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# Analysis of Thermal Comfort and Energy Consumption for Educational Building

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**ABSTRACT**

Building envelope maintenance and management which has a very close relationship with building energy consumption and indoor thermal comfort. Thus, the proper of building envelope maintenance and management is essential to reduce energy losses and increasing occupant comfort and satisfaction. Providing a building condition with comfortable and healthy environment without any building defects is one the main function in educational building. The primary objective of this study is to investigate the building condition and thermal comfort of classroom buildings. The modeling and the energy simulations were performed by IES VE software. The building is located on the Permatang Pauh campus. In this case study, questionnaire and walkthrough assessment were carried out to gather information. First, a set of questionnaires has been distributed to the 1000 respondents. The majority of the respondents claim that the room temperature as dissatisfactory (74.3%). In overall, most of the respondents want the classroom to be cooler. Secondly, walkthrough assessment has been carried out to recognize the building condition. Indoor environmental parameters such as temperature and relative humidity of classroom buildings were recorded. There have 4 types of case study; 1) utilized without occupants, 2) utilized with occupants, 3) non-utilized without occupants, and 4) non-utilized with occupants. The analysis of energy consumption was performed by using building simulation, IES VE software. The results indicate that the case study (2) was 1,819 kWh/month, while the case study (4) was about 1,936 kWh/month. It was found that the room type; non-utilized with occupant is higher compared to utilized with occupant. By comparing the average value for each case study, the classroom can be classified as a very inefficient building in terms of energy consumption. The maintenance such as repair and replace the building components in classroom were suggested to improve the energy performance.

## 1. Introduction

The building maintenance is necessary for keeping the building functional, safe and comfortable. Poor and improper building maintenance will lead to cause more damages and costly repair works if

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left unattended [1]. Unfortunately, building maintenance is still weak. Furthermore, if this situation is left unanswered and unattended, it will lead to more risk and serious problems for the building occupancy and activities. The main functional of a building is to protect the occupants from the extreme weather such as rain, wind and temperature. The most important is building provide the comfort and satisfaction of occupants with their indoor environment.

Building defects is one of the biggest nightmares for the occupant. Defects are often classified as major or minor. Common types of building defects include: structural defects resulting in cracks or collapse; defective or faulty electrical wiring and/or lighting; defective or faulty plumbing; inadequate or faulty drainage systems; inadequate or faulty ventilation, cooling or heating systems; inadequate insulation or sound proofing; and inadequate fire protection/suppression systems [2]. In Malaysia, the problems of leakage at buildings are always happen due to tropical condition, improper design and poor workmanship [3]. The common of building defect occur on the ceiling, window, wall, floor and roof. This defect also affecting the total energy consumption of a building.

The building defect also influence on the occupant comfort and satisfaction. The comfort and satisfaction is very subjective because different person have a different perception. Thermal comfort is about senses and feelings [4]. There have six variables that drive occupant thermal comfort such as air temperature, surface temperature, humidity, air velocity, activity level and clothing level [5]. Humidity is a major source of problems in building [6] and is lead to ceiling defect, wall and floor defect. This problem will affect to increase the heat transfer through envelope and overall building energy consumption [6]. Furthermore, building dampness and mould growth have been positively associated and will leads to the health effect such as asthma [7].

The building consists the window is better than windowless. However, the design and material of window glass and window frame are significant to consider. The poor elements cause the window defect such as solar radiation and daylighting. Solar radiation falling directly on a person significantly affects their perception of thermal comfort [8].

The educational building is equipped with services and installations such as air conditioning system, lighting and elevator system. The energy consumption in educational building indicate over 80% energy use for air conditioning system [9]. Long term energy saving can be achieved by improving the building design [10]. The inefficient of building design and maintenance can cause energy wastage, customer complaints, poor indoor air quality and environmental damage. In order to achieve energy efficiency in buildings, the proper guidelines of building maintenance is required. Building performance and the condition physical of the building components could not be separated and interrelated [11]. Thus, implementation of condition assessment of physical building from time to time is the best option in order to enhance the building performance. Besides that, building condition with presence of air conditioning system are influence student achievement [12].-Earthman [13] investigated the relationship between school building condition and student achievement. The findings shows that the condition of school building is significance influence to student learning.

