Estimation of energy consumption efficiency in office rooms cooling systems to create thermal comfort for the user

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Abstract. Conservation and energy efficiency in air conditioning systems are very relevant to be conducted to increase efficiency and save energy as an effort to reduce energy consumption in buildings and reduce the formation of CO2 gas emissions, which are one of the main causes of increasing environmental temperature. Offices and settlements have a quite large dependence on energy. At the office, for instance, the spatial comfort greatly affects the user's mood and the quality of work produced. Air conditioning or air controlling system is an effort to process the air to control room temperature, relative humidity, air quality, and its refreshment to maintain comfort requirements for room users. The purpose of this research was to assess the measurement of energy consumption used in the office of three floors and to respond to energy consumption savings that are used as an effort to yield efficient energy use, especially in air conditioning systems. The research method used is the Ecotect v.5 simulations, with the characteristics of a closed office space model and full of air conditioning throughout the rooms. The energy consumption in a room cooling system was calculated by using SNI 6196-2011. The amount of heat energy accumulated in each room, which is influenced by solar radiation, space leveling, activity, and lighting was also measured. By calculating the temperature distribution in the space of each floor by comparing the Ecotect v.5 simulation results with the existing EEI (Energy Efficient Index) field measurements generated by 46.22 kWh/H/m²/day based on the calculation of working operational hours, it was assumed that 8 hours/day with real operational 2920 hours/year and the total energy consumption of 16330 kWh/year were considered as a very wasteful criterion. The temperature on each floor differs from 26.8°C to 29°C, the difference between the simulation calculation and the existing measurement was 0.78°C, with an average temperature of simulation result was 27.53°C, the existing was 26.75°C. Besides, the temperature obtained was different in each room, this was influenced by the room orientation to the sun which affected the comfort level of the room.

1. Introduction
The intensity of human activity is more frequent indoor, then they need a comfort indoor to do activity well, quietly and comfortably, therefore the goodspeed of airflow indoor affects activity indoor[1]. A comfortable room when working influences mood of the user and the quality of work that is yielded.

Air conditioning or air system is an effort to process for controlling room temperature, relative humidity, air quality, and its refreshment to keep comfort requirement for room users. The dependence of energy users is huge on office necessity and settlement. In particular, in the office building, the usage of energy is more extravagant, the usage of energy wasteful is caused by the use of electrical energy for cooling room temperature indoor by air conditioning.
It is recorded the use of electrical energy at office building reaches out 240 kWh/m². Wasting energy is caused by several factors, such as the usage of the air system does not work optimally and efficiently, the use of cooler and heater, conduction result from solar radiation, and length of sun exposure on each side of the building[2]. The conservation and energy efficiency on air conditioning system becomes a thing which was relevant to do for increasing efficiency and saving energy as one of the effort of reduction consuming energy on building and decreasing the of construction CO2 gas emission that becomes one of the main cause of increasing environmental temperature[3].

The calculation of heat load in each room is one of the crucial factors in determining cooler capacity which is needed. The calculation of heat load appropriately is saving the opportunity of energy on building. The cooling load is heat which is thrown away by Air Conditioning from indoor to outdoor in order to air temperature indoor does not go up and stays within the limits of thermal comfort. [4][5]

In the tropic area, the limit of level comfort of temperature at a room is 19-26°C TE[6]. Temperature 19°C TE has a dry temperature of about 19.5-20.5°C on the humidity relative 65-85% and the speed of the wind is 1.5-2 m/det. While temperature 26°C TE has the dry temperature about 27-29°C on the humidity relative 65-85% and speed of the wind is 2.6-2.9 m/det. For Ecotech simulation v.5. The limit of comfort for the tropic area is suggested around 18-28°C [7]. The use Air condition as a room cooler is a necessity that has been considered effectively and efficiently to achieve that temperature.

This research conducted an observation and computed the energy consumption on office building which is located in Banda Aceh by using Air condition as one way to give the surrounding comfort in a building. Through applying principle and cooling actively on the building was expected it could minimize energy consumption on artificial ventilation, this matter is crucial to be conducted because it could minimize energy consumption and was able to manifest an energy-efficient building and environment friendly.

2. Research Methods
The building model is 20 m in length and 16 m in width. This office building consists of 3 floors with a huge 960m² is located in Banda Aceh. This office building is used as Office of International Affairs (OIA). The building has a core located in the central district area. The orientation is evaluated is the east side since it receives the most sunlight exposure in a day. The stage of research which was conducted to reach the research goals, namely doing calculation the estimation of energy consumption on office building which has characteristic of closed building system, with material wall building plaster brick, ceramics floor, gypsum plafond, door, and window are frame glass of aluminum.

