Feasibility analysis of rooftop solar photovoltaic for non-academic building in an educational institution in Malaysia

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Abstract. An educational institution is one of the sectors that consume a high amount of energy. An identify the energy consumption gives information to forecast the energy saving. The research aims to utilize rooftop solar photovoltaic (PV) at non-academic buildings in Malaysia's educational institution. A detailed energy audit has been conducted at Politeknik Sultan Azlan Shah (PSAS) involving three non-academic buildings to identify the buildings' energy usage. The three different building involved is the Islamic Centre (Mosque), Sports Centre, and Multipurpose Hall. The energy audit analysis is divided into four end-load groups comprising lighting, fans, air conditioning, and other equipment to identify each type of load's energy consumption. Which equipment consumes the highest amount of energy in non-academic buildings in PSAS is determine. The results show that the highest energy consumption at the Islamic Centre and Multipurpose Hall is an air conditioner for a while Sports Centre is lighting equipment. Annual power generation and energy bill savings are calculated based on rooftop solar PV installation for self-consumption. From the feasibility analysis, the forecast of energy-saving for at-least 5% per year has been estimated. It significantly reduces the amount of carbon emission release to the environment.

1. Introduction

World Energy Outlook stated that reducing global emissions should be a priority. Malaysia committed to achieving reducing greenhouse gases (GHGs) emission intensity of Gross Domestic Product (GDP) by up to 45% by 2030 compared to the 2005 level [2]. To achieve the target of reducing the nation's carbon emissions, focus on a renewable source is imperative [3]. Electricity is identified as the highest energy consumed in Malaysia by commercial office buildings by about 40% [4]. Office building refers to government buildings where is including institutions of higher learning [5]. Rahman et al. found that energy consumption at large office buildings in Malaysia reveals that significant energy users are air conditioners, where about 57% [6]. The research by Getu et al. [7] concludes that reducing gas emissions on campus is proportionally related to reducing energy consumption at its premise. Leonardo et al. [8] conducted a study about evaluating greenhouse gas emissions at the university in Chile and preparing proposals to reduce gas emissions at their campus. This study stated this university already signed a Cleaner Production Agreement with the National Agency for Cleaner production in Chile. One of the objectives of this agreement is to measure the output of greenhouse gas emissions. The investigation about energy consumption at the campus through an electricity audit is significant for achieving a sustainable environment. The energy audit by focusing on energy consumption per equipment such as
lamps, cooling, water heating, and other equipment has been conducted by Escobedo et al [9] at Mexico university.

Reducing energy consumption in government buildings and installing a solar power generation system is currently the most widely used in the building sector [10]. The research conducted by Ruben et al. [11] stated most universities in Indonesia applied an off-grid solar energy system. In this research, the author presents the feasibility analysis of photovoltaic power installation using HOMER software. Installing solar power generation in the off-grid mode system is a practical solution for reducing campus energy consumption. This paper will analyze data as the same as the previous research conducted by [12], but using a different methodology to analyze the data. The energy forecast has been estimated using the energy audit data without using HOMER software [11]. A research conducted by [13], where the authors focus only on the photocopier machine in the academic building at PSAS without exploring the other types of equipment to evaluate more details.

The research aims to analyze the potential of energy savings through 4 end-load groups located at the non-academic building in PSAS. The four end-load groups are comprising lighting, fans, air conditioning, and other equipment. The feasibility analysis was calculated using the energy audit data of 4 end-load groups of equipment at non-academic buildings, assuming the building's rooftop already installed with the solar power generation system. The Implementation of feasibility analysis through the solar energy system for energy-saving purposes was confirmed to have a significant environmental impact on the PSAS.

