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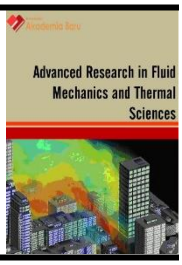

Energy Profiling of a Plant Factory and Energy Conservation Opportunities

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ABSTRACT

Precision farming is one of the important areas to ensure food security by coping with climate change and increase farmer's productivity. Plant factory is one of the aspects of precision farming and recently sought attention among modern farmers in Malaysia. While ensuring continuous supply of crops throughout the year with increased quality and yield, plant factories consume large amount of energy to maintain their micro-climatic condition. This paper presents the energy consumption profiling of a plant factory, owned by Malaysian Agricultural Research and Development Institute (MARDI) in Serdang, Malaysia. This study is important to establish the status quo of consumption pattern of the plant factory towards reducing the energy consumption. Hence, energy audit was carried at the plant factory for duration of 2 weeks. From the audit it was found that the energy was distributed as follows: Air conditioning system - 51%, LED - 36%, pump - 3% and others - 10%. Finally, suitable energy conservation measures were proposed to reduce the energy intensity of the plant factory.

1. Introduction

The movement towards concentrating on energy conservation in Malaysia has gained momentum in recent years especially the rapid rise of oil prices [1]. In spite of the fact, an oil-exporter, it has not been insusceptible to the developing acknowledgment of the need to conserve its energy resources. However, it's the need for rapid economic development that leads conflicted with these conservation considerations. Malaysia also consumes increasingly more energy as its economy grows quickly, as all know; energy is a crucial element for socio-economic advancement of

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all countries. National Energy Efficiency Master Plan (NEEMP) was developed by Malaysian government to strategize efforts to address issues of energy security, global warming, and climate change. A target for a ten-year period from 2012 has been proposed by the National Energy Efficiency Master Plan with a total accumulated energy saving of 79.8 kWh in three industrial, commercial and residential sectors. With about three years remaining to achieve this target, the government through Ministry of Energy, Science, Technology, Environment & Climate Change (MESTECC) has introduced many incentives such as Net Energy Metering. In line with this target, energy audit required to be done to premises consuming high amount of energy to establish the status-quo as well as planning for Energy Efficiency [2,3]. For energy conservation purposes, energy production and consumption data are essential. It is also important to analyze where and when energy is consumed within the plants so that the problems in the energy sector can be better understood and effective solutions can be applied [4]. Apart from energy, food security has also became a serious concern. Demographers anticipate a dramatic rise in the urban population in the upcoming years. Simultaneously, land experts (such as agronomists, ecologists, and geologists) warn of insufficient farmland [5–7]. Plant factory is a facility own by MARDI relates to a thermally insulated and almost airtight warehouse-like plant cultivation unit. Multiple culture shelves are stacked vertically inside with electric lamps on each shelf. Air conditioners, air circulation fans, CO_2 and nutrient solution supply units and an environmental control unit are other required equipment and devices for a plant factory. Among benefits from plant factory are high resource efficiency, high annual productivity per unit land region and high-quality of production of plant without using pesticides [8-10]. With this facility it allows farmer to harvest their product within 23 to 25 days for one cycle, it is 2 time faster to be compare with traditional method which allows farmer to harvest their product within 40 – 50 days based on Malaysian climate. This building also known as a climatic control building where all element need for farming were control include source of light, concentration of carbon dioxide, temperature, humidity, air flow and fertilizer. The system includes air-conditioning system which is responsible to ensure operational temperature and humidity of a plant factory remain conducive for the plant growth. A good air-conditioning system will also provide good air circulation inside a plant factory [11,12]. On top of the air conditioning system, a plant factory is also equipped with lighting system, air conditioning system, plant watering system and fertilizing system are fully automatic [13-16].

In this paper the energy consumption profiling of a plant factory, owned by Malaysian Agricultural Research and Development Institute (MARDI) in Serdang, Malaysia was presented. This study is important to establish the status quo of consumption pattern of the plant factory towards reducing the energy consumption.

