Energy efficiency analysis in office building through thermal modelling

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Abstract. Malaysia is hot and humid country with high temperature and humidity. The air conditioning systems that have huge energy consumption are an essential component in daily life. The aims of this research are to build a building thermal HVAC model, which could predict the amount of energy consumption required to get the comfort level using eQUEST and purpose energy saving methods. In the model the different physical properties of the building, weather, and internal load, HVAC system, operating strategies and schedules taken to account. From the result, huge energy used for space cooling resulting low room temperature outside the range of Malaysian Standard MS1525. Among the purposed method, packaged VAV DX coil air conditioning system has the most energy saving on the building’s overall energy consumption following by roof and wall insulation (24°C) indoor temperature, standard VAV CW coil air conditioning system, and daylight control with low e glass. The energy reduction range from 6.0% to 21.2%. This study are significant to study and improve the building energy efficiency.

1. Introduction

The tropical climate in Malaysia is hot and humid with average temperatures of 23.7°C to 31.3°C throughout a day. The average relative humidity throughout a day as between 67% to 95%. With this kind of climate, it may have an adverse impact on occupant comfort indoor [1] Air conditioning is one of the essential techniques employed to provide human comfort, as well as to generate favourable conditions for industrial, agricultural and biological processes [2].

Heating, ventilation and air conditioning (HVAC) system consumes energy to provide the thermal comfort in the building [3]. Modern buildings and their heating, ventilating and air-conditioning (HVAC) systems are the biggest consumers of energy [4]. The energy saving potential of HVAC systems deserves therefore constant attention [3]. Therefore, energy performance simulation programs are powerful tools used to study energy performance and thermal comfort during the building’s life-cycle [5].

From literature, building envelope has a major role in controlling energy consumption in buildings and maintaining indoor comfort, because it acts as a thermal barrier to prevent heat loss and provides shading to control solar gains [6]. Besides, the characteristics of occupant adaptation behaviours will affect air conditioning load and energy consumption [7]. Climate factors and conditions also have a significant influence on the energy consumption of air-conditioning systems. These factors mainly include outdoor temperature, relative humidity of the outdoor air, wind direction and speed, solar radiation intensity, cloud cover, and precipitation. [8]. F. Basrawi et al. have reported different external wall types have a slight effect on the life cycle net saving and fiberglass urethane was the most cost effective [9]. Abdeen Mustafa Omer reported exploitation of renewable energy in buildings and
agricultural greenhouses, can significantly contribute in reducing dependency on fossil fuels [10]. M.F. Zafirah indicate that the latent efficiency decreased and in contrast the recovered energy increased with increasing airflow rates [11]. The underground temperature for Malaysia’s climate has been determined using empirical equations in which, at a depth below 2.0 m, the ground heat exchanger (GHE) is able to produce significant passive cooling for any application [12].

The habit of having low temperature setting in the building has resulted in high energy consumption. In addition, the thermal comfort of the building occupants has also being compromised. Thus, the objectives of the work are to analyze the energy consumption of the building and purpose ways to reduce energy usage in the building.

2. Measurements and instrumentation
A faculty administration building used as the model. The indoor thermal condition of the building were determined by using temperature and humidity data logger. Besides, eQuest used as energy performance analysis tool.

2.1. Temperature and humidity data logger
The data loggers mainly used for temperature and humidity recording during air conditioning of office. The data time interval is set to 5 minutes and the observation is done for 5 days.

2.2. eQuest Simulation Software
eQuest (Version 3.60) is a public domain tool and is based on the DOE-2.2, the latest version of DOE-2 (GBS 2007a). eQuest predict the energy use and cost for all types of buildings. The computation principle of eQuest is dynamic transient. eQuest is used within a design process that involves other software (e.g. CAD, spreadsheets, presentation, etc.) the assessment of the compatibility and interoperability of each tool focuses on typical software used in the industry.

3. Methodology

3.1. Outdoor weather conditions
The weather data in Kuantan for 2017 used as outdoor weather conditions. Hourly dry bulb temperature and relative humidity data used as the input to the simulation software.

3.2. Indoor thermal conditions
Temperature and humidity data placed in five different places that are faculty admin office, automotive admin office, conference room, AHU supply and AHU return shown in Figure 1. The data used to plot a graph for further analysis.