The evaluation of energy consumption by using energy auditing methods SNI 6196-2011 is a new update from SNI 03-6196-2010. On SNI 6196-2011, the procedure of auditing energy becomes more complete by dividing the procedure stage of auditing energy on a building is divided into several stages, it included walkthrough audit, preliminary audit, and detailed audit.

In this research, the auditing procedure used is a preliminary audit, this method needed data of building documentation, monthly electricity payment account within a year of usage, rate of occupancy during working time (9 a.m. – 05 p.m.) auditing energy on a building is conducted to calculate the value of Energy Use Intensity, or it is total of energy consumption per unit area of the room which used air condition within a year is multiplied the ratio of standard time operational with real operational time within a year, the formula is:

\[
EEI = \left( \frac{(2000/\text{real operating hours}) \times \text{total electricity consumption}}{\text{room m}^2 \text{ with AC}} \right)
\]
Table 1. Standar Valeu IKE

| kWh/m²/month  | Criteria       |
|---------------|----------------|
| 4.17 – 7.92   | Very efficient |
| 7.92 – 12.08  | Efficient      |
| 12.08 – 14.58 | Quite efficient|
| 14.58 – 19.17 | Quite wasteful |
| 19.17 – 23.75 | Wasteful       |
| 23.75 – 37.5  | More wasteful  |

According to the procedure of preliminary audit energy, in this study is also conducted measurement directly in the field by using Quest Thermal Environmental Monitor (QTEM), is a tool which is used to measure the level of endurance of body toward heart stress indoors, that is the effect of temperature, the humidity, and airflow toward the human body.

Working system QTEM is worked automatically by using battery 9 volts as the energy source. The tool sensor would work stably to measure temperature in a room. The instructional is below:

- Put down the tool on a safe place 100 cm from the floor.
- The time setting of measurement is conducted at an interval of 60 minutes.
- Measurement is conducted at 9 a.m.- 5 p.m.

As shown in Diagram 1, research is done in three phases. The first phase is done by calculating the intensity of energy consumption based on input data existing. Furthermore, auditing energy is done if the value of energy Use Intensity is bigger than the target value which is decided based on the criteria as shown in Table 1. The second phase is done through measuring QTEM based on existing data, the result of measurement which is obtained would be simulated with Ecotech simulation modeling. For work step phase 2 is shown in Diagram 2. Afterward, phase 3 validated ratio data of calculation result with the field measurement result.

![Diagram 1](image1)

![Diagram 2](image2)
The table below is shown the result of measurement QTEM which is done on the office building. The result of QTEM will be validated by the result of data simulation Ecotech.

### Tabel 2. Comparing ecotect & Field Measurements

| Time | Lobby | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 |
|------|-------|--------|--------|--------|--------|--------|--------|--------|
| 9 AM | 32.8  | 35.5   | 29     | 30.3   | 29.9   | 31.9   | 30.1   | 31.3   | 30.2   | 29.7   | 29.7   | 29.5   | 31.6   | 31     | 33.6   | 33.4   |
| 10 AM| 33.3  | 36.4   | 28.8   | 30.4   | 29.8   | 32.1   | 30.1   | 31.5   | 30     | 29.8   | 29.7   | 29.6   | 31.2   | 31.2   | 32.6   | 34     |
| 11 AM| 33.3  | 36.5   | 28.9   | 30.4   | 29.9   | 32.2   | 30.4   | 31.6   | 30.4   | 29.9   | 29.7   | 29.8   | 31.6   | 31.3   | 33.3   | 34.1   |
| 12 AM| 33.2  | 35.8   | 29     | 30.3   | 30     | 32.2   | 30     | 31.6   | 30     | 29.9   | 29.8   | 29.8   | 32     | 31.5   | 33.3   | 33.7   |
| 1 PM  | 33.3  | 34.6   | 29.2   | 30.2   | 30     | 32.1   | 30.3   | 31.4   | 30     | 29.9   | 30     | 29.9   | 32.2   | 31.1   | 33.6   | 33.3   |
| 2 PM  | 33   | 33.4   | 29.3   | 30.2   | 30     | 32.1   | 30.9   | 31.5   | 30.1   | 29.9   | 30.2   | 30     | 32.3   | 31.1   | 33.8   | 32.8   |
| 3 PM  | 32.7  | 31.7   | 29.6   | 30     | 30.2   | 32.1   | 31.2   | 31.4   | 30.6   | 29.7   | 30.7   | 30     | 32.6   | 30.9   | 34.2   | 32.3   |
| 4 PM  | 32.3  | 29.6   | 29.7   | 29.9   | 30.3   | 32     | 31.5   | 31.2   | 30.5   | 29.6   | 31     | 30     | 32.9   | 30.6   | 34.9   | 32.1   |
| 5 PM  | 30    | 27.4   | 29.7   | 29.8   | 30.6   | 32     | 31.1   | 30.9   | 30.8   | 29.4   | 31     | 30     | 31.9   | 29.6   | 33.6   | 32.2   |

### 3. Simulation Model

Simulation modeling is done on the whole building floor in each room which used Ecotech v.5 air conditioning when the window was closed tightly and when empty without any occupant. Lamp and electronic devices were turned off to calculate how the room temperature and heat which is accumulated in the building caused by solar radiation.