2. Methodology

The key step to optimizing energy is an energy audit. It is a survey on energy flow to reduce energy consumption within a building, process or system, without adverse effects on the power output. Therefore, the energy audit is a continuous strategy to manage a building energy pattern. The costs of the audit are related directly, how much data will be collected from the analysis and how many conservation opportunities can be identified. The first distinction is therefore drawn between the costs of the audit that determine the type of audit to be carried out. The other difference is between the types of facility. For instance, a building audit can highlight the requirements for building cover, lighting, heating and ventilation.

A written report on energy use based on local climate criteria, thermostat settings and roofing may be included in an energy audit. The building's user behavior, climate and age are among the most important effects on energy use. Due to the daily temperature and day cooling data obtained from recent local weather figures, the energy billing history of the local utility can be calibrated together with the thermal energy model of the building. Energy audits are also an important step towards ensuring the success of their performance contracting project by energy services firms. Before starting the energy audit, it is helpful to have some ideas of the scope of the project and level of effort necessary to reach expectation.

2.1 Walk-through Energy Audit

The process of the walk-through energy audit is to establish an overall picture of the potential energy savings through visual inspection of the chiller plant. Before conducting a walk-through energy audit in the selected chiller plants of each building, a meeting with the technician in charge of the area will be held. The objective of this meeting is to familiarise the physical condition and day-to-day operation of the air conditioning system in the selected buildings and to identify areas where auditors' attention should be focused during the walk-through audit.

2.2 Standard Audit

The standard audit provides a thorough energy analysis for the facility's energy system and quantifies energy consumptions and losses through a more detailed examination and analysis of equipment, system and operational characteristics. This analysis may also include measurements and tests on site to determine if the energy used is efficient for the different systems. The standard energy engineering calculation is used for the analysis of efficiency, the calculation of energy and cost savings based on improvements or changes to each system. The standard audit also includes an economic analysis of the conservation measures recommended. Figure 1 shows the power logger used to obtain the data for this research.

Fig. 1. HIOKI PW33360-1 power measuring instruments to analyze the energy consume by air conditioning

2.3 Detailed Energy Audit

The detailed energy audit includes a thorough examination of the way in which energy is currently consumed, existing systems are currently performed and various potential energy conservation measures are identified. It also provides estimated costs and easy payback times for all the energy conservation measures recommended. The detailed energy audit was shown Figure 2 and it involves 4 main processes which are

i. data collection
ii. end-use load apportioning
iii. identification of energy conservation measures
iv. reporting and presentation

