

Development of Web-Based Real-time Energy Monitoring System for Campus University

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Abstract—This study presents development of real time energy monitoring system installed in Level 17, Tower 2, Engineering Complex, Universiti Teknologi MARA (UiTM), Malaysia. The device and programming uses microcontroller board Arduino, ESP8266 Wi-Fi module, sensors and Emoncms.org web server to record and display the real time power and energy consumption, energy cost, energy index and CO₂ emissions. The device allows 3 phase measurement of energy use in the building level where the main power source has been divided into several loads such as lighting, power plug, and Air Conditioning (AC) fan. The device is capable to transmit the data at set time interval using Wi-Fi communication and logging directly to local SD card for further analysis. The device was calibrated using FLUKE 485 power meter concurrently to meet a good reliable result with lower tolerance. The device was installed and tested during testing period including weekdays and weekend to see hourly energy performance in the particular building level. It is found that the device provides reading with average error of 2.04% as compared to commercial meter during one week testing period.

Index Terms—Calibration; Energy Monitoring System; ESP8266 Wi-Fi Module; Energy Performance; 3 Phase Measurement.

I. INTRODUCTION

UiTM Malaysia is the biggest campus out of thirty six campuses which located in Shah Alam. Amongst many of faculties available, Engineering Complex consists of four blocks of buildings are recorded to be the highest energy user per month with an average of energy recorded was 582.946 kWh per month in 2013. Meanwhile, an increase of electricity tariff in 2014, have given a big impact to the utility bill. Aware of this situation, Faculty of Electrical Engineering (FKE) along with other faculties related, has set up an energy committee to oversee this problem. One of the initial proposed solutions is to increase awareness of energy saving to the blocks' consumers such as students, lecturers, staffs and others. Other than awareness campaign and energy saving competition, a monitoring system that accessible by everyone as in [1] is proposed to be placed at each level of the building to monitor the energy performance. FKE is also in the process of implementing Sustainable Energy Management (SEMS) for pursuing AEMAS Energy Management Gold Standard. AEMAS is defined as ASEAN Energy Management

Accreditation Scheme which is designed to improve credibility of energy managers and commercial end-users through accreditation and certification. Effective energy management requires energy use is monitored for each Energy Accounting Centre (EAC) defined by the user.

Currently, each and every blocks in the engineering complex are equipped with commercial energy monitoring devices. These devices are based on software as a service delivery model, requiring only a connection to the internet and a hardware connection to meters or an energy data system. The advantages of the system are it usually requires very little capital investment, do not sit behind a firewall, do not require complex shared savings formulas, and involve no software maintenance or set-up fees beyond the original license/hardware costs [2]. However, these monitoring devices which located at Main Switching Board (MSBs) room only display the accumulated energy use of each block with no acknowledgment of energy activities inside and furthermore it cannot be accessed by anyone except the energy manager.

Recent development in cellular technology and advance communication protocol, data logging and data store from energy consumption monitoring device make the system becomes easier to use and more economical [2]. An advance development of microcomputer technology has enable energy monitoring system to be easily constructed and require a lower maintenance [3]. Arduino boards are one of the microcontrollers that come with easy programming language. The boards come with modules, sensors and shields design and ready to be attached to the main boards. With slight adjustment and correct code, energy measurement device can be developed via the microcontroller board.

With the current increases of power consumption in a building [4], the concern is not only focusing on balancing the power demand with required power, but also focuses on ways to reduce power consumption to achieve optimal energy saving. With the ability to monitor the amount of power consumed by buildings in real time can help consumer in controlling power consumption effectively, thereby reducing energy consumption and saving the costs.

Therefore, this paper presents the development of real time energy monitoring system using ESP8266 wifi module installed and tested at Level 17, Tower 2, Engineering

Complex, UiTM. The development of this device consists of three parts; 1) development of measuring device, 2) development of web-page monitoring system to measure and display energy consumption and 3) device calibration. This energy monitoring system allows the measurement of 3-phase voltage and current, logging data to local SD card and transmitting data at set interval through Wi-Fi connection. A web page is developed to show real time power and energy consumption, energy cost, energy index and CO₂ emissions. The device was installed and tested for a week to see the energy performance during weekends and weekdays.

II. EXISTING ENERGY MONITORING SYSTEM

Some researchers have done studies on real-time energy monitoring system. The system has been evaluated as one of the next-generation energy solutions. There are several experiments had been conducted that proved the system actually could reduce the entire energy consumption up to 10-30% [5-6]. Tsuyoshi Ueno et al. developed a monitoring system that was set up at 10 residential houses and its effect on the energy consumption is analyzed. The total energy consumption was reducing by 12% after the installation of the system and about 60% of the houses were able to reduce their standby power consumption [5]. A thesis titled “Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives” focuses on personal choices influence in electricity and water consumption. The system managed to create reduction of 32% in electricity use and 3% reduction in water use [6].