2. Methodology

2.1. Energy audit

The process of collecting data follows the methodology applied by [14], where energy audit has been conducted in 3 non-academic buildings in PSAS. Three non-academic building involved in this research is the Islamic Centre (IC), Sports Centre (SC), and Multipurpose Hall (MH). These buildings were chosen because of the operating time during office hours and at night and weekend days. Though this building is not an academic building, it is amongst the building in PSAS that contributes to the total high energy-consuming. The estimation of energy consumption per equipment can help to identify which type of equipment uses high energy. Most researchers [9, 13, 15] use energy audit techniques to determine energy use for every single building. In this research, the equipment types that use the highest energy in a non-academic building are identified through energy audits per equipment. The energy audit process collects information about types of equipment, quantity, power, and operating hours. The energy audit analysis is divided into four end-load groups comprising fans, lighting, air conditioning, and other equipment. Table 1, Table 2, and Table 3 show the types of equipment, quantity, power, and operating hours by referring to the academic calendar PSAS 2019 at IC, SC, and MH.

Table 1. Summary of types of end load, a total of quantity, rating power, and operating hours for normal routine activity at IC

| No | End-load          | Quantity | Total Power (kW) | Average Operating Hour (h/year) |
|----|-------------------|----------|------------------|-------------------------------|
| 1  | Fan               | 52       | 0.45             | 708                           |
| 2  | Lighting          | 205      | 0.086            | 828                           |
| 3  | Air-conditioning  | 17       | 5.59             | 708                           |
| 4  | Other equipment   | 10       | 3.84             | 1886                          |
|    | Total             | 284      | 9.97             | 4130                          |
Table 2: Summary of types of end load, a total of quantity, rating power, and operating hours for normal routine activity at SC

| No | End-load         | Quantity | Total Power (kW) | Average Operating Hour (h/year) |
|----|------------------|----------|------------------|--------------------------------|
| 1  | Fan              | 54       | 0.21             | 708                            |
| 2  | Lighting         | 139      | 0.754            | 708                            |
| 3  | Air-conditioning | 17       | 5.59             | 708                            |
| 4  | Other equipment  | 34       | 7.22             | 1634                           |
|    | TOTAL            | 244      | 13.77            | 3758                           |

Table 3. Summary of types of end load, a total of quantity, rating power, and operating hours for normal routine activity at MH

| No | End-load         | Quantity | Total Power (kW) | Average Operating Hour (h/year) |
|----|------------------|----------|------------------|--------------------------------|
| 1  | Fan              | 21       | 0.20             | 708                            |
| 2  | Lighting         | 199      | 0.50             | 828                            |
| 3  | Air-conditioning | 12       | 26.87            | 708                            |
|    | Total            | 232      | 27.57            | 2242                           |

2.2. Equations (estimation calculation)

The estimated energy consumption per year for end-load equipment located in the non-academic building PSAS has been calculated based on equation (1) [14, 16]

\[ EC = P_r \times H_o \times L_f \] (1)

EC is representing estimation energy consumption per year in kWh, \( P_r \) is the power of equipment in kW, \( H_o \) is estimated operating hours annually, \( L_f \) is the loading factor of equipment.

In this research, all the loading factors for end-load equipment will be considered ideal and set to 1 for calculation [16]. The estimated operating hours for lighting and air-conditioning have been calculated by assuming the total active hour per day in routine is 8 hours. However, not all the equipment is ON at the same time. The number of days the electrical equipment is ON condition for one year is calculated based on 32 weeks of lectures plus the other four weeks for the final examination. The estimation of annual energy saving for end-load equipment in the PSAS is calculated using the following equation (2)

\[ AES_L = P_r \times H_{avg} \times R_p \] (2)

where \( AES_L \) is the energy-saving estimation of per year in kWh, \( P_r \) is the power of electrical equipment in watt, \( H_{avg} \) is an operating hour operation by year, \( L \) is the loading factor of electrical equipment, and \( R_p \) is a percentage of electrical equipment replacement. Energy-saving for electrical equipment has been calculated based on the rate of different replacement quantities or percentage energy supplied by solar energy. Annual bill savings using solar energy power generation is calculated using the following equation in (3) [14]

\[ ABS = AES \times E_c \] (3)
Where ABS is annual bill savings (RM), AES is annual energy saving (kWh), and Ec is the average energy cost (RM/kWh). Tariff rate for PSAS refers to tariff C1 for medium voltage general commercial tariff.

