Indoor environment and energy consumption analysis for a university academic building

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Abstract. An energy audit was conducted on a university building located within the main campus of Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia. Some of the physical parameters particularly energy consumption, air velocity, airflow, operating temperature, relative humidity and lighting intensity were compared to the Malaysian Standards 1525:2014. This work aims at understanding the comfort level of the occupants and investigates the impact of lighting changes to the overall energy consumption. Based on the data collected, the team could estimate the current energy consumption for all floors. As expected, the air conditioning recorded the highest rate consumption at 72% of electricity usage in the building, followed by the consumption of lighting at 18% and other equipment only 10%. The average operating temperature was recorded at 22.758°C, which is less than that of the recommended range of 24°C – 26°C. The average humidity was about 68.31% while the average lighting intensity was recorded at 461.422 lux. Additionally, the Building Energy Index (BEI) for the 2016-2017 period is 128.53 kWh/m²/year and 137.55 kWh/m²/year for 2017/2018. BEI values in 2017-2018 were a little higher than that specified in MS 1525:2014 Standards, which is 135 kWh/m²/year.

1. Introduction
Environmental issues are getting the much-needed attention in many public policies around the world and sustainable building strategies play a huge role especially in developing countries because of the energy crisis and increase knowledge in energy management [1,2]. The progress of commercial complexes and housing projects directly impact the demands for energy. Hence, many approaches are taken by the government and local authorities to proceed with these development projects sustainably amid concerns for the environment [3,4]. The electrical power utilized in city buildings continues to rise exponentially in the foreseeable future [5], helped by the abundance of advanced technologies used in new electrical equipment [6]. Therefore, energy audits are becoming vital to achieving optimal energy performance while reducing energy waste. Other advances include the improved efficiency of air-conditioning and lighting systems [7,8]. Nonetheless, thorough assessments and detailed investigations are needed to obtain actions that would maximize the energy efficiency in buildings [9,10].
There have been many types of research and developments on building energy performance focusing on energy audits like reported by [11,12] that explained the audits as the gathering data of electricity use that include those in university or college settings. Those works concluded that to improve the electrical energy performance in buildings, the inhabitants of the buildings need to minimize energy excesses and incorporate the use of efficient equipment and control systems as these are possibly the most dependable approaches to upgrade building energy efficiency, particularly through lighting and air-conditioning. This was also the finding by Getu and Attia [13] who also investigated various building electricity consumptions. Their works concluded that significant electricity savings are possible if the traditional lighting system is swapped with the much more energy-efficient light-emitting diode (LED) type fixtures.

Consequently, in general, energy savings may be accomplished through the use of more energy-efficient air-conditioners (ACs) and other appliances. A study by Sait [14] who analysed of energy consumption of an educational building in a hot and humid area located in Rabigh city in Saudi Arabia, saw that based on the analysis of their audit, some recommendations were brought to table that could slash the electric energy consumptions by up to 35.3%. The study also predicted that the air-conditioning system efficiency could then increase by about 31%

The main take from these audits shows an increase in energy efficiency index and this provides opportunities for continuous energy-saving practices. Several energy consumptions, energy savings, and emission analysis in Malaysian office buildings investigations were conducted by Saidur and Masjuki [15]. The authors estimated that 77,569 MWh of energy can be saved and a huge reduction of emissions could be achieved through the application of advanced glazing, compact fluorescent lamps (CFL), insulation, housekeeping, and by increasing the set temperature of air conditioners. Energy-efficient motors in building systems with variable motor loading percentages could contribute to additional energy savings.

Jamaludin et al. [16] reported the energy use and potential of electric power reduction at 12 dormitory halls located in a tropical region of the University of Malaya Campus in Kuala Lumpur, Malaysia. The team conducted energy audits where the power consumption data were collected and analysed for a five-year period. The study found that residential colleges like the dorms with special features in building layout and arrangements exhibited better energy consumption because of the use of day-lighting and natural air ventilation. However, the common practice nowadays for thermal comfort and energy performance in buildings is to optimise the use of Heating, Ventilation and Air-Conditioning (HVAC) systems [17]. This paper focused and examined the energy utilisation in the entire school building in a colder-climate region.

In this present work, a detailed energy audit has been conducted at the selected university building where all related data about that building was collected in order to get the overall picture of the building energy consumption. From this data, potential energy-saving measures that could be implemented in the building are discussed. An index number will then be calculated and compared to the guidelines set in MS 1525:2014 [18].