The objective of this paper is to investigate the building condition in the classroom. Interaction with building users was carried out via a questionnaire survey to determine the thermal comfort in classroom. IES VE is a building simulation program which has capabilities to solve energy system problem. In this paper, IES VE software is used to simulate energy consumption of a centralized air conditioning system in tropical Malaysia climate using thermal analysis. Comparison of each case study for the building condition and energy consumption were presented and discussed.

## 2. Methodology
### *2.1 Case Study*

The case study concerns the building of the Faculty of Mechanical Engineering (FKM) of Universiti Teknologi MARA. It is located in Permatang Pauh, a city in Penang, Malaysia and characterized by hot and humid climate. The FKM built in 2003 and has two buildings which is Wing A and Wing B, a mid-rise building with the four-storeys. This building consists are classrooms, office, laboratory and workshop. The building is equipped with centralized air conditioning system, lighting and elevator system. The classroom are usually occupied from 8:00 h. to 13:00 h. in the morning and from 14:00 h. to 16:00 h. in the afternoon. A classrooms building is shown in Figure 1.

**Fig. 1.** FKM classrooms building

### *2.2 Questionnaire Survey*

In order to comprehensively understand the thermal analysis and energy consumption in educational building, the questionnaire survey is designed with content as shown in Table 1. The survey content include respondent background, building condition, building system and level of satisfaction on indoor environment. The survey consists of 20 questions grouped into four sections. A summary of question types is presented in Table 1. A set of questionnaires was distributed to the 1000 respondents in via face-to-face method in order to investigate the thermal comfort of the occupants.

**Table 1**
Items of the questionnaire sheet

| Section | Content |
| --- | --- |
| Background | gender, age, courses and programmes, class frequency, classroom activity, hourly occupancy |
| Building condition | wall condition, window condition, door condition, floor condition, ceiling condition |
| Building system | air conditioning, lighting |
| Satisfaction | satisfaction on unit size, indoor comfortable level |

### *2.3 Simulation*

The simulation was done with the Integrated Environment Solution-Virtual Environment (IES VE) software using Apache Modules for thermal analysis. In modelling the classroom, a few assumptions were made. M.C Dubois [14] stated that the difference of modelling between with furniture and empty room has ranged from 0 to 35%, varied as a function of sun angle, distance from window and also furniture arrangement. Thus, the furniture arrangement will give a specific illuminance distribution [15]. However, the furniture arrangement for daylighting study is unpractical to generalize [15]. Therefore, in this case study, classroom furniture was ignored in order to simplify the modelling. Moreover, window frame was also neglected because there was no significant effect on modelling. The ceiling height of classroom is 3.2 meter. Indoor environmental parameters such as temperature and relative humidity were recorded using MHB-382SD Temperature/Humidity/Barometric Data Logger. This equipment is used to accumulate data on indoor classroom building temperature and relative humidity. The indoor parameters were taken in 60 seconds of time intervals. During the investigation, all the data collected were saved in the SD Card Data Logger.The simulation modelling were carried by four types of case study; 1) utilized without occupants, 2) utilized with occupants, 3) non-utilized without occupants, and 4) non-utilized with occupants. The numbers of occupants is from 20 to 35 persons in one classroom.