3. Results and Discussion
Analysis of energy audit data for end-load equipment has been conducted in 3 non-academic buildings. The quantity of equipment, power rated (kW), operating hours, energy consumption, and energy bill, is also recorded and calculated. The energy consumption and energy bill for all types of end-load in 3 non-academic buildings have been computed by year using equation (1). The calculation estimation of energy bills using the TNB tariff rates category C1. The tariff under medium voltage general commercial category using one rate for all kWh per month at a charge rate of RM0.365 [17].

3.1 Energy consumption and energy bill
Using the data from Tables 1, 2, 3, and calculated using equation (1), then the details of total energy consumption and energy bills for five types of lighting are shown in Tables 4, 5, and 6 respectively for IC, SC, MH. Table 4 summarizes energy consumption and energy bill by year for Islamic Centre, where this building has a 26” industrial stand fan, 26” industrial wall fan, and 16” wall fan. The type of light has been audit in this building, only T8 36W, and downlight. Four kinds of capacity were audited for air-conditioning, such as 1hp, 1.5hp, 2hp, and 5hp. The audit results revealed seven other types of equipment available at the Islamic Centre, such as water dispensers, refrigerators, vending machines, CCTV cameras, freezer, television 50”, and PA systems. According to the person in charge at IC, three regular programs are held, such as Maghrib lectures, Prime lectures (Monday and Thursday), and Friday prayers. During this program is running and mostly the end-load are operated in almost full capacity. The estimation of average operating hours has been calculated using this information.

| No | End-load               | Quantity | Total Power (kW) | Energy consumption/year (kWh) | Energy bill/year (RM) |
|----|------------------------|----------|-----------------|-------------------------------|-----------------------|
| 1  | Fan                    | 52       | 0.45            | 6,173.76                      | 2,253                 |
| 2  | Lighting               | 205      | 0.086           | 8,405.86                      | 3,068                 |
| 3  | Air-conditioning       | 17       | 5.59            | 20,325.26                     | 7,419                 |
| 4  | Other equipment        | 10       | 3.84            | 12,747.60                     | 4,653                 |
|    | **Total**              | **284**  | **9.97**        | **47,652.48**                 | **17,393**            |

Table 5 summarizes energy consumption and energy bill by year for Sports Centre, where this building has a Ceiling fan, Exhaust Fan, and 16” Wall Fan. The type of light has been audit in this building, only T8 36W, T8 16W, high bay light, and spotlight. While for air-conditioning, consists of 4 types of capacity are audited, such as 1hp, 1.5hp, 2hp, and 2.5hp. The audit results revealed 11 other types of equipment available at the Sports Centre, such as water dispenser, track mill fitness, indoor exercise bike, and PA system. Among the audited places are the Gym, Squash Room, Modern Music Studio, and Futsal Court.
### Table 5. Summary of energy consumption and energy bill for four end-loads in SC

| No | End-load          | Quantity | Total Power (kW) | Energy consumption/year (kWh) | Energy bill/year (RM) |
|----|-------------------|----------|------------------|-------------------------------|-----------------------|
| 1  | Fan               | 54       | 0.21             | 2,329.32                      | 850                   |
| 2  | Lighting          | 139      | 0.754            | 7,283.90                      | 2,659                 |
| 3  | Air-conditioning  | 17       | 5.59             | 16,631.63                     | 6,071                 |
| 4  | Other equipment   | 34       | 7.22             | 9,352.80                      | 3,414                 |
|    | **Total**         | 244      | **13.77**        | **35,597.65**                 | **12,993**            |

Table 6 summarizes energy consumption and energy bill by year for Multipurpose Hall. The energy audit in this building only for three end-loads without involving other equipment like in the Islamic Centre and Sports Centre. This building only has a wall fan type without involving other different types of fans. Five types of lamps have been audited in this building; T8 36W, T8 16W, Compact Fluorescent lamp 24W, Metal Halide 400W, and Ttube 18W. Four types of capacity are audited for air-conditioning, such as 1hp, 2hp, 2.5hp, and 10hp. In PSAS, only Multipurpose Hall has 10hp air-conditioning in its building. Besides that, it also not involving end-loads under type "other equipment" in the auditing process.