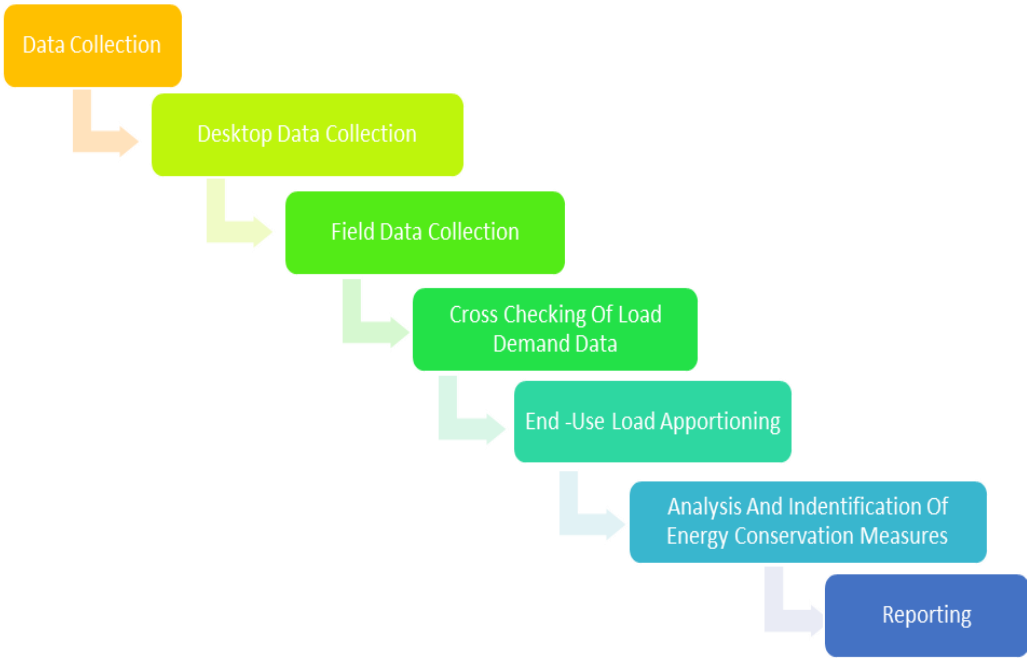

Fig. 2. Detailed energy audit process

3. Results

3.1 Plant Factory

The plant factory is a facility that has been design for indoor and precision farming. The word precision means that the plant factory has a fix schedule which allow the plant to be harvest in 23 to 25 days. The method of farming basically same as hydroponic method but have some different in their climate. This facility also utilizes artificial control of light, temperature, moisture and concentration of carbon dioxide. In order to archive precision farm, there are several conditions that must be meet such as ambient temperature which is 23 °C to 25 °C, duration of light exposure and efficient system. To meet all these conditions, a lot of energy is used. So, to optimise the used of energy, energy auditing was performed to gather data and analyse the distribution of energy in the plant factory. Table 1 shows the building detailed information while Table 2 to Table 6 shows the electrical equipment used in every room in the plant factory.

Table 1
Audit form

Building detailed audit form	
Company name and address	MARDI's Plant Factory Mardi 43400 Serdang, Selangor
Name, Designation, Telephone, Fax no. & Email of Company's Person In charge	En Khairul Anuar Shafie Pegawai Penyelidik
Operating hour (days, week, month)	23-25 days in month
Electricity tariff category	C1
Building age	2 years
Building function	Indoor Farming
Gross floor area (m^2)	210
Percent of gross floor area that using air conditioning (%)	95%
Utilities area (%)	5%

Table 2
Office Electrical Equipment

No	Electrical equipment	Unit	
1	LED Office	12	18.0 watt
2	Air Conditioner	2	2.0HP
3	Desktop	1	N/A

Table 3
Entrance electrical equipment

No	Electrical equipment	Unit	
1	Down Light	6	18 watt
2	Fan (Mistral 20")	1	113watt
3	Air Curtain	2	89watt
4	Air Conditioner	1	1.5HP

Table 4
Utilities Room Electrical Equipment

No	Electrical equipment	Unit	
1	Small Led	4	10.0 watt
2	Fan (KDK)	1	0.08HP
3	Pump (Walrus HQ400)	1	0.37kW

Table 5
Post-harvest electrical equipment

No	Electrical equipment	Unit	
1	Down Light	9	18.0 watt
2	Air Conditioner	1	2.0HP
3	Refrigerator	1	N/A

Table 6
Plant Room Electrical Equipment

No	Electrical equipment	Unit	
1	LED Light	1260	
2	Air Curtain	4	89W
3	Fan (Mistral 20”)	4	113W
4	LED White	12	18.0 watt
5	Fertilizer Pump	18	N/A
6	Water Pump	9	0.5HP
7	Exhaust Fan	1	N/A
8	FCU	2	10 Hp
9	Intake Air Fan	1	N/A

3.2 Energy Load Profile

A load profile is a picture or chart that show utility customer energy usage and allow them to plan how much generation capacity they need to operate. Load can be classified as electricity demand for any particular time. Plant factory load profile has been divided into 4 parts which is LED, pump, air conditioning system and others as reflected in Figure 3.