## 3. Results and Discussion

### *3.1 Measurement and Survey Results*

The result shows that 98.4% of the respondents are student and the rest is staffs. Majority of the respondents are from the mechanical engineering faculty which represent 82.8 % of the total respondents. The other 18.2 % respondents came from the electrical, civil, chemical engineering faculty members. About 39% of the respondents come to classroom for 2 to 3 times a week and 35.9% of respondents are comes every day in weekdays. The next 10.9% of respondents comes at least once a week whereas the last 14% of respondents are only once in a month. According to the question of respondent's satisfaction towards the air conditioning system in the classroom. The result shows 73.4% of the respondents dissatisfied with the air conditioning system performance whereas the other 26.6% were satisfied. Based on the feedback, most of them are feeling uncomfortable since the morning 08.00 h. and during class session. In overall, most of the respondents want the classroom to be cooler. The feedback stated that they could not focus during class sessions when the classroom felt hot. They are feel tired, sleepy and uncomfortable. In this survey, the respondents need to rate the air conditioning level which is excellent, good, moderate, poor, and disappointing. It shows that majority (42.2%) of respondents are given the rate of air conditioning system is moderate, 25% rate is poor, 23.4% rate is good and following by 7.8% rate is disappointing and lastly only 1.6% rate the air conditioning temperature is excellent. The data obtained can conclude that the percentage of dissatisfied respondents increased during the class sessions because the slightly lower air temperature.

### *3.2 Classroom Condition*

The building condition gives impact to the users. Performance of academic students are depend on the building condition. They are likely to perform better, if they are in the building with the best condition [16]. Thus, building condition and student performance has positive relationship. The building condition with acceptable indoor air quality is the most important factor to the learning performance of the students [17]. In this case study, the walkthrough assessment for each classroom in 2$^{nd}$ and 3$^{rd}$ floor of FKM building has been investigated. Besides that, observational surveys and interviews to random students were also conducted. This study will focus on building defect that occur in classroom. Results from the survey shows that the components of building such as window, ceiling, door and curtain have defects. Table 2 shows the findings of survey physical condition in classroom at FKM building. The findings show the 18 classes have a defects. The main defects is that the building components cannot function properly. All the elements need to be repaired and replaced.

**Table 2**
Number of defects for building component in classroom

| Room | Window | Lamp | Ceiling | Door | Curtain |
|---|---|---|---|---|---|
| BKM 2.07 (A) | 3 | 7 | 3 | - | 3 |
| BKM 2.08 (B) | - | 2 | 2 | - | 2 |
| BKM 2.09 (C) | 1 | - | 1 | - | 2 |
| BKM 2.10 (D) | 1 | 3 | 2 | - | 1 |
| BKM 2.11 (E) | 1 | 2 | 1 | - | 2 |
| BKM 2.12 (F) | - | 1 | 1 | - | - |
| BKM 2.13 (G) | - | 4 | 1 | - | - |
| BKM 2.14 (H) | 2 | 4 | 2 | - | 1 |
| BKM 2.15 (I) | 4 | 2 | 1 | - | 2 |
| BKM 2.16 (J) | - | 1 | 2 | - | - |
| BKM 2.17 (K) | 2 | 2 | 4 | - | 1 |
| BKM 2.18 (L) | 7 | - | 1 | 1 | 1 |
| BKM 2.19 (M) | 2 | 1 | 2 | - | 1 |
| BKM 2.20 (N) | 2 | - | 2 | 1 | 1 |
| BKM 3.02 (O) | 4 | 21 | 5 | - | 2 |
| BKM 3.03 (P) | 5 | 4 | 5 | - | 2 |
| BKM 3.04 (Q) | 7 | 2 | 6 | - | 2 |
| BKM 3.06 (R) | 2 | 3 | 1 | - | 1 |

There have two type of window size which is big and small size. However, most of them have a defects like window cannot lock properly, window lock broken and corrosion on window frame. Table 3 shows the summary of window defects. The window defects are affect to thermal comfort. The thermal comfort is one of the indoor environment factors that affect health and human performance. When a window cannot be locked properly because the window hinges are stuck, the outdoor air will enter through the open windows. Air conditioning is a closed system, which means that the indoor air is constantly regulated, controlled and cooled until the desired temperature is reached. Outdoor air entering the building will affect the cooling system. Therefore, all windows in the classroom should be closed properly. Table 4 shows the defects occurred on the window of the classroom.