### Table 6. Summary of energy consumption and energy bill for three end-loads in MH

| No | End-load          | Quantity | Total Power (kW) | Energy consumption/year (kWh) | Energy bill/year (RM) |
|----|-------------------|----------|------------------|-------------------------------|-----------------------|
| 1  | Fan               | 21       | 0.20             | 2,973.60                      | 1,085.36              |
| 2  | Lighting          | 199      | 0.50             | 11,527.42                     | 4,207.51              |
| 3  | Air-conditioning  | 12       | 26.87            | 44,853.49                     | 16,371.53             |
|    | **Total**         | 232      | **27.57**        | **59,354.51**                 | **21,664.40**         |

3.2. Highest energy consumer

Based on the analysis conducted on three non-academic buildings, the total energy consumption estimation of end-load per year is about 142,727 kWh. The energy bill per year is about RM 52,050. The analysis also helps to identify which equipment uses the highest amount of energy in the buildings involved. From the analysis of energy consumption per equipment, it was found that the air conditioning has identified as the highest energy consumption among the three non-academic buildings is audited. The amount of total energy consumption for air conditioning is about 81,810.38 kWh. It is about 57% of the whole energy consumption at three buildings involved.

3.3. Feasibility analysis of clean power generation system

The feasibility analysis has conducted at three non-academic buildings in IC, SC, and MH. The research undertaken by assuming at the roofs of these buildings has been installed in the solar photovoltaic (PV) system. The energy-saving potential in these three buildings has calculated by considering energy supplied come from solar PV. In this research, the power generated by rooftop solar PV is using for self-consumption only [18]. The power generated is an off-grid type and entirely for itself without transfer the produced energy to the grid system. An energy-saving (kWh) and bill saving (RM) per year for the end-load involved has been calculated. The feasibility analysis has conducted using a solar PV monocrystalline module 340W. Assuming the average of the peak sun hour for Malaysia is 4 hours, one solar panel is generating 1.36 kWh per day and about 40.8 kWh per month. Based on Table 4, the energy consumption for end-load in IC is 47,652.48 kWh per year, and the energy bill is RM 17,393 per year. It means the energy consumption is about 132 kWh per day, and the energy demand for end-load in IC
is approximately 33 kW per day. By assuming the panel solar PV has an efficiency of 80%, the solar panel generates power energy of about 38,122 kWh based on energy consumption per year. In IC, the total number of panels solar to install for covered the total energy consumption in this building is 97 units.

According to Table 5, the energy consumption for end-load in SC is 35,597.65 kWh per year, and the energy bill is RM 12,993.32 per year. It means the energy consumption is about 99 kWh per day, and the energy demand for end-load in SC is approximately 25 kW per day. In SC, the total number of solar panels to install for covered the total energy consumption in this building is 73 units. Table 6 shows the energy consumption and energy bill per year in MH are about 59,354.51 kWh and RM 21,664.40, respectively. It means the energy consumption is about 165 kWh per day, and the energy demand for end-load in SC is approximately 30 kW per day. The total number of solar panels to install for covered the total energy consumption in this building is 121 units. Using the data from Tables 1, 2, and 3 and calculated using equations (2) and (3) then the total energy saving and energy bills per year are shown in Tables 7, 8, and 9 respectively for IC, SC, MH. The forecast for energy-saving and bill saving has been calculated for three years based on the percentage of increment for energy supplied by rooftop solar PV starting from 5% to 15%. The 5% value is chosen based on a Malaysian Polytechnic POLYGreen Blueprint 2015 [19]. It stated that all the polytechnic institutions in Malaysia must reduce their utility costs by at least 5% per year. The percentage represents the forecast energy savings for 2020 to 2022 years.

