Performance evaluation of an actual building air-conditioning system

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Abstract. Air-conditioning contributes significantly to high energy consumption in commercial buildings. It is essential to monitor and evaluate the performance of air-conditioning systems to avoid unnecessary energy wastage. This paper presents the results of a study carried out to evaluate the performance of an actual building air-conditioning system with reference to the Malaysian Standard MS1525. The results of the air-conditioning system’s performance and thermal comfort analysis are presented and a comparison is made to the results of a survey conducted among the occupants of the building. Although the results indicate a satisfactory coefficient of performance for the building despite the age of the system, recommendations on system improvements are proposed to further save energy.

1. Introduction
Building consume about one-third of the world’s energy and it is expected that the trend will grow further until the year 2025. Among the buildings in Malaysia, office buildings consume the most energy for air-conditioning system compared to shopping complexes, hotels and residential buildings[1]. Thus, office building owners should take action to save more energy to avoid unnecessary energy wastage. In general, building air-conditioning system can be classified into the following categories:
   i) Split/Window units
   ii) Package units
   iii) Centralised air-conditioning systems

The split unit consist of the indoor unit and outdoor unit. The indoor unit is installed inside the area to be cooled. It can be ceiling or wall suspended and comprises of the evaporator and blower. The outdoor unit is installed outside the building and comprises of the compressor, condenser and blower. Package units are for higher capacity air-conditioning loads in the range of 3 to 15 tonnes. They comprise of the filtering, cooling and dehumidifying as well as air handling components with water-cooled or air-cooled condensers. The centralised system can be of the direct expansion system or the indirect chilled water system. This study is focused on an actual building installed with a package unit air-conditioning system and some individual split units.
In order to implement energy saving initiatives, the performance of the air-conditioning system should be a major consideration. The performance of an air-conditioning system is measured by the Coefficient of Performance or COP. It is the ratio of the desired output over the required input of the system which is a ratio of the heat removed from the cooled space over the input work or electrical energy consumed. The COP can be calculated as in Eq. (1).

\[
COP = \frac{\text{total heat load}}{\text{total electrical load}}
\]

(1)

The heat removed from the cooled space can be determined by considering the chilled water heat rejection or condenser water heat gain or the heat rejection in the building Air Handling Units (AHU). For the package unit in this study, the heat rejection in the building AHU will be considered.

Thermal comfort is also an important consideration in evaluating the performance of an air-conditioning system. The main factors that affect thermal comfort are dry bulb temperature, relative humidity and air velocity. Air cleanliness, odour, noise and radiation effect also affect the comfort level of occupants in a conditioned space [2].

2. Case study
The study was carried out at the P02 Building which is one of the Faculty of Electrical Engineering’s (FKE) buildings in Universiti Teknologi Malaysia (UTM). The objectives of this study are to determine the performance of the air-conditioning system of the building and to identify energy saving potentials for future improvement.

The P02 Building is a four storey building and consists of administrative offices, lecture rooms, lecturers’ rooms and laboratories. The building is mainly installed with Water-Cooled Package Unit (WCPU) air-conditioning system. The condensers of the WCPU are cooled by cooling water from a nearby cooling tower. The cooling tower also serves two other buildings in the faculty. Apart from the WCPU air-conditioning system, there are also some rooms in the building which are installed with individual split units.

3. Methodology
The performance analysis of the air-conditioning system was carried out using data collected through an energy audit and a thermal comfort survey. Each level of the building was divided into several zones depending on the activities of the occupants.

3.1. Energy Audit
Data were collected from the rooms in the P02 building for temperature, relative humidity, air velocity and flow rate as well as carbon dioxide concentration. The audit was carried out to include both types of air-conditioning systems installed in the building. The air-conditioning system heat rejection load for the WCPU was obtained by assuming that the heat load rejected through the AHU is equal to the amount of cooling distributed by the AHU and can be determined using the following equations:

Total Heat Load = Total Sensible Heat + Total Latent Heat  \hspace{1cm} (2)

Sensible heat [W] = 1.21 \times Q \text{ [l/s]} \times \Delta T \text{ [°C]} \hspace{1cm} (3)

where,

\[ Q = \text{supply air flow rate [in litres/sec]} \]
\[ \Delta T = \text{mixed air temperature – supply air temperature} \]