2. Methods and apparatus
The methods taken in this current work are as follows. First, gather field data by doing measurements and field study on the energy consumption at the Centre for Language and Human Development (PBPI) building within the Universiti Teknikal Malaysia Melaka (UTeM). Inspection of the air-conditioning and mechanical ventilation (ACMV) and lighting systems were conducted at the academic hall. Second, some computer spreadsheet tables are used to analyse all data gathered from fieldworks and to produce explanatory graphs. The power consumption study in the PBPI building considered the period from July 2016 to July 2018 while the field data was taken in the autumn of 2018.

2.1. Building description
The PBPI academic building is located on the main campus of UTeM. It consists of many amenities like the language laboratories, staff offices, classrooms and administration offices as shown in Table 1. The total floor area of the building is 5992.58 m² and the building is shown in Figure 1 which comprises three levels. The normal operating hours of this building is from 8:00 am to 5:00 pm on weekdays.
Table 1. Spaces in the PBPI building.

| Floor | Content |
|-------|---------|
| Ground | 1 Lobby, 7 academic staff offices, 3 Language labs, 1 Main office |
| First | Language teacher offices, Lecturer offices, 4 Language labs, Dean’s office, staff lounge |
| Second | 9 staff offices, ISO room, Seminar room |

Figure 1. The PBPI building.

2.2. Equipment considered in the study

Generally, this part of the work involves several steps. First, electricity power readings were conducted. Second, this data was analysed. Finally, the conclusion was drawn and recommendations were suggested. In Malaysian buildings, the air-conditioning and mechanical ventilation or ACMV system consists of many types of equipment and components that are integrated to dehumidify, cool, filter, and blow the conditioned air that is originally from the outside to the space inside the building. The ACMV system for PBPI consists of two air-cooled chiller package, three air handling units, 19 fan coils, mechanical ventilation fans and water pumps distributed in the three floors.

The air-cooled chiller package system of the PBPI hall is YSCA 170 DRE from York air-conditioning manufacturer with a 97-ton capacity each. The units are equipped with air-cooled screw compressors. The building also has three air handling units from model YSM 40×60 that is also by York. The units are situated in the building as listed in Table 2. Also listed are the machine power requirements and their output capacities in cubic feet per minute (CFM). These values will be taken into calculations later on to understand the impact on expected thermal comfort.
The PBPI hall is fitted with two three-phase 51-kW pumps on the ground floor to distribute the water from the ground pipeline to the air handling units. Furthermore, there are mechanical ventilation units that generally is fixed to the wall to blow foul air in the bathrooms to the outside of the building as well as to maintain the temperature in hotter spaces where there are chillers and transformers. The ACMV system in PBPI has mechanical ventilation fans that are located at special points to provide proper ventilation in the building.

As stated earlier, the power demands for lighting can be decreased by the use of energy-efficient light fixtures. A lighting load that produces 350 lux can require between 6 W/m² and 30 W/m². Additionally, substantial savings may be accomplished by controlling the electric light according to occupancy i.e. the number of people that can be sensed in the space and according to daylight that can be utilised in that space. If we could reduce the power used for lighting from 30 W/m² down to 10 W/m², the power consumption can decrease by 75 kWh/m²/year. This is achievable if savings through the mechanical cooling and ventilation is considered as well.

After knowing the types of lamps for each space in a building, the current lighting system energy data can be analysed. The investigation involves the electricity usage of the academic building and comparison made for the particular period of time and the estimated total of the average cost of the academic building.

In this study, the PBPI hall is divided into several zones. For each zone in this building, the data from several sources like the machine power requirements can be used to calculate the amount of energy consumed during the observation period from 8.00 in the morning to 5.00 in the afternoon. An approximate total of the average energy cost in the hall can be calculated after gathering the energy consumption data from all the zones.

The type of bulbs used in the building is a fluorescent lamp. A fluorescent lamp usually requires a ballast, which is a component that manages the electric current used by the lamp. The ballast is used mainly for starting and for circuit protection. The device also uses up a lot of energy to function and some types have an efficiency that improves if the fluorescent lamp is left on for a long time. Energy-saving for current lighting units can be improved by the following measures.

- Replacing the lamps with one of lower wattage.
- Replacing the lamp ballasts if applicable.
- Changing lighting fixtures to types that are more efficient like the compact fluorescents.

### Table 2. The air-handling unit (AHU) in the PBPI building.

| Equipment   | Location   | Qty. | Power  (kW) | Power source                      | Flow (CFM) |
|-------------|------------|------|------------|-----------------------------------|------------|
| AHU-G-1     | Ground floor | 1   | 7.5        | 415/3ph/50Hz                      | 12191      |
| AHU-L1-1    | 1st floor   | 1   | 8.5        | 415/3ph/50Hz                      | 14257      |
| AHU-L2-1    | 2nd floor   | 1   | 8.5        | 415/3ph/50Hz                      | 13996      |

2.3. Data collection

There were several devices used in this work to collect readings. A CENTER 337 lux meter was used in the environmental check to read the levels of illumination and light monitoring in general. The handheld device has special sensors in the system that are capable to detect light rays like in human eyes.