**Table 3**
Window defects in classroom building

| Room | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lock broken | / | | | | / | | | | / | | | / | | | / | / | / | |
| Hinges stuck | / | | / | / | / | | | / | / | | / | / | / | / | / | / | / | / |
| Frame corrosion | | | | | | | | / | | | | / | | | / | / | / | |

**Table 4**
Evidence of types of defects related to window

| Lock broken | Hinges stuck | Frame corrosion |
|---|---|---|
|  |  |  |

As seen in the Table 5, the common ceiling defects that occurred in most of the classroom buildings are water leakage, flaking paintworks, dampness and cracks ceiling. Most of the classrooms ceiling have ceiling dampness. The ceiling dampness occur due to condensation of atmospheric moisture which is the water is deposited on the ceiling.

**Table 5**
Ceiling defects in classroom building

| Room | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water leakage | / | / | | | | | | / | | / | / | | / | / | / | / | / | |
| Flaking paintworks | | | | | | | | | | | | | | | | / | / | |
| Dampness | / | / | / | / | / | / | / | / | / | / | / | / | / | / | / | / | / | / |
| Crack ceiling | | | | | | | | | | | | / | | | | | | |

For the ceiling issues, there have two type of defects which leaking and condensation problem. One of the leaking causes is improper design by improper installation of waterproofing. The issue of condensation affect the ceiling because the different temperature has created the water drop below the floor slab and above the ceiling [3]. Figure 2 shows the watermarks on ceiling due to water drop.

**Fig. 2.** Watermarks on ceiling due to water drop (condensation)

The next defect cause of condensation problem is ceiling dampness. Figure 3 shows the ceiling dampness and mould growth. The condensation happened due to different temperature between the floors above and below.  The level of condensation and mould growth are depending on the level of humidity.

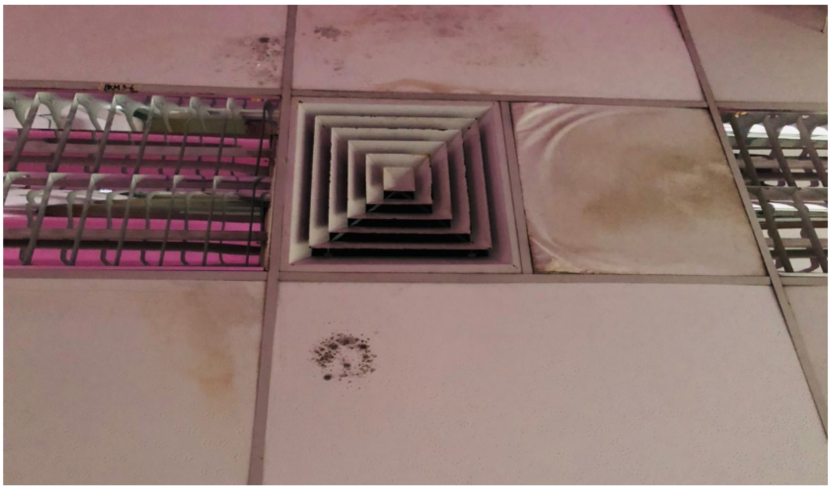

**Fig. 3.** Ceiling dampness and mould growth

Each of classroom has provide vertical blind curtain to control daylighting. The louvers of vertical blind are available in a variety of fabrics and also look stylish. The function of vertical louver blind is to prevent the direct solar radiation and glare. The solar radiation through window and glare will make the students are feeling not comfortable. The heat from the sun through the windows with open curtains is affects to the air conditioning system. Closed the curtains on this window is the best solution. Figure 4 shows the vertical blind curtain condition in classroom. Most of the vertical blind curtain is not function to protect daylighting through a window and glare.

