A Preliminary Analysis of Energy Consumption in Academic Buildings

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Abstract. Current technological advancement and pressing environmental issues emphasise the need for better energy management to minimise wasting depleting resources. Energy consumption can generally be divided into two, namely residential and commercial. Commercial energy consumption involves commercial buildings that include, but not limited to, banks, hotels, offices and academic buildings. While awareness on optimising energy use is more evident now, there is still a lack of understanding of the parametric values that are crucial in analysing the energy consumption of a commercial building that is unique to the building’s function. This study aims to identify the relationships between a number of identified variables and the overall building energy consumption. The study intended to become the preliminary case study in identifying the correlations between selected variables and energy consumption. The analysis was carried out using covariance matrix on identified variables such as electricity consumption, user traffic, and maximum outdoor temperature. This study identified positive relationships between electricity consumption, user traffic, and maximum outdoor temperature.

1. Introduction
For the past half a century, we have seen the growth of buildings, especially in main cities or urban areas where human populations are the densest. Buildings consume large volume of energy in order to maintain their indoor temperature, ensuring its occupant comfort [1]. However, excessive energy consumption raised concern about its detrimental effect to the environment [2]. It is common to see buildings activating their energy resources to the full capacity, despite having less human traffic in the building. This is more evident for buildings aged 20 years or more, which did not have many feasible building’s automation options during the time they were built. With the pressing environmental issues, organisations such as the International Energy Agency (IEA), European Union (EU) and The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) proposed standards and guidelines to emphasise better energy consumption practice for buildings. These include identifying appropriate controls based on influencing variants such as occupancy behaviour and outdoor temperature.

Effective building energy management requires a thorough understanding of the conditions of the building. This is especially true for old building. There is a need to gather data related to energy consumption and occupants behaviour in order to better understand the correlation between known variants. Both energy consumption and occupancy behaviour could vary depending on the functions of the interior spaces in the building [3]. For example, a section of an academic building could function fully as the staff’s offices or a combination of functions such as staff’s offices on one floor and classrooms on another. In the situation where building functions as the staff’s offices only, it is safe to
assume that the energy is fully utilised given that the staff are usually required to be in the offices during workday, generally from nine to five. However, the same cannot be assumed when partial spaces in the building are used as classrooms. Some classrooms are only utilised once or twice a day, at a period of one to three hours maximum per use. As most of the old buildings are supported by centralised cooling system and lighting, this could lead to waste. Regardless, assumptions on the correlation between energy consumption and occupants’ behaviour need to be supported by formulation or mathematical proof for validation.

In this study, a number of information related to the energy consumption of three academic buildings at an institution of higher education in Malaysia is gathered. The main aim of the study is to verify the impact of the selected variables on the electricity consumption of the buildings. To achieve this, covariance analysis is selected and reviewed in order to identify the relationships between the variants. The data are gathered from the billing information, the recorded occupants’ attendance and the classroom hour usage of the three selected buildings. The three buildings have various functions ranging from offices, classrooms, laboratories, students and resource centres. Observation is carried out on monthly basis, from January 2019 to November 2019. Apart from identifying the correlation between the selected variables and the electricity consumption, this study intends to understand the size of data that is useful for good analysis.

This study would be a preliminary case study for energy analysis on campus buildings in Malaysia. This paper is segmented into six main sections. Section 1 provides introductory to this study, issues faced and the motivation behind the building energy analysis. Section 2 provides an overview on energy analysis, segmented into three different types of commercial buildings namely office, hotel and academic building. Section 3 describes the building under study while section 4 elaborates on the methodology, which includes forming the initial hypothesis and the utilisation of covariance matrix to observe relationships between identified variants. Section 5 discusses the findings of the covariance matrix analysis. Finally, section 6 concludes the overall findings of the study and proposes possible future work.

2. Overview of Energy Analysis

Commercial buildings have varied individual uses, functions and occupancy patterns. Occupants’ movements in a building could have a massive impact on the overall energy use in a building [4]. Hence, analysis is more reliable when the components are expanded to consider geographic location, building’s function and user’s behaviour. The following list refines the focus of analysis components deemed crucial in building energy efficiency (BEE).

(1) Geo location and building function. It is vital to identify the climate condition where the building is located. Building functions are generally used to roughly estimate user traffic in the building. Indoor sensing and monitoring should be based on the types of the building and the functions of specific areas in the building.

(2) Indoor and outdoor temperature. Surrounding outdoor temperature could heavily impact the indoor energy use of a building.

(3) Analysis on the occupancy behaviour. Profiling energy use based on the user traffic in the building is important as any action taken to optimise the energy use should not create discomfort to users. While BEE generally focuses on reduced energy use, approaches to achieve the optimisation actions could vary due to different building traffic.

Subsequent subsections will review studies related to energy analysis for three types of commercial building, namely office, hotel and academic building.