III. PROPOSED WEB BASED REAL-TIME ENERGY MONITORING SYSTEM

A. Overview of Proposed Real-Time Energy Monitoring System

The real-time energy monitoring system consists of voltage and current sensors, micro controller board (Arduino Mega), wifi module, sd card and server for data logger. Arduino Mega acts as the main board to calculate all the analog input from 9 current sensors attached at incoming wire inside the Distribution Board (DB). Arduino programming language is similar with physical computing platform such as C++ programming and easy to use. The powers measured by the CTs are sent to open sources web page monitoring called Open Energy Monitoring (OEM) to display the data. All the energy data and graphs will be shown in OEM dashboard. Wi-Fi module ESP8266 is used to send the data through available Wi-Fi network. Figure 1 shows the block diagram for the whole project meanwhile Figure 2 shows the flowchart represents the process work of the system.

There are three major parts in completing the works in this paper; 1) hardware development, 2) data transmission and display at web server and 3) calibration process. Hardware development involves constructing and integrating the CTs, Arduino Mega, temperature and humidity sensor, LCD screen and SD card into the system. Meanwhile, the data transmission and web server involves sending the data through ESP8266 using Wi-Fi communication and display the result at a web page. Finally, the calibration process involves verifying

measurement reading of the proposed device with a commercial meter.

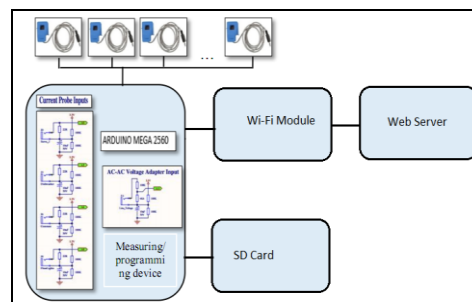


Figure 1: Block diagram of proposed monitoring system.

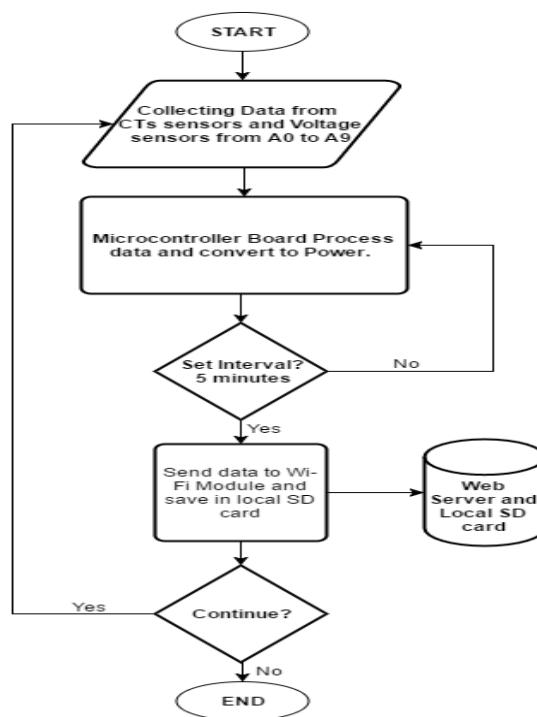


Figure 2: Flowchart of the proposed device

B. Hardware Development

Figure 3 shows the overall schematic design for the energy monitoring system which consists of Current Probe Inputs (CTs), Arduino Mega, AC-AC Voltage Adapter and DHT11 sensor for temperature and humidity. This project uses Arduino Mega board as its Central Processing Unit (CPU) due to number of analogue input and its capabilities for faster processing. As the main source from the MSB is divided into several load sections, it is proposed to use nine CT sensors to measure the current flow at different type of loads in DB. These nine CTs were attached in the DB room located at Level 17 Engineering Complex, UiTM Shah Alam. Six CTs are used for detecting current flow for Air conditioner fan which are for wing A and wing B and each of them is in 3-phase. Two CTs are used to measure the current flow for plug load (wing A and wing B) and one CT is used to measure the current flow for lighting. The six CTs connected at air-conditioner load are shown in Figure 4.