**Fig. 4.** Vertical blind curtain condition in classroom

*3.3 Case Study Analysis*

The simulations to investigate the effect of building condition and indoor parameters on the energy consumption. Air temperature and humidity are common components of thermal comfort. Maisarah *et al.* [18] stated that both temperature and humidity are significant environmental factors for human thermal comfort. The range of indoor parameters; temperature is 28°C to 32°C and humidity is 55% to 85%. Energy simulations has conducted with four cases which is 1) utilized without occupants, 2) utilized with occupants, 3) non-utilized without occupants, and 4) non-utilized with occupants. The meaning of non-utilized is the building components have defects, meanwhile the utilized means the building components in good condition. The analysis of energy consumption was performed by using building simulation, IES VE software.

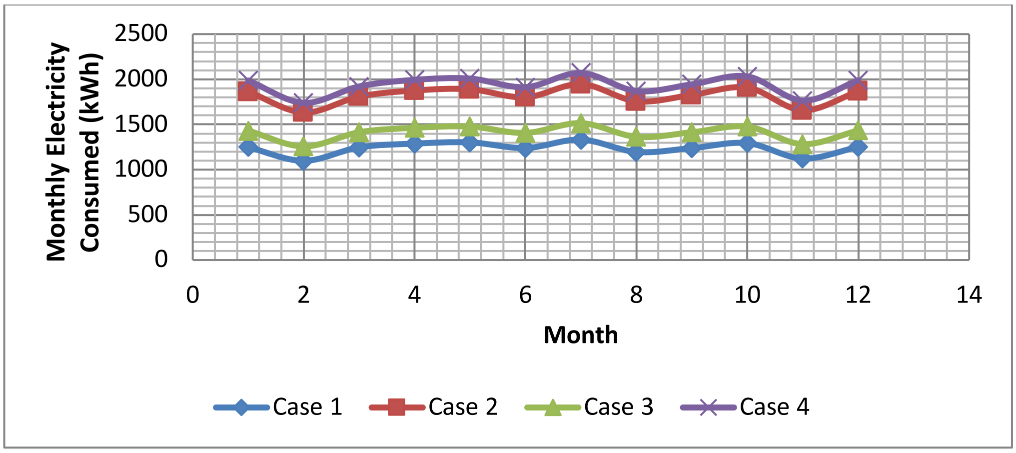


**Fig. 5.** Energy consumption pattern for each case study

The Figure 5 shows the energy consumption pattern for each case study within setting indoor temperature and humidity. Each of case study has the different range of temperature and humidity. Comparing the results for each cases shows that the difference of energy consumption. The case study (2) and (4) are highest compared to case study (1) and (3). The results indicate that the case study (2) was 1,819 kWh/month, while the case study (4) was about 1,936 kWh/month. It was found that the case study (4); non-utilized with occupant is higher compared to utilized with occupant. Thus, the building components with poor condition has effect to energy consumption. The building components with good condition will reduce the energy consumption with 6.02%. As expected, the building components with defect is worse compared to the building components with good condition.

## 4. Conclusions

The building condition and energy consumption have been analysed for a classroom in FKM building. A walkthrough assessment and questionnaire survey was conducted and this data was used in order to quantify the effect of the energy consumption. Based on the survey, 74.3% showed feedback from the respondents are dissatisfied with the performance of air conditioning system in the classroom. Based on the feedback, most of them are feeling uncomfortable since the morning 08.00 h. and during class session. In overall, most of the respondents want the classroom to be cooler.

The building components such as window, door, ceiling and curtain in the classroom have a defect and damage. All the components need to repair and replace. The investigation shown that the window and curtain are not function properly due to lock broken, hinges stuck and frame corrosion. This leads to discomfort which is daylighting directly through the windows and causes glare.

The results of the simulation showed that the case study; utilized with occupants is 1,819 kWh/month, while the case study of non-utilized with occupants is 1,936 kWh/month. It was found that the case study of non-utilized with occupant is higher compared to the utilized with occupant. The building components with good condition will reduce the energy consumption with 6.02%. As expected, the building components with defect is worse compared to the building components with good condition. Therefore, the maintenance such as repair and replace the building components in classroom were suggested to improve the energy performance.

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