building area is 55m2, consist of a living room, two bedrooms, toilet and service area (Figure 4). The house orientation is North and South, with the East and West side of the building is the adjacent housing (Figure 5). The window is facing South only because the house was using the whole land.

Data collection is done by: direct observation of the case study house and collecting data from the owner regarding the building's construction materials. With the site visit, the owner's data regarding the size of the building and the materials used are clarified and arranged in the table (Table 1). The information collected was used to build the house model in the building energy software. All data is then examined in the next step to look at the building performance under specific conditions.

Building monitoring carries out by measuring the temperature and relative humidity in the building using loggers placed in the living room area 7m x 2.6m, master bedroom 3m x 3m, and outdoor area.
The logger used was Tinytag data loggers, which operates a Business Management System which follow ISO 9001 and ISO 14001 [14]. Data logger temperature reading ranges from -40°C to +85°C, sensor type 10K NTC Thermistor (Internally mounted), response time 25 mins to 90% FSD in moving air and reading resolution 0.01°C or better. A logger locate in every room, which was located 1.5m above the floor level. The loggers have recorded the air temperature for three months with one hour’s intervals.

Figure 4. Case study house perspective. Figure 5. Floor plans of the row house.

| Building elements | Construction layer | U- Value (W/m²K) |
|-------------------|--------------------|-----------------|
| Walls             | 25 mm cement plaster + 100 mm bricks + 25 mm cement plaster | 2,894 |
| Intermediate-walls| 25 mm cement plaster + 200 mm bricks + 25 mm cement plaster | 2,244 |
| Floors            | 8 mm ceramic floor + 22 mm cement screed + 100 mm concrete floor + soil layer | 3,264 |
| windows           | Single-layer glass6 mm thick (total solar transmission (SHGC) = 0.819) | 5,778 |
| Ceiling           | 6mm gypsum board | 3.125 |
| Roof              | 20 mm tile roof + 25 mm wood frame. | 6.061 |

Table 1. Building data from direct observation.

Figure 6 - Figure 9 shows the information gain from site observation. The graph below indicates the temperature and humidity ratio between the outside room and the inside room. In Figure 6 and Figure 7 can be seen that the external air temperature is relatively high. The external temperature fluctuated between 26°C to 35°C. Low temperatures mainly occurred around 4 am, and high temperatures mainly occurred around 1 pm.

The room air temperature is still lower than the maximum external air temperature, but the room temperature is still above the comfortable temperature. The average room air temperature in the living room and bedroom is around 29°C – 32°C, with fluctuations, that mimicking the external temperature. From this information can be seen that the room air temperature is lower than the maximum building temperature. During the night, the outside temperature has reached 26°C, and the temperature in the room is still high at around 29°C.

The bedroom has a slightly different performance (Figure 7), where during the daytime, the bedroom air temperature is relatively the same as the family room, but at night, the temperature in the bedroom looks close to the outside. The temperature difference is caused by the use of air conditioning while
sleeping in the bedroom. By using air-conditioning, the temperature in the bedroom can reach a comfortable condition.

The results of the observation of the case study building show that the air temperature in the observed room is relatively high and followed by high relative humidity (Figure 8 & 9). The air temperature and relative humidity are still above thermal comfort. Special treatment is needed to reduce the air temperature and relative humidity in the building. The high room temperature and high room relative humidity at night can interfere with the resident sleep quality. To achieve occupant's thermal comfort in the bedroom, if the room is using air-conditioning.

![Figure 6. Comparison of the temperature of the living room measured with the temperature of the outside.](image)

![Figure 7. Comparison of the temperature of the bedroom as measured by the temperature of the outside.](image)

![Figure 8. Comparison of the humidity of the living room as measured by the outdoor temperature.](image)

![Figure 9. Comparison of the humidity of the bedroom as measured by the temperature of the outside room.](image)

4. Discussion
The building information was gain from a site visit and site monitoring. Collected data was to create a building model in an energy simulation software (IES VE). Two buildings model created are the original building (OB model) and the insulated model (IB model). OB model was created using the building information gained from site visits, and the IB model is the same building model that modifies by adding insulation in the building. The insulation location is in walls, floors, and roofs; to inspect the effect of
outdoor air temperature changes in the building interior. The software validation was by creating the identical condition simulated in the software, and the results must show that the building performance was relatively mimicking the onsite situation.