Latent heat [W] = 3 \times Q \text{ [l/s]} \times \Delta M \text{ [g/kg]} \hspace{1cm} (4)
where,
\[ Q = \text{supply air flow rate [in litres/sec]} \]
\[ \Delta M = \text{mixed air moisture content} - \text{supply air moisture content} \]

Data collected from the AHU includes temperature, flow rate and relative humidity for the supply air, return air and mixed air. The total electrical load of the WCPU was obtained by considering the electric consumption of the compressor and blower of the refrigeration plant as well as the electric consumption of the cooling water pumps and cooling tower fan. The electrical power input for the compressor and blower of the refrigeration plant was obtained from the distribution board in the AHU rooms. The electrical power input for the cooling water pumps and cooling tower fans was obtained from the cooling tower building. A similar calculation and analysis were also used for the individual split units. The COP of the building’s air-conditioning system was then determined using Eq. (1) and compared to the standards published in MS 1525:2007.

A heat load analysis was also carried out for the building by taking hourly measurements from the AHU rooms. Equations (3), (4) and (2) were used to calculate the sensible heat, latent heat and total heat rejected by the AHU respectively. The heat load was plotted against time to study the hourly trend of the heat load.

3.2. Thermal Comfort Survey
A thermal comfort survey was conducted among the occupants in P02 Building, FKE. The survey was distributed among a total of 55 occupants. The questions were focused on the comfort level and the effect of temperature and air quality on their office activities.

4. Results and discussion
This section presents the findings of the energy audit and thermal comfort survey carried out at level 3 of the P02 Building. The rooms located on level 3 include the dean and deputy dean’s offices, meeting room and lecturer’s rooms. The area of the audited zone is 503 m² and the floor layout is as shown in figure 1.

![Figure 1. Layout of Level 3](image)

Level 3 is divided into five zones according to the location of the area, air-conditioning usage pattern and source of supply air. Zone 1 consists of two deputy dean offices and personal assistant’s office. Meanwhile, Zone 2 comprises of dean’s office and meeting room, and Zone 3 is an administrative office area. Lastly, Zones 4 and 5 consist of lecturers’ rooms.

4.1. Questionnaire Survey Analysis
A thermal comfort survey was conducted among the occupants on level 3 to get their feedback on the comfort level and the effect of air-conditioning on carrying out their office activities with regards to
temperature and air quality. 13 occupants on level 3 participated in the survey and the analysis is presented according to the assigned zones as shown in figure 2 and 3.

4.2. Feedback on room comfort.
Figure 2 shows the feedback on room comfort from the occupants in the respective zones. The feedback obtained varied according to the zones. 15% of the occupants surveyed felt that the air-conditioning in their office is comfortable while the majority or 46% felt neutral on the issue of room comfort. Those that felt comfortable with the air-conditioning system were mainly occupants in Zone 1 and Zone 3. There were no occupants surveyed in Zone 2. The occupants that were uncomfortable especially in Zones 4 and 5 attribute their feedback due to the low temperature in their zones.

![Feedback on room comfort at Level 3.](image)

4.3. Feedback on the effect of air-conditioning on office activities.
Figure 3 shows the effect of the air-conditioning system on the office activities of the occupants. The majority of the occupants surveyed did not feel that the air-conditioning system was helpful to them in carrying out their office activities. 38% of the occupants felt slightly disturbed due to the low air temperature making them uncomfortable and affecting their productivity. They had to put on a jacket almost all the time to keep warm. Those that were slightly disturbed by the air-conditioning system were from zones 4 and 5 and these feedbacks seem to be in agreement with the findings on room comfort as observed in figure 2.
4.4. Comfort Level Analysis

An analysis on comfort level for the building was carried out based on the data measured and tabulated in table 1.