Building modeling by *Ecotech v.5* programs is finished as a simulation of thermal calculation program, to compute energy need on building to avoid the usage energy excessively or less of energy necessity on building that caused uncomfortable for building user. Thermal calculation on *Ecotech v.5* programs required capital of building in a three-dimension form which was able to do through converting the building from building geometric should be drawn directly on *software Ecotech v5*, fit to the dimension of the existing building with ratio 1: 100. Some data that have to input to model building, namely input geographic location which has to fill are latitude, longitude, and time zone GMT that has provided by *Weather Manager* from that Ecotech v.5 programs. Climate data obtained is data needed by the *Weather Manager* program, which has built-in Ecotech v.5 programs. Measurement data used is annual data from May 2019 – May 2020.
Furthermore, modeling through drawing rooms following existing buildings. Each existing floor is drawn in one zona which is defined as a thermal zone so that each zona should be completed element; roof, wall, and floor, and the complexity is opening position and elements other room formed. The amount of zona is simulated in accordance total of the room which is on the existing building. **Figure 2.**

The value of building material properties that are used on office building put in Element Library has built-in Ecotech v.5 2011 program. If Element Library was provided appropriate to a material
characteristic which would use on building simulation was able to use directly as highlight thermal, however, if a material characteristic is different from which has provided in Element Library, then it was created new element with a material characteristic which would use on building simulation,[8].

The next stage on Ecotech v.5 simulation process is activity management by input data in accordance existing, such as settings of the total occupant, kind of activities which is held, habitation time and heat output from lamp or electronic device would affect heat load in room temperature and then affect air condition capacity in consuming electricity.

Figure 5. Zona Management set the room conditions according to the room conditions to be achieved Ecotech v.5 simulation

4. Result and Discussion
The result of computing energy auditing by SNI 03-6390-2000, based on the data recapitulation electricity bill on office building from January until December 2019 Table 3. Total electricity energy consumption within a year was 16330 Kwh/Tahun. The use of real operational time within a year was assumed based on working time/day, therefore a total of real operational time within a year was 2920 hours.

Value EEI/IKE was gained was 5.86 kWh/m²/mount. If the value EEI/IKE was compared with the standard value of EEI/IKE, so that value was in interval of standard EEI/IKE that reveals the criteria of energy consumption was very efficient (4.17–7.92kWh/m²/mount). According to EEI/IKE value, this office building was included unwasteful criteria. However, unfortunately, those criteria only survey the use of electrical energy without requiring a level of comfort.

Table 3. Total KWH Office Building Usage per years

| Per month | KWH  |
|-----------|------|
| January   | 1500 |
| February  | 1014 |
| March     | 5000 |
| April     | 920  |
| May       | 920  |
| June      | 920  |
| July      | 1679 |
| August    | 657  |
| September | 872  |
| October   | 970  |
| November  | 1026 |
| December  | 852  |
| **Total** | **16330** |
The result of Ecotect.v.5 simulations is the comparison between result QTEM of room temperature Table 2, with a room temperature of simulation result or calculation with Ecotect.v.5 2011 Table 3, was able to know that overall there are no temperature differences significantly between simulation result temperature with measurement result temperature.

### Table 4. The results of measuring the temperature of each zone

(a) without activity ; (b) with activity.

| Time | Temperature (ºC) | Lobby | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 |
|------|------------------|-------|--------|--------|--------|--------|--------|--------|--------|
|      |                  |       | 1st    | 2nd    | 3rd    | 4th    | 5th    | 6th    | 7th    |
| 9    |                  |       |        |        |        |        |        |        |        |
| 10   |                  |       |        |        |        |        |        |        |        |
| 11   |                  |       |        |        |        |        |        |        |        |
| 12   |                  |       |        |        |        |        |        |        |        |
| 1    |                  |       |        |        |        |        |        |        |        |
| 2    |                  |       |        |        |        |        |        |        |        |
| 3    |                  |       |        |        |        |        |        |        |        |
| 4    |                  |       |        |        |        |        |        |        |        |
| 5    |                  |       |        |        |        |        |        |        |        |