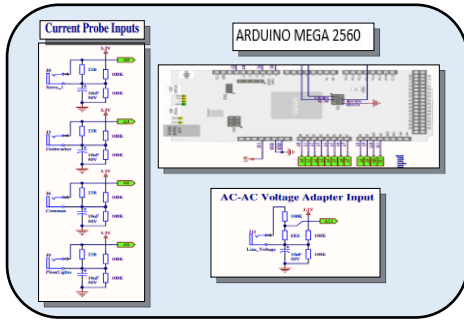


Figure 3: The schematic diagram of the circuit.



Figure 4: Six CTs connected at 3-phase air conditioner load

In the hardware implementation, a common circuit design using Arduino for energy monitoring system is used in this paper. However, some modifications to the circuit are performed to get the desired output of voltage and current. At this stage, the value of resistor for biasing the voltage divider is determined.

Figure 5 shows how the CT sensor is interfaced with the electronic circuit to get the voltage and current from the Arduino board in phase. In order to find the burden resistor, the ranges of the output current need to be defined. In this case, 100A is chosen as the maximum current output. Then, the RMS current is converted to peak-current by multiplying with $\sqrt{2}$. After that, the peak-current is divided by the number of turns in the CT to calculate the peak-current in the secondary coil. The number of turns in the CT can be obtained from the data sheet of the CT sensor. Finally, the value of the burden resistor is equal to the voltage of the Arduino over the secondary peak-current. The equations of primary peak-current, secondary peak-current, and ideal burden resistor are shown below;

$$I_{pp} = I_{RMS} \times \sqrt{2} \quad (1)$$

$$I_{sp} = I_{pp} / n_{ct} \quad (2)$$

$$BR = V_{ref} / I_{sp} \quad (3)$$

where I_{pp} is primary peak current, I_{RMS} is RMS current, I_{sp} is secondary peak current, n_{ct} is number of turns in CT, BR is burden resistor and V_{ref} is voltage reference at Arduino.

The final step of hardware development is PCB design using Proteus software to combine all the circuits. The DHT11 i.e. temperature and humidity sensor are also connected to the system to measure outdoor temperature and humidity. These energy governing factors are important to be measured in order to study the correlation of these factors with the energy consumption in the building as recommended by International Performance and Measurement and Verification Protocol (IPMVP) [7]. Figure 6 shows the completed hardware which is ready for testing.

The software used to program Arduino can be obtained from the Arduino home page. This assembly language is easy to use because it is similar to C++ programming software. All the data saved in Arduino are analyzed and converted into real power using programming code written in Arduino software.

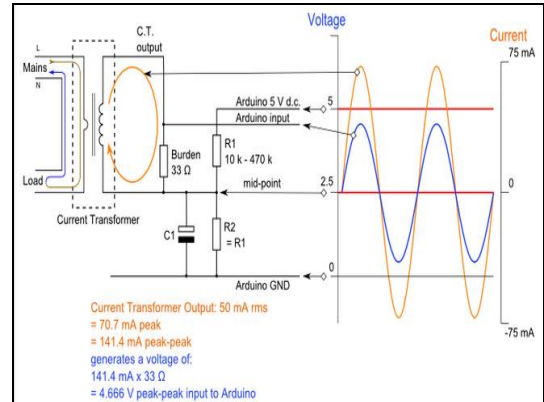


Figure 5: Interfacing CT sensor to the circuit design [7]



Figure 6: Complete energy monitoring device

Real power is the average of instantaneous power. On the other hand, instantaneous power is a multiplication of the measured instantaneous voltage and instantaneous current. Sum of these instantaneous power divided by the number of samples will give a result of real power. Real power determination is shown in Figure 7 and using Equation 4.

$$P = \frac{1}{T} \int u(t) \times i(t) dt \equiv U \times I \times \cos(\varphi) \quad (4)$$

where P is real power, $u(t)$ is the instantaneous voltage at time t , $i(t)$ is the instantaneous current at time t and φ is phase angle.

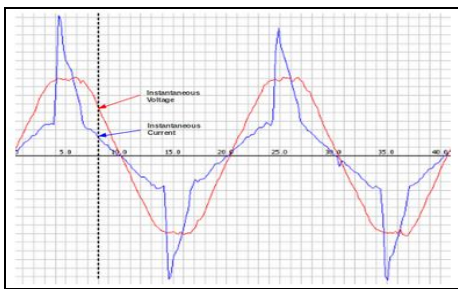


Figure 7: The sample of instantaneous voltage and instantaneous current [8].