Table 1. Measured comfort level data for Level 3

| Level | Zone | No. Of Occupants | Average Temp [°C] | Average RH [%] | Average room air velocity [m/s] |
|-------|------|------------------|-------------------|---------------|---------------------------------|
| 3     | 1    | 4                | 23.7              | 66.9          | 0.19                            |
| 3     | 2    | 1                | 23.3              | 67.5          | 0.16                            |
| 3     | 3    | 7                | 24.7              | 63.8          | 0.15                            |
| 3     | 4    | 6                | 20.4              | 74.1          | 0.14                            |
| 3     | 5    | 3                | 20.6              | 73.3          | 0.16                            |

Table 1 shows the average measured values taken during the audit. The level was divided into five zones and the zone was divided according to the location of the area, air-conditioning usage pattern and source of supply air. The data in table 1 were then plotted on a psychrometric chart to identify if the zones were within the comfort range according to the Malaysian Standard (MS 1525:2007) as shown in figure 4 below.
According to figure 4, Zone 4 and Zone 5 were a bit colder where the temperatures in these zones were much lower than the recommended range of 23°C – 26°C. The percentage of relative humidity was also beyond the recommended design relative humidity of 55% - 70%. This is because Zone 4 and Zone 5 consist of rooms that are always vacant.

*Heat Load Analysis*

The heat load during office hours for level 3 is shown in figure 5. It can be observed that the heat load was high at the start of the day but remained almost constant until noon. The heat load decreased gradually from 12 noon to 2 pm due to the lunch break which mean fewer activities and less people were inside the office. The heat load can be seen to increase again after 2 pm until 4 pm. The centralized air-conditioning was switched off at 4.30 pm.
Coefficient of Performance, COP determination

The COP of the air-conditioning system on level 3 was obtained by determining the heat removed from the conditioned area and the electrical power input to the system. Table 2 gives the measured data obtained at the AHU room. The data required for the determination of the heat load includes temperature, relative humidity and flow rate of the air at various locations in the AHU. The electrical power was measured from the distribution board to identify the power consumed by the AHU. Electrical power input for the cooling tower water pumps and fans were also taken into consideration to determine the electrical load of the AHU.

Table 2. Measured parameters at AHU Level 3

| Field Measurement | Return Air | Mixed Air | Supply Air | Distribution Board |
|-------------------|------------|-----------|------------|-------------------|
| Temperature (°C)  | 23.7       | 24.2      | 20.0       | -                 |
| Humidity (%)      | 70.6       | 74.1      | 84.4       | -                 |
| Flow rate (m³/s)  | 5.59       | 5.45      | 5.87       | -                 |
| Voltage (V)       | -          | -         | -          | 408               |
| Current (A)       | -          | -         | -          | 17.7              |
| Power (kW)        | -          | -         | -          | 9.38              |
| Power Factor      | -          | -         | -          | 0.75              |

By using Equation (1), the COP was determined to be 2.82 which is slightly lower than the minimum requirement COP of 3.0 as in the Malaysian Standard [4].

Conclusion

This paper has presented the results of a study carried out on an air-conditioning system of an actual building. The COP obtained is slightly lower than the minimum recommended COP of 3.0 but the result is as expected since the system has been installed for more than 20 years. Zones 1 and 3 were found to be within the recommended comfort zone according to the Malaysian Standard
1525:2007. Zones 4 and 5 were found to be outside the recommended comfort zones. But the results were in agreement with the survey carried out on thermal comfort based on the feedback from the occupants. The results of the study also showed that there is room for improvement in terms of thermal comfort and energy efficiency.

**Recommendations**

There is a need to study further on how to use energy more efficiently especially as can be seen from the results for Zones 4 and 5. Both these zones were not occupied most of the time but since both zones were installed with centralized air-conditioning system, this would result in energy wastage. A control system that takes into consideration variation in heat load could be installed to save energy for the air-conditioning system. Installing a Fault Detection and Diagnosis (FDD) system to detect possible failures and localize faults [5] would also benefit the air-conditioning system. According to [6], a successful FDD may save up to 40% of heating, ventilating and air-conditioning (HVAC) energy consumption and reduces unnecessary energy wastage.

**Acknowledgements**

The authors would like to thank the Ministry of Higher Education, Malaysia and Universiti Teknologi Malaysia for financially supporting this research project under the GUP Flagship Grant (Vot 00G18; Vot 00G20). The authors would also like to thank Universiti Teknikal Malaysia Melaka for the support.

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