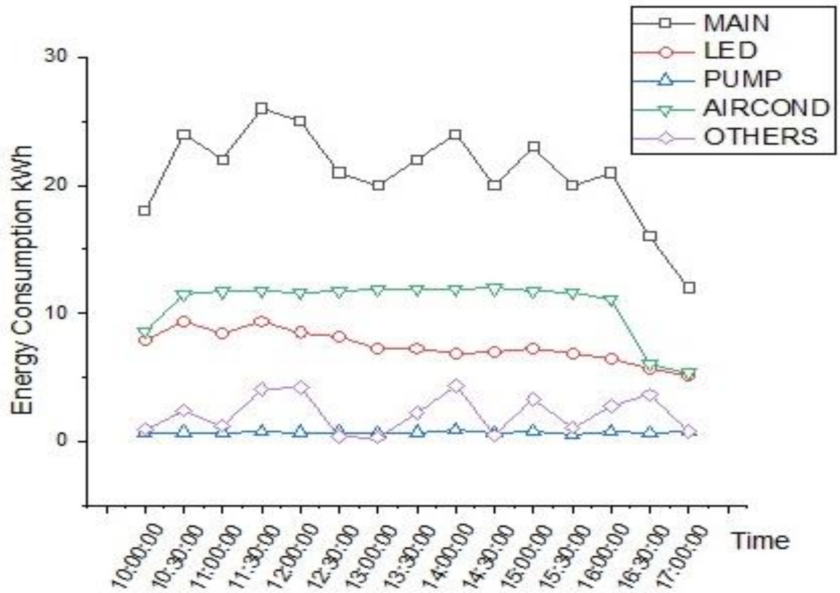

Fig. 3. Plant factory load profile

3.3 LED Load Profile

Based on the chart shown in Figure 4, LED show inconsistence pattern when they reach their peak at the 10.00 am and 11.30 am due to visitor at that moment. The people in charge at the plant factory show the visitor how the system work so they switch on and off the Led light. While in the evening the chart slowly decreases due to the plant exposer time. Smaller plant need less time of exposer time to be compare with bigger plant to run their photosynthesis process.

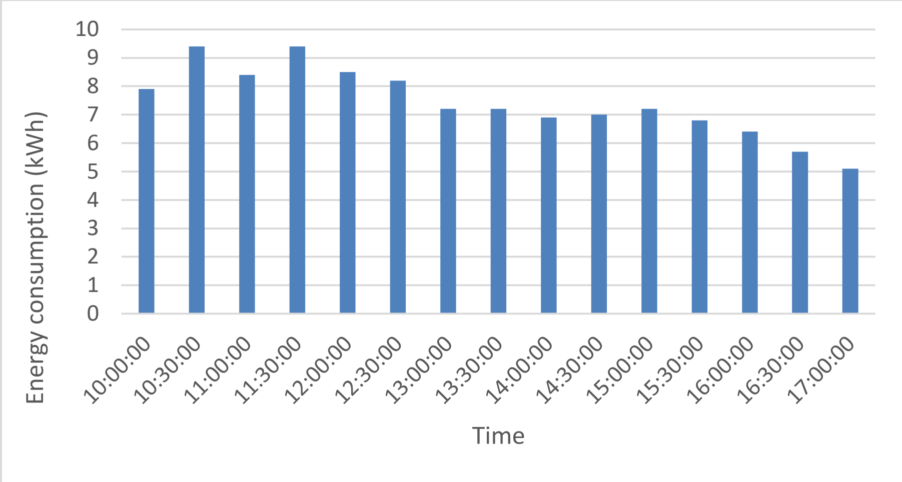

Fig. 4. LED load profile

3.4 Air-Conditioning Load Profile

Based on the chart shown in Figure 5, the air conditioner system shows a fluctuated graph which the load was based on the temperature of surrounding, at the starting at 9.30 the graph was increased until reach their peak and then stay constant until evening, the graph then slowly decreases until 8.00 pm to change their rotation squealed. The plant factory has 2 units of 10hp air conditioner unit. Every unit run for 12 hours per day. Then the chart begins to be constant until morning.