Another apparatus is the air velocity meter that measures the force of air that flows into the device against a spring-loaded inlet. Then, a linear potentiometer that revolves together with air door measures
the inlet opening angle and sends a signal to the engine control unit or ECU in short. The reading is then corrected for air density based on its temperature and barometric pressure so as to reflect the air mass. Other than that, a measurement tape was also used to verify or to take extra measurements of the spaces being investigated. The Development Office of UTeM was kind to supply the building layout of the PBPI hall with various information especially the room areas and also the electricity bills for that particular building.

Next, an economic analysis was carried out that calculates the energy cost of the building. The estimation of the power cost is founded primarily on the ACMV cooling load value, lighting usage and the equipment by building operation hours per day. This analysis incorporates the current tariff rates based on the selling energy price from energy provider. Consequently, the total of the electricity cost per year could be determined for the calculation of the retrofitting cost and the simple payback period for saving purpose. Nevertheless, return on investment is not reported in this paper.

Previous work also explored the use of transfer function method (TFM) that can be used to estimate the building cooling load. The cooling load calculation process could most closely estimate the heat balance, which considers the cooling load temperature differences (CLTD), solar cooling load factors (SCL), and internal cooling load factors (CLF), to calculate cooling loads as an approximation of the TFM. Some of this is described in [19,20]. Rismanchi et al. [21] also suggested the use of ice thermal storage (ITS) as part of the building cooling system for offices in hot climate regions. They also detailed out the savings that could be achieved using this approach.

To a lesser extent, retrofitting was also studied in this work. The retrofit analysis focuses on ways to enhance energy efficiency in the building by recommending the installation or upgrading of existing equipment that could possibly decrease the total of energy consumption. At the end of retrofitting phase, there will be a simple payback period calculation to evaluate annual cost saving and cost of retrofitting.

3. Results and discussion

This section discusses the data collected and the result obtained from the calculation and sites walkthrough. All the data will be interpreted and discussed related to the case study building in this paper. The results of physical parameter measurement will be compared with the Malaysian Standards for future recommendation to evaluate their performance.

3.1. Experimental output

The collected data for electricity consumption for the duration of two years (Jul 2016 to Jun 2018) is presented in Figure 2. As the figure indicates, most of the energy consumption decreased significantly in the months when the classes are out for breaks and holidays.

![Figure 2. Monthly energy consumption between Jul-2016 into Jun-2018.](image-url)
The PBPI building was also divided into levels, where each level is divided into ten measuring points and the process of observation was conducted. The process observes the ACMV and Lighting specifications of every zone. The observation was divided into two main sectors, firstly, the survey of the ACMV and lighting system which include the types, power consumptions, number of operating hours, and number of parts. The second step involved with the measurement of the physical properties like the temperature, humidity, air velocity, CFM and lighting lux for each designated point in the PBPI hall. Table 3 lists the power consumed for ACMV and the lighting system of each level that obtained from the site survey for ACMV, lighting system and other equipment in details. Figure 3 depicts the results in a pie chart.

| Levels      | Power Consumption (kWh) |
|-------------|-------------------------|
|             | Lighting | ACMV | Others | Total  |
| Ground floor| 38.43    | 153.55| 20.108 | 212.088|
| First floor | 31.5     | 105.542| 14.056 | 151.098|
| Second floor| 34.461   | 165.048| 25.602 | 225.111|
| Total       | 104.391  | 424.14 | 59.766 | 588.297|

Figure 3. Pie chart representation of the energy consumption in the PBPI hall.

3.2. Other physical parameters
The aim of this section is to analyse data from the field measurements to determine and illustrate the real physical parameters conditions of the PBPI building. The fluctuation of the indoor air parameters and lighting lux.

Data collected show fluctuation of the average air velocity (m/s), average flow (CFM), average operating temperature (°C), average relative humidity (%) and average lighting lux in the PBPI building at different levels and at various times. This measurement has been conducted inside 10 different zones.
The average air velocity (m/s) on first floor has the lowest value 0.131 m/s at 9:00-11:00 am between the floors. The other two floors ground and second have the values 0.187 and 0.89 m/s respectively. The value in the ground floor was 0.201 m/s. The average flow in CFM in the ground floor at 3:00-5:00 pm was recorded as the lowest at 9.93 CFM and the first floor recorded the highest value at 11.58 CFM while the value in the second floor is 10.042 CFM.