The two building models’ locations are the same and with the same environmental conditions to see the difference in building performance. The air-conditioning model is also made the same in both models, with settings that provide comfort in temperature and humidity in the monitored room. The electrical appliances modelled in the software are light that turns on during nighttime and fans that turn on in the living room during daytime.

Thermal comfort is a benchmark in designing the performance of the air-conditioning. The simulation results are in Figure 10, comparing the temperature and humidity in the living room and bedroom. This graph indicates a difference between the cooling performance in the case study model (OB Model) with the insulated building model (IB Model). The case study building shows that most of the building temperatures are below the thermal comfort line. Conversely, in the insulated building model, air conditioning can maintain building comfort in the thermal comfort zone throughout the year.

The simulation results analysis of the living room area indicates that with the cooling system, the temperature in the room can be kept below 28°C throughout the year with the cooling system used (Figure 11). However, by adjusting the air-conditioning to provide thermal comfort, the room's relative humidity in the OB model remains high even with low room temperature (Figure 13). Cold temperatures cannot overcome the high relative humidity of the existing air, which is possible because there is still air leakage from outside the room into the building.

Figure 10. Distribution of humidity and room temperature within one year in buildings that use air conditioning.

Air conditioning systems system made to provide comfort in terms of air temperature and relative humidity cannot reduce the room's relative humidity with the building is not given special treatment. The simulation results indicate that installing insulation can provide thermal comfort concerning air temperature and relative humidity. Figure 11 shows that the room temperature in the family room can be maintained stably in the comfort zone throughout the year with the air conditioning system made. Figure 11 also shows how the performance of the building in the bedroom by using insulation in the building. Figure 11 and Figure 12 also indicate how the room temperature in the case study building (OB model) is low. This low temperature is due to the efforts of the air conditioning trying to reduce the high humidity of the room. Figure 13 and Figure 14 shows that relative humidity in the room can also reach the comfort zone if the building uses insulation (IB model).

The building simulation results indicate that the two-building model's air conditioning system can maintain the room temperature in the comfort zone. With the cooling system made, the room temperature in the case study model and the building model with insulation was in the comfort zone. However, there is a difference in relative humidity in the master bedroom and Livingroom, between the case study building and the insulated building. To cool the room under the comfort zone in the hope of
reducing the room relative humidity in the case study building still change the humidity condition of the room.

There is a big difference in terms of energy used by air-conditioning in two conditions of the building model, the case study building and the building with insulation. Figure-15 indicates that the energy used for cooling in the case study building is three times higher than cooling energy when the building is insulated. With insulation in a building can reduce the cooling's energy significantly, and at the same time achieving the comfort level.

Figure 11. Comparison of living room temperatures between the case study building model (OB) and the building with insulation (IB).

Figure 12. Comparison of bedroom temperature between the case study building model (OB) and the building with insulation (IB).

Figure 13. Comparison of humidity in the living room between the case study building model (OB) and the building with insulation (IB).

Figure 14. Comparison of humidity in the bedroom between the case study building model (OB) and the building with insulation (IB).
5. Conclusions
Air conditioning usage to achieve thermal comfort, especially for the location that has high temperatures and high relative humidity. Air conditioning usage continues to increase, which is not in line with the issue of global warming. In avoiding global warming, it is necessary to reduce energy use, especially fossil energy.

Building with insulation is a common practice in developed countries, especially countries with four seasons. However, in Indonesia, buildings are mostly built without insulation. But the analysis has shown that insulation in buildings can increase the effectiveness of air conditioning and maintain the air temperature and relative humidity of the room in the comfort zone.

The analysis results show us how the performance of the insulated building when compared to the non-insulated building. Building with insulation indicates lower cooling energy than buildings without insulation. Buildings with insulation can provide a stable comfort in terms of air temperature and relative humidity. With insulation, the building performance is better, and the energy used is also less.

However, further research needs to be done, especially regarding the advantages of reducing cooling energy compared to the investment made by making buildings with insulation. It is also necessary to study the extent to which the building should apply the insulation.

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