3.3. eQuest simulation set up
The model set up by using design development wizard in eQuest. The building type and seasons defined. Next, insert the weather file into eQuest. Based on architect drawing, start to construct the building shell with different zone pattern and building construction materials. After that, define activity areas allocation, building operations schedule and HVAC systems. The steps repeated until the whole model of faculty administration building completed. The general workflow in the design development wizard of eQuest shown in Figure 2.
Figure 1. Data logger and its location placed in building (a) data logger (b) faculty admin office (c) Automotive admin office (d) conference room (e) AHU supply (f) AHU return

Figure 2. General workflow in the design development wizard of eQUEST

4. Results and discussion

4.1. Actual observation indoor thermal condition

The temperature and humidity data collected by using temperature and humidity data logger to draw a temperature and humidity verse time graph shown in Figure 3. In faculty administration office, the indoor average temperature is 22.2°C and indoor average humidity was 67.1%. In faculty Level 1 conference room during office hour, the indoor average temperature was 21.3°C and indoor average
humidity is 74.0%. In automotive administration office, the indoor average temperature was 20.7°C and indoor average humidity was 80.4%. In AHU return, the indoor average temperature was 24.6°C and indoor average humidity was 77.2%. In AHU supply, the indoor average temperature is 15.7°C and indoor average humidity is 99.8%.

In faculty administration office, the average indoor condition during office hour were (22.2°C, 67.1%). In faculty Level 1 conference room the average indoor condition during office hour were (21.3°C, 74.0%). In automotive administration office, the average indoor condition were (20.7°C, 80.4%). In AHU return, the average indoor condition were (24.6°C, 77.2%). In AHU supply, the average indoor condition were (15.7°C, 99.8%). Meanwhile, Malaysian standard for indoor condition were (23°C-26°C, 55% - 70%). In Figure 4, the results shows that the conditioned indoor condition in faculty administration building which were faculty administration office, faculty Level 1 conference room and FKM automotive administration office was not inside the range of Malaysian standard (MS1525:2007). This means the building has higher energy consumption of air conditioning system.
Figure 4. Indoor condition for (1) automotive administration office (2) faculty Level 1 conference room (3) faculty administration office (4) AHU return (5) AHU supply relative to Malaysian Standard MS1525

4.2. Building shell

Based on architect drawing, the building geometry and parameter of the baseline design were completely set up in eQuest and shown in 3D view. The top view, front view, right-side view and isometric view of the baseline design shown in Figure 5. All the windows, doors and zones were set and
located based on faculty administration building design. The top view shape of the building was alike to “L” shape. The front view were facing west. The right-side view were facing south. The faculty administration building consists of three number floors of building, one hall and one administration office.

4.3. Building interior
The space size of each activity zones were completely set up and shown in 2D view. Each zones were set to maximum occupants and assigned with specific activities. Within the zones, it were assigned to be conditioned by air conditioning system and non-conditioned without air conditioning system. Meanwhile, different equipment loads will be set with different assigned activities. Thus, these parameters will affect the internal loads as well as cooling load of the building. All the building interior details shown in Table 1.

Table 1. Faculty administration building interior

| Building Interior 2D View | Area: Level Ground |
|---------------------------|--------------------|
|                           | Max Occupant: 75   |
|                           | Conditioned zones: Classroom/lecture, office (general), corridor, computer room (instructional/pc lab) |
|                           | Dimension: 24m x 60m x 4m |

| Area: Level 1 |
|---------------|
| Max Occupant: 60 |
| Conditioned zones: Classroom/lecture, conference room, corridor |
| Dimension: 24m x 60m x 4m |

| Area: Level 2 |
|---------------|
| Max Occupant: 30 |
| Conditioned zones: Office (executive/private), corridor, lobby (office reception/waiting), copy room (photocopying equipment), conference room |
| Dimension: 24m x 60m x 4m |

| Area: DK300 |
|-------------|
| Max Occupant: 90 |
| Conditioned zones: Classroom/lecture |
| Dimension: 16m x 16m x 8m |

| Area: Automotive administration office |
|----------------------------------------|
| Max Occupant: 40 |
| Conditioned zones: Office (executive/private) |
| Dimension: 8m x 16m x 4m |
4.4. Water-side HVAC

The water-side HVAC system is the HVAC system that used to cool the water for air conditioning purpose shown in Figure 6. When the water inside HVAC was cooled, it will supply to the multiple coils. Then, the return air that pass through the coils will be cool down and supply to the building again. Meanwhile, the water inside the coils will be heated up and return to the chiller to be cool down again. The chiller system was electric hermetic reciprocating. It uses piston driven by a crankshaft as compressor mechanism using electric power and sealed completely.