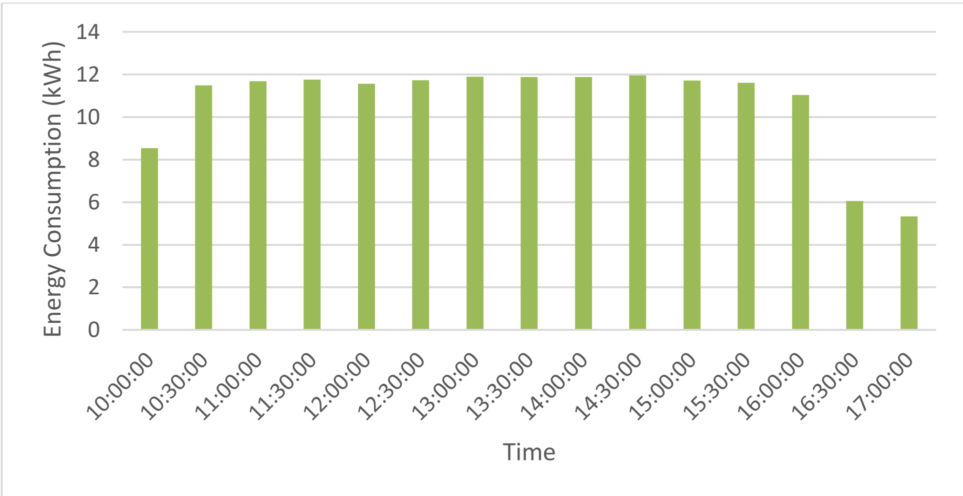

Fig. 5. Air-conditioning load profile

3.5 Pump Load Profile

Figure 6 show a pump load prolife. The chart pattern shows almost a constant graph where the contribution of energy consumption by the pump was almost not affected the pattern of the plant factory load profile. This event occurs because the pump was design to deliver water from tank to the top of the planting rack, then the water just flows through the entire rack using potential energy.

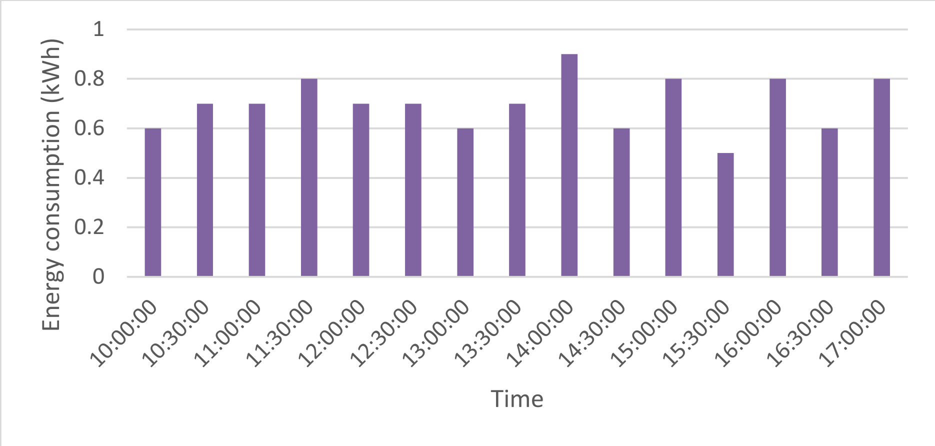

Fig. 6. Pump load profile

3.6 Others Load Profile

Other electrical devices show unregularly patterns it appears in Figure 7. Their usage of other divide is based on work and visitor. At the plant factory there are several electrical devices such split unit air conditioner, refrigerator, fan, air curtain and etc.