2.1. Office Building Energy Analysis Review

Office buildings are dedicated spaces commonly used by organisation(s), be it public or private, to conduct business activities. According to United States Energy Information Administration (EIA), office buildings are among the highest energy consumers for 2012 [4]. Authors in [5] utilise energy informatic components to evaluate energy performance and present the importance of studying their impact to the buildings in the long term, apart from coordinating multiple related agencies/organisations, in order to truly realise the low carbon and energy efficient building initiatives
in United Kingdom. Energy analysis study is carried out for office buildings in United States based on the positioning of windows in the buildings in different climate regions [6].

2.2. Hotel Building Energy Analysis Review
Hotels are common buildings that exist in every main city in the world. Large scale hotel usually consumes large volume of energy to maintain the comfort level services that suit their guests’ preferences. Study in [7] investigates energy performance of five-star hotels in China using questionnaires. Energy modelling is formulated based on gathered information such as the types of occupant in the buildings, various space functions, the climate of the region where the buildings are located at and the source of energy consumption. Meanwhile, Nigeria is dependent on the localised energy generation to maintain its main business operation, including hotels. Hence, study by [8] formulates an energy consumption model and carbon footprint threshold as guidelines for hotels in Nigeria.

2.3. Academic Building Energy Consumption
United States EIA reported that commercial buildings built for education sectors contribute to ten percent of the total consumption in 2012 [4]. Academic building comprised of classrooms, offices, communal areas, and activity centres, among others. Certain areas in academic buildings, such as library, operate for 24 hours and seven days a week, especially during active semester. Some academic buildings are built to retain more than a decade without major modification. Authors in [9] investigate the relationship between energy consumption and the level of occupant’s comfort and indoor air quality (IAQ) in an academic building in France. The paper proposes formulation of the best energy management strategy that is unique to occupants’ comfort in the building. Occupants’ indoor comfort is vital, apart from optimising BEE, as highlighted in [10]. Principal component analysis (PCA) is seen used in [11] to analyse energy use for three different buildings in Spain.

3. Buildings Under Study
The three buildings under study cover an area of more than 18,000 square metres where each building is interconnected to one another. Each of the buildings has a combined functionality as classrooms, offices, students and resource centres. As this study looks into electricity consumption ranging from January 2019 to November 2019, the term calendar during the selected months is acquired to better understand its impact on the electricity consumption. Table 1 summarises the term activity from January 2019 to November 2019.

| Month    | Term Activity                  |
|----------|--------------------------------|
| January  | Class and Exam                 |
| February | Semester Break                 |
| March    | Special Semester               |
| April    | Exam                           |
| May      | Semester Break and Class       |
| June     | Class and Semester Break       |
| July     | Class                          |
| August   | Class                          |
| September| Exam and Semester Break        |
| October  | Semester Break and Class       |
| November | Semester Break                 |

Figure 1 illustrates the electricity distribution between the three buildings. As shown in the figure, there are two main distribution boxes (main DB) supported by the main switch board. Main DB provides electricity support for the biggest building among the three buildings, while, Main DB 2 provides electricity for the other two smaller buildings.
4. Methodology

Analysis is carried out from two perspectives. Initial analysis studies the impact of each selected variable to the electricity consumption based on generated graphs. Subsequently, further analysis is carried out using covariance matrix to understand the effects of each variable to electricity consumption. Due to the limitations of the gathered data at the moment, further analysis using PCA will not be carried out in this study. Instead, PCA will be applied in the extended study later when more data of the buildings are gathered.

4.1. Data Collection

Data gathered for this study include monthly electricity consumption of the three buildings. Since two buildings share the same main DB, there are two separate electricity consumption readings. Apart from this, this study managed to acquire data in regard to monthly students’ access to one of the buildings. The access is separated into two areas, namely main entrance to the resource centre and the 24-hour area. Classroom schedules for another two buildings are also gathered for the study. In addition, this study looks into the monthly peak outdoor temperature to observe any impact of the temperature on the electricity consumption.

Due to the dynamic nature of some of the data gathered, first analysis will be direct analysis from graph observation. Part of the analysis will be tested with covariance matrix to further verify the dependencies of the selected variables. This study specifies initial hypotheses, to be verified in the findings and analysis section. They are:

- Null Hypothesis, $H_0$: building electricity consumption is directly related to the occupancy behaviour in the building.
- Alternate Hypothesis, $H_1$: building electricity consumption is directly impacted by the peak outdoor temperature.