| Table 7. Forecast for energy and bill saving per year at IC by install rooftop solar PV |
| --- |
| **Energy supplied by solar** | **Energy-saving per year (kWh)** | **Bill saving per year (RM)** |
| 5% | 2,383 | 870 |
| 10% | 4,765 | 1,739 |
| 15% | 7,148 | 2,609 |

| Table 8. Forecast for energy and bill saving per year at SC by install rooftop solar PV |
| --- |
| **Energy supplied by solar** | **Energy-saving per year (kWh)** | **Bill saving per year (RM)** |
| 5% | 1,780 | 650 |
| 10% | 3,560 | 1,299 |
| 15% | 5,340 | 1,949 |

| Table 9. Forecast for energy and bill saving per year at MH by install rooftop solar PV |
| --- |
| **Energy supplied by solar** | **Energy-saving per year (kWh)** | **Bill saving per year (RM)** |
| 5% | 2,968 | 1,083 |
| 10% | 5,935 | 2,166 |
| 15% | 8,903 | 3,250 |

Figures 1 and 2 illustrate the forecast for energy-saving and bill saving per year at MIC, SC, and MH if PSAS installs rooftop solar photovoltaic by setting for self-consumption. The estimate for energy-saving for three buildings involved starting in 2020 is about 7,131 kWh. The graph shows that through increase the percentage amount of energy supplied by solar will decrease energy consumption provided by TNB and directly save the bill. The rooftop solar power generation system consists of PWM solar charge controller 12/24V, where the energy produced by solar PV is stored in the battery sealed lead acid 12V 330Ah. The output from the battery will convert by 3000W inverter 12V 330 Ah.
Figure 1. Forecast for energy saving per year at IC, SC, and MH by installing rooftop solar PV

Figure 2. Forecast for bill saving per year at IC, SC, and MH by installing rooftop solar PV
3.4. Carbon Emission Reduction

The installation of solar PV at the PSAS building can reduce the number of carbon emissions to the environment. The potential reduction of carbon emissions CO2 is shown in Tables 10, 11, and 12, respectively, for IC, SC, and MH. The energy generated by this PV solar system is similar to the energy savings obtained by the buildings involved. The CO2 reduction calculation in PSAS is calculated by multiplying the total energy savings per year by an emission factor of 0.693 kg CO2 per kWh [20].

| Table 10. CO2 reduction per year for IC |
|----------------------------------------|
| Energy supplied by solar (kWh) | CO2 reduction (kg of CO2) |
| 2,383 | 1,651 |
| 4,765 | 3,302 |
| 7,148 | 4,954 |

| Table 11. CO2 reduction per year for SC |
|----------------------------------------|
| Energy supplied by solar (kWh) | CO2 reduction (kg of CO2) |
| 1,780 | 1,234 |
| 3,560 | 2,467 |
| 5,340 | 3,701 |

| Table 12. CO2 reduction per year for MH |
|----------------------------------------|
| Energy supplied by solar (kWh) | CO2 reduction (kg of CO2) |
| 2,968 | 2,057 |
| 5,935 | 4,113 |
| 8,903 | 6,170 |

4. Conclusion

Based on the analysis, the total energy consumption estimation of end-load in 3 non-academic buildings in this research is about 142,727 kWh. The energy bill per year is about RM 52,050. The energy consumption analysis per equipment found that the air conditioning is the highest energy consumer for all buildings involved. The amount of total energy consumption for air conditioning is about 81,810.38 kWh. It is about 57% of the whole energy consumption at three departments involved. The installed building at PSAS with rooftop solar PV where the supporting energy supplied by solar just 5% can avoid 4,942 kg of CO2 from released into the air in 2020.

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