C. Development of Data Transmission System Using Wifi Module (ESP8266) and web server

Wi-Fi module ESP8266 is installed together with the Arduino Mega i.e. the main board to collect the data from level 17 FKE DB. The data collected by Arduino will be sent to the ESP8266 at specified pre-defined interval time. These data includes power, temperature and humidity. In the data transmission system, the Wi-Fi module ESP8266 will first search for available Wi-Fi until it successfully connected to it. ESP8266 is set as a web client where its function is to communicate between Arduino board and web server. The ESP8266 then will send all the data to the OEM web input processing. ESP8266 is programmed to match the type of input allowed to the input processing in OEM.

OEM is a powerful open-source web-app for processing, logging and visualizing energy, temperature and other environmental data. Data can be processed, manipulated and displayed at data dashboard. There are a variety of methods and tools can be used to transmit data to OEM website at Emoncms.org. In this project, Wi-Fi modem type ESP8266 is used to send data collected from Arduino Mega to the OEM page. The main function of the input processing in OEM is to allow for conversion and processing before storage; where there are over 23 different input processing can be performed. Some calculations will be performed in the input processing. For example in this project, power (kW), temperature and humidity are the measurement outputs of Arduino to ESP8266. On the other hand, the parameters below are calculated in the input processing:

1. Real energy consumed

Real energy consumed is the total power consumed in the building over a specified duration time. This real energy will be accumulated over the time for one day.

2. Estimated annual energy

Estimated annual energy is the estimated value of energy consumed per year based on the daily energy consumption.

3. Energy index, EI

Energy index is the total energy consumed per square meter of the building. Estimated annual energy index can be calculated as follows:

$$EI = \text{Annual Energy Use (kWh)} / \text{air-conditioned building area (m}^2\text{)} \quad (5)$$

4. CO₂ emission

CO₂ emission is the total CO₂ emission released by the building from the total energy use (kWh) in the building. CO₂ emission is calculated by multiplying the energy use (kWh) with Green House Gas Grid Intensity (GHGG) (kg. CO₂/kWh).

$$CO_2 = \text{Energy use (kWh)} \times \text{GHGG (kg.CO}_2\text{/kWh)} \quad (6)$$

5. Energy cost, EC

The web page will also show the energy cost per day based on the new TNB tariff C1 – medium voltage general commercial tariff i.e. 36.5 sen/kWh.

$$EC = \text{Energy use (kWh)} \times \text{Tariff (sen/kWh)} \quad (7)$$

All the data from input processing will be processed and stored in data feeds. The stored data in the data feed can be downloaded and saved in Character-Separate-Value (CSV) file format. After the feed has been created, the data then will be logged into OEM dashboard to display data and graphs. There are varieties types of graph can be visualized in the dashboard.

In this project, the dashboard can be set either public or private. For public setting, the data are open for public view. For the private setting, only owner of the account can view the dashboard created. All the data can be viewed through the device with capability accessing the internet. OEM web page can be viewed with all type of browser.

D. Device Calibration

Device calibration is performed to verify the reading from the proposed energy monitoring system with a commercial meter at an acceptable tolerance. The calibration was done at Green Energy Research Centre (GERC), UiTM Shah Alam. The device was setup concurrently with power meter Fluke 485 which attached to the main source 3 phase utility line. To calibrate the energy monitoring device, the measured value from the device which are voltage, current and power factor were adjusted to actual value with small tolerance. The device was then set to log the data at 5 minute interval. Figure 8 shows the device calibration process.

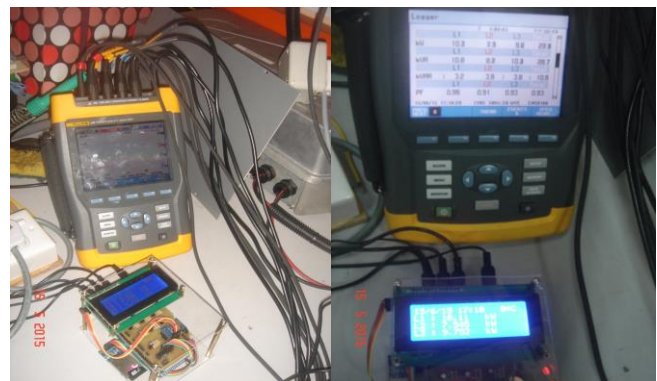


Figure 8: Calibration process

IV. RESULTS AND DISCUSSION

This section shows the results obtained from the energy monitoring that were tested at Level 17, Tower 2 Engineering Complex, UiTM. It based on the experimental methodology by using instrument tools for the energy monitoring process. The measurements were taken on 11th June 2015. The results show real power calculated by Arduino Mega. Meanwhile, the last part of this section shows the calibration to the device compared to power meter Fluke 485.