For the temperature parameter, the ground floor recorded the highest value 23.75 ºC at 3:00-5:00 pm and second floors was recorded a lowest value 21.51 ºC. For average indoor air humidity, the first floor has the highest value (70.61%) at (12:00-2:00 pm) and lowest value in the second floor at 65.75%) in the interval of 9:00-11:00 am. The biggest average lighting lux value is 523.9 lux that was recorded in the second floor at the 3:00-5:00 pm interval, while the ground floor recorded 354.2 lux in between 12:00-2:00 pm. The average readings for the whole building can be summarised in Table 4.

| Physical Parameters         | Average | Malaysian Standard MS 1525 |
|----------------------------|---------|---------------------------|
| Average air velocity (m/s) | 0.1764  | 0.15 – 0.5                |
| Average air flow (CFM)     | 9.8755  | 8 – 10                    |
| Average temperature (ºC)   | 22.758  | 24 – 26                   |
| Average relative humidity (%) | 68.306 | 50 – 70                   |
| Average lighting intensity (lux) | 461.422 | 300 – 500                |

3.3. The building energy index
The calculation of the Building Energy Index (BEI) is simply based on the annual electric power usage over the total area of the building. The equation is as follows.

\[
BEI = \frac{\sum\text{Energy consumed per year}}{\sum\text{Building Area}}
\]  

(1)

During the first year, the total consumption was 770230 kWh and the total area is 5992.58 m². Hence, the BEI is 128.53 kWh/m²/year. The results show that the Malaysian standards for BEI for the PBPI Building for the 2016-2017 period is lower than the maximum range of the MS1525.

The second year of 2017-2018 saw an increase to 824240 kWh. Therefore, the BEI becomes 137.55 kWh/m²/year. This is a little higher than the 135 kWh/m²/year value recommended in the MS 1525:2014. The increase could be attributed to the increase in the number of students, activities, or even regional ambient temperature during that period being studied.

3.4. Retrofitting and its savings
In this phase, many changes could be suggested with the aim to save money through decreasing the energy consumption. Table 5 lists the recommendations of fixtures and the reduction in energy use that is predicted. The economic implication from this action could result in the savings of about RM 47,000 per year.

Other than that, further savings can be reached if the temperature for the air-conditioning is set within the range of 24 – 26 ºC as advised in MS 1525:2014. Currently, the temperature setting is about
23°C. However, further this may take into account the ambient temperature outside the building as well as the effects of global warming is becoming more prevalent. Other equipment like the chillers and fans or blowers should also be maintained regularly to ensure they are working accordingly.

Table 5. Predicted energy savings by retrofitting in the PBPI hall.

| Floor  | Energy before retrofit (kWh) | Suggested actions | Energy before retrofit (kWh) |
|--------|------------------------------|-------------------|-----------------------------|
| Ground | 38.43                        | • Change TL-D 36 W to 18 W High Efficiency fluorescent lamps (TL5) | 15.540 |
| First  | 31.5                         | • Change to 8 hours operational time (1 hour – switching off during break time). | 12.852 |
| Second | 34.461                       | • Maintain 18 W recessed channel fluorescent fitting (TL-D 18 W) | 14.784 |
| Total  | 104.391                      | • Incorporate smart sensors to detect human presence in the space. | 43.176 |

4. Conclusion
An energy audit is proven to be an effective tool to determine energy utilisation and to understand the energy consumption in a building. Nonetheless, there are challenges in auditing that include the absence of separate metering devices for individual loads. Most the building has only one installed power meter in order to measure energy consumption for whole building. Based on the results obtained by energy audits conducted in this paper, existing ACMV system was found to be the main contributor to the total energy usage at 72%. It is followed by the lighting, demanding about 18% of total energy used. Other appliances and equipment consumed only 10%.

This result reveals the importance of taking actions to reduce energy consumption. There are several recommendations to reduce the energy consumption and enhance it that include improving the physical properties of building components and materials, setting higher air-condition temperature, reconsidering low occupant areas and installing occupant sensors that switch a lamp for various spaces within the PBPI hall, especially the classrooms and language laboratories.

Acknowledgments
The authors would like to thank various parties in UTeM for helping in the data taking at the facility and for providing electricity usage data. This work was also presented in the poster as well as a two-page article at the Sixth Mechanical Engineering Research Day 2019 (MERD’19). The proceeding could be found at http://www3.utm.utm.my/care/proceedings under the ID 122. This is based on the graduate work by Alhammali at UTeM.

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