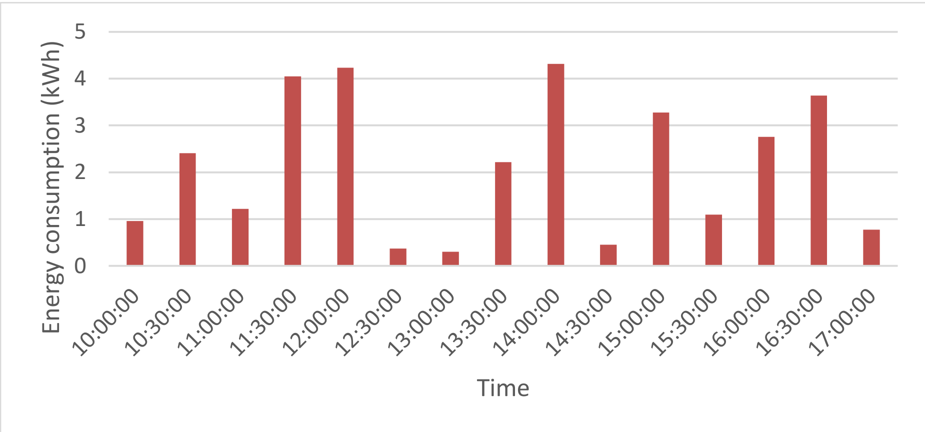

Fig. 7. Others load profile

3.7 Energy Apportioning

Energy apportioning is a divide of total energy consumption based on the usage of equipment for the building to operate. The plant factory apportioning has been divide into four categories which is Air Conditioning System, Pump, LED and others. Based on the pie chart on Figure 8 we can see that the energy usage is mostly used by Air conditioning system with 50.5% energy usage followed by LED which is 36% energy usage, then Others with 10.2% energy usage and lastly Pump with 3.3% energy usage. Based on the Malaysian industrial energy audit guideline, usually air conditioning system and pump will consume more energy compared to lighting and others equipment. But, at the plant factory the air conditioning system and lighting system consume more energy. The scenario happens because of the purpose of the plant factor which indoor farming with climate control. So all the plant there use LED as their sources of light for the photosynthesis process. The pump is use to pump water from tank to the highest level of the rack.

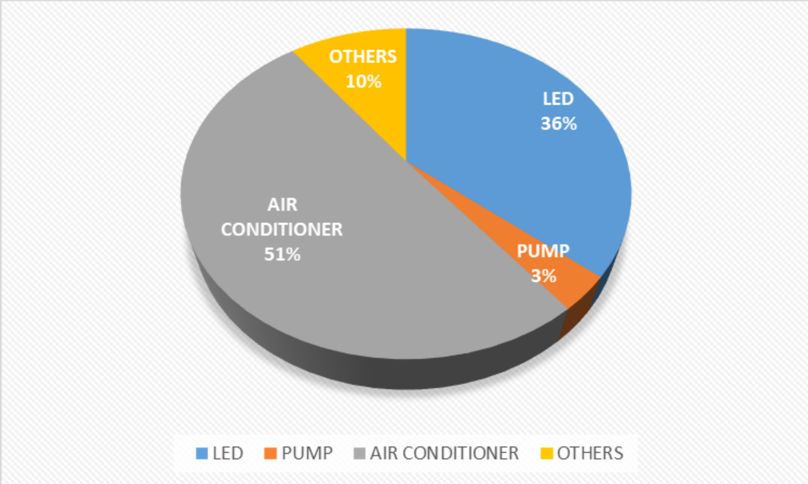

Fig. 8. Plant factory energy apportioning

3.8 Potential Energy Saving Measures

Based on the finding, there are several suggestions that can be made in order to improve the efficiency of energy usage that lead to the potential of energy saving.

i. Efficient Energy Monitoring
ii. Installation of sub metering is a starting point for a monitoring and targeting system to be established within the factory. With the installation of sub metering for electricity to all main consumer of energy is consumed per product output. The collected data should be used to set suitable target for energy used for each consumers. Study has shown that proper implementation of sub energy metering as well as monitoring and targeting program, will contribute significantly to energy saving.
iii. Maintenance and operating practices
iv. Good maintenance regime and housekeeping practices will improve production efficiency, reduce inadvertent waste generation and minimise energy use.
v. Alternative energy use
vi. The use of biomass-based or any order carbon neutral fuel is much very recommended, as it is both environmentally friendly and cost effective. Cogeneration and partial cogeneration is also an effective method of meeting both the electrical and thermal requirements of the factory.
vii. Tariff structure
viii. In order to change the tariff structure, the maximum demand must be managed properly and maintained. In some cases, it is recommended that some form of load shedding measure be put in place. It is also important that the production planning optimises a peak/off peak production ratio of at least 40% to 60%.

4. Conclusions

The plant factory energy audit shows some useful data where the energy efficiency measures must be prioritise. Based on data collected it can be concluded that the plant factory air conditioning system consume more energy to be compare with other appliances. With this data also further improvement with the air conditioning system at the plant factory can be made. Status quo for energy load apportioning at plant factory is finally established.

As for improvement at the plant factory there as several suggestions that can be made for further improvement.

i. Reschedule planting time.
ii. The plan factory can be operating at off peak time which is at 10.00 p.m until 8.00 a.m. where the tariff was about 40% less compare with peak time.
iii. Rearrange rack
iv. To increase the efficiency for delivered cold air at the plant at once lower the load for air conditioning system
v. Improvement air conditioning ventilation
vi. Improving ventilation of the air conditioning system so that, the cold air can be delivered to the designated area.

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