4.2. Covariance Matrix

In mathematics, matrix is commonly used to understand linear relationships of a fixed variable sets. For example, a set of equations as shown below. Note that the multiplier values in the equations are specified generically for the purpose of explanation.

\[
2a + 3b + 5c = 7d \tag{1}
\]
\[
a + 4b - 5c = -10d \tag{2}
\]

In this example, $a$ is sample variable to indicate electricity consumption, $b$ indicates user traffic pattern at the main entrance of the building, while $c$ indicates user traffic pattern the 24-hour access area and $d$
is for the maximum outdoor temperature of the months. Note that the values set in the equation are just an example and do not represent the real values in this study. Transforming the linear presentations in (1) and (2) into a matrix form gives us the following.

\[
\begin{bmatrix}
2 & 3 & 5 & 7 \\
1 & 4 & -5 & -10
\end{bmatrix}
\]

(3)

For the given sample values, we first find the mean and the standard deviation of every variable, i.e. \(a, b, c,\) and \(d,\) using the following formula.

\[
\mu = \frac{\sum x_i}{n}
\]

(4)

\[
\sigma = \sqrt{\frac{\sum (x - x_o)^2}{(n - 1)}}
\]

(5)

Before covariance valuation is carried out, the matrix is standardised by subtracting the original value with the calculated mean, divided by the standard deviation. This is done based on equation (6).

\[
Z = \frac{(X - \mu)}{\sigma}
\]

(6)

The covariance matrix is calculated by multiplying standardised matrix \(Z\) with the divided, transposed standardised matrix \(Z,\) i.e. \(Z^T.\) This is shown in equation (7). The result yields positive and negative values that will be further discussed in the next section.

\[
V = Z \times Z^T \times (1/n)
\]

(7)

5. Analysis and Findings

Analysis from the gathered data are looked upon from a number of different perspectives. First, data gathered from Building 1 (the largest building) is represented in a form of graph presentation, as shown in Figure 2. The figure displays electricity consumption pattern for Building 1 in comparison to the occupancy behaviour of the building’s main entrance access and 24-hour area access. The main entrance is accessible to the students from 8.30 a.m. until 10 p.m. and to staff from 8 a.m. until 6 p.m.

![Figure 2. Electricity consumption vs. occupancy behaviour for Building 1](image-url)

The cooling system in the building is centralised and automatically switched off at the pre-set time. Outside 8.30 a.m. until 10 p.m. time frame, the 24-hour area temperature is maintained using high volume low speed (HVLS) fans. While it is clear that the graph disproves the null hypothesis, \(H_0,\) there are two outcomes from the analysis. First, more relevant data need to be collected and focused
interviews need to be carried out with the building managers. Second, this pattern can serve as a basis for proposing better building energy management. Figure 3 displays the graph pattern of the electricity consumption over hourly class use for the other two building, Building 2 and 3. Building 2 and 3 generally function as classrooms for students during semester terms. However, these two buildings are also used as offices and laboratories. The graph has shown indication that follows null hypothesis, H₀. However, similar to Building 1, more data need to be gathered to better observe the pattern. From the graph, the month of January has shown peak electricity use which is directly proportional to the hourly classroom use. In the month of February, the hourly use is low and has shown quite low electricity consumption. Meanwhile, Figure 4 illustrates the impact of peak outdoor temperature towards electricity consumption. The graph shows the highest peak temperature is in March 2019. However, the electricity consumption in the said month is the lowest. Standard variation of the peak temperature in March 2019 is 1.26, which means that the temperature does not vary much within the days of the month. While one can easily assume from the observation that the alternate hypothesis, H₁, is not fulfilled, more data is again needed to verify this assumption.

Figure 3. Electricity consumption vs. hour usage for Building 2 and 3

Figure 4. Electricity consumption vs. outdoor temperature for Building 1

Figure 5 illustrates the peak outdoor temperature versus electricity consumption for Building 2 and 3. Similar to the previous figure, the graph does not seem to show correlation pattern between the peak outdoor temperature and the electricity consumption. While this means that alternate hypothesis is not accepted in this study, it also means that bigger data set is needed to properly test the theory.

Figure 5. Electricity consumption vs. outdoor temperature for Building 2 and 3

To further verify the relationships between the proposed variables, analysis based on covariance matrix is carried out. The covariance calculations yield the output that indicates there is correlation between building electricity consumption and the occupancy of the main entrance and the 24-hour area in building 1. The values obtained are 0.47 and 0.37 respectively. The values fall within the acceptable covariance matrix, namely [0,1]. The values verify the relationship between the selected variants. However, improvement on the data volume is needed to ensure the calculated covariance value reaches
6. Conclusion
This paper presents the preliminary study on academic building energy consumption in relation to occupancy behaviour and peak outdoor temperature. The analysis carried out leads to a number of outcomes. The verification process is not yet complete. More extended study is needed with larger data sets to enable accurate observation. However, this study is expected to be the preliminary study that will be the stepping stone to in-depth analysis of energy consumption in academic building. Future work includes an extensive interview session with building managers to better understand the consumption pattern, more data collection with the aid of additional sensing mechanisms, and extended analysis on the correlation pattern using PCA or other more meaningful analysis methods.

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