4.5. Air-side HVAC

The air-side HVAC system is the HVAC system that used to cool the air conditioning purpose shown in Figure 7. When the cool air inside that pass through the coils in AHU room, it will supply to the multiple zones through ducting system using supply fans. Then, the air from the multiple zones will be returned to the ducting system and transfer to outside air economizer and back to AHU room using return fans. The fans type was forward curved centrifugal with discharge dampers. The air-site HVAC system was multi-zone air handler. It supplies the cool air to multiple zones and return the hot air from multiple zones.
4.6 Monthly electric consumption

Figure 8 shows the average electric consumption by space cool was 14.43kWh. The average electric consumption by ventilation fans was 6.12kWh. The average electric consumption by pumps and auxiliaries was 0.91kWh. The average electric consumption by exterior usage 0.13kWh. The average electric consumption by miscellaneous equipment 3.73kWh. The average electric consumption by area lights was 5.36kWh. This shows that the space cooling has highest average energy consumption following by ventilation fans, area lights, miscellaneous equipment, pumps and auxiliaries and exterior usage.

4.7 Annual electric consumption

In Figure 9, it shows that the energy consumption of the air conditioning systems accounts for 40–60% (or even higher) of total energy consumption in large public buildings [8]. The results from simulation also shows that the total electric consumption of space cooling and ventilation fans in air conditioning systems were accounted 67% of total electric consumption of faculty administration building (246.62kWh). Therefore, the air conditioning systems consumed huge amount of building energy consumption.
4.8 Energy efficiency measure electrical consumption

In Figure 10, daylight and low emission glass reduced total electric consumption by 22.05kWh (6.0%). A study evaluated the electric lighting energy savings obtained by utilizing a daylight dimming system with simulation software [13]. A study has quantified the energy saving potential of different type of single and double glazing glasses especially in case of tropical climate condition. [14].

Roof and wall insulation (R-19) design has reduced 16.4% of total electric consumption. This is because thermal insulation is known as one of the most effective ways to reduce the heat transmission rate and energy use for both space cooling and heating in buildings [15]. The numerical results showed that the different wall insulation forms had a remarkable effect on the temperature response rate and the heat flow of the inner surface under the air-conditioning intermittent operation, although they had the same heat transfer coefficients. [16].

Standard VAV CW coils has reduced 10.5% of total electric consumption. However, packaged VAV DX coil has reduced to 21.2%. This shows that packaged VAV DX coils more energy efficiency than standard VAV CW coils and baseline air conditioning system. A research was carried out shows that coolant directly expanding air conditioning system has low energy consumption and high system efficiency compared to chilled water air conditioning system [17].

24°C indoor temperature design has 10.9% reduction of total electric consumption compared to baseline design. The temperature of air-conditioning in office buildings in hot climates could be set to a higher level than it usually was, so that air conditioning energy could be saved while occupants’ comfort won’t be sacrifice [18].

5. Conclusion

A building thermal model to predict the amount of energy consumption has developed. The physical properties of the building, weather, internal load, HVAC system, operating strategies and schedules have taken to account. The result shows that the observed indoor condition of temperature and relative humidity are generally outside the range of Malaysian Standard MS1525. In addition, packaged VAV DX coil air conditioning system has the most energy saving on the building’s overall energy consumption. The energy reduction ranges from 6.0% to 21.2%. Investigation of other energy efficiency parameter for building also needed for energy efficiency design. The parameters such as climatic conditions, expected thermal comfort, initial and capital cost, the availability of energy sources and the application of the building must considered to properly design and select an energy-efficient HVAC system.
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