### Table 5. Room temperature and environment simulation results ecotec v.5

| Time | Temperature (ºC) | Lobby | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 |
|------|------------------|-------|--------|--------|--------|--------|--------|--------|--------|
|      |                  |       | 1st    | 2nd    | 3rd    | 4th    | 5th    | 6th    | 7th    |
| 9    |                  |       |        |        |        |        |        |        |        |
| 10   |                  |       |        |        |        |        |        |        |        |
| 11   |                  |       |        |        |        |        |        |        |        |
| 12   |                  |       |        |        |        |        |        |        |        |
| 1    |                  |       |        |        |        |        |        |        |        |
| 2    |                  |       |        |        |        |        |        |        |        |
| 3    |                  |       |        |        |        |        |        |        |        |
| 4    |                  |       |        |        |        |        |        |        |        |
| 5    |                  |       |        |        |        |        |        |        |        |

Although several rooms had a difference of temperature about 1 and 2 °C (1 – 8.02%), technically it could be accepted in Table 4 and Table 5. Therefore, the thermal analysis mathematical model on Ecotech v.5 programs could be used for counting the amount of cooling load. The main function of Air Conditioning (AC) was for throwing out the excessive heat from indoor to outdoor in order to a total of heat indoor is not excessive so that it does not cause the air temperature to get up above the limit of thermal comfort.

On Ecotech v.5 simulations, the building orientation toward sunshine is the defining point of building performance in responding to solar radiation. This sunshine orientation also influenced the intensity room temperature and thermal comfortable in OIA office building.
Figure 6. The Building Orientation of the path of the sun on each floor of building by the intensity of building performance in responding heat to gain optimal thermal comfort. High and low temperatures in each zone could be seen virtually.

Figure 7. Heat that is received on the third floor is higher, particularly on the dark roof area.

Figure 8. Heat on each room is obtained at different levels of temperature.

From the result of data validation which is gained, either from field measurements or simulation results, the temperature on each zone is not too sufficiently different. To examine that matter is conducted regression analysis toward both data measurements[9]. Linear Equation[10]: \( Y = 51.39 - 1.06X_1 - 0.23X_2 + e \). The meaning of Constant / intercept \((b_0) = 51.39\) indicates that if the variable \(X\) or Constant time then the average value of variable \(Y\) or Temperature is 51.39. The Coefficient of Regression \((b_1) = -1.06\) indicates that if the variable \(X\) or Time increases by 1 unit it increases the variable \(Y\) or Temperature by 1.06 degrees. The sign (+) indicates that if the variable \(X\) or time increases then the variable \(Y\) or Temperature will also increase. The Coefficient of Regression \((b_2) = 0.23\) indicates that if the variable \(X\) or Time increases by 1 unit it increases the variable \(Y\) or Temperature by 0.23 degrees. The sign (+) indicates that if the variable \(X\) or time increases then the variable \(Y\) or Temperature will also increase. In the output above nila R Square \((R^2)\) is 0.99 this can be interpreted that the variable temperature of QTEM Temp \((X_1)\) and Ecotect Temperature \((X_2)\) determines a valid temperature of 99%, while the other 1% is determined by other variables outside the model (variables other than \(X_1\) and \(X_2\)), Table 6.

### Table 6. Room temperature and environment simulation results by regression analysis

| SUMMARY OUTPUT | Regression Statistics |
|----------------|-----------------------|
| Multiple R     | 0.995416922           |
| R Square       | 0.990854849           |
| Adjusted R Square | 0.987806465       |
| Standard Error | 0.302409511           |
| Observations   | 9                     |
5. Conclusion
The amount of heat energy accumulated in each room, which is influenced by solar radiation, space leveling, activity, and lighting, was also measured. By calculating the temperature distribution in the space of each floor by comparing the Ecotech v.5 simulation results with the existing EEI (Energy Efficient Index) field measurements generated by 46.22KWH/H/m2/day based on the calculation of working operational hours, it was assumed that 8 hours/day with real operational 2920 hours/year and the total energy consumption of 16330 kWh/year were considered as a very wasteful criterion. The temperature on each floor differs from 26.8°C to 29°C, the difference between the simulation calculation and the existing measurement was 0.78°C, with an average temperature of simulation result was 27.53°C, the existing was 26.75°C. Besides, the temperature obtained was different in each room. This was influenced by the room orientation to the sun which affected the comfort level of the room.

Temperature measurement results and comfort level on office building which had three floors in Banda Aceh, based on data logger of QTEM tool, in the room that has Air Conditioning (AC), the humidity up to 40-70% with air temperature 25 – 30 °C and speed of air movement 0.4 – 0.5 m/s, the temperature comparison with thermal sensation scale that sensed by employer showed that thermal sensation in a room is felt a difference. The differences in the thermal sensation that felt by everybody differently are caused by several variables that were determined thermal comfortable, including rate metabolism and insulation rate[11][12].

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