A. Output Display Via LCD Screen.

The real power extracted from the Arduino is displayed at LCD screen. Figure 9 shows that the LCD screen displays the time and date at the first line of the screen. The next three lines displays the total power of air conditioner, total power of the plug load and total power of the lighting. The time and real power is updated every second.

B. Output Display Via SD Card.

The output data is also saved in the SD card and can be read in Notepad. From the Notepad the data can be transferred to Microsoft Excel for further analysis and plotting. Figure 10 and 11 show the trending of power consumed by level 17 during weekday and weekend as plotted in the Excel.

The power trending is different during weekday and weekend. The energy trend during weekday and weekend were measured to see how the energy was consumed in the building. More energy use during office hour and weekday are seen because most of the staff, lecturers and students were in the building compare to weekend and after office hour. It can be seen that during weekday, the power started to increase at 7.50 am when lecturers started came to the office. The power gradually increased until 10.15 am which shows the maximum demand time of level 17 when more lecturers were in their room. The power consumption started to reduce at 12.00 pm when some lecturers went out for lunch and increased again after 2.00 pm. However, during weekend and after office hour, the base load was still exists. This wastage of energy must be reduced to save energy. The correlation between outdoor temperature and electricity use in level 17 is quite significant with coefficient determination, R2 of 0.63 (Figure 12).



Figure 9: Output display at LCD

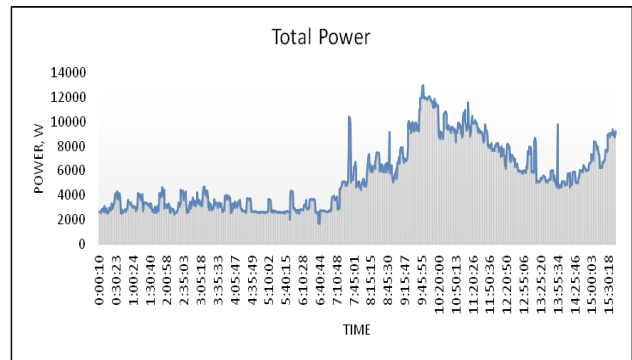


Figure 10: Energy use during weekday

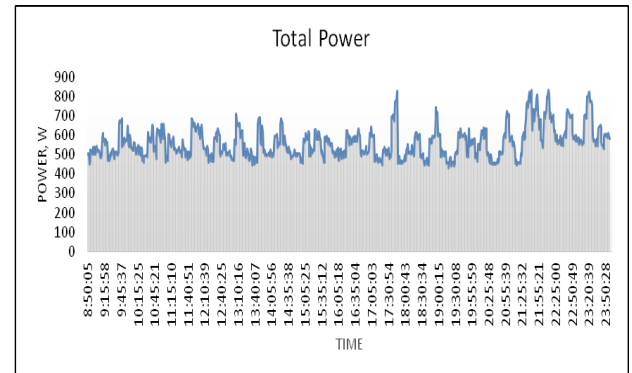


Figure 11: Energy use during weekend

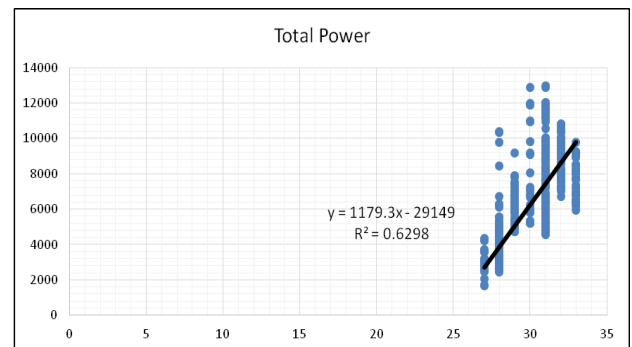


Figure 12: Correlation of energy use and outdoor temperature

C. Web Page for Real Time Energy Monitoring System

Figure 13 shows the homepage of the energy monitoring system. It describes details of how the load are connected to measuring devices and monitored.

The real time power is displayed at OEM web base for three types of loads, i.e. air-conditioner, plug load and lighting. Each of these measured powers is shown in a real time graph and updated for every 10s. All the historically data are also stored and displayed in the line graphs. The total powers from these three types of loads are also displayed. All the measurements shown in these results were taken on 27th May 2015 for 1 hour. Figure 14 shows the total three phase air conditioner power consumption at level 17 wing A and wing B. Figure 15 shows the power draw from the lighting load and Figure 16 shows the total plug load from wing A and wing B. Figure 17 shows the total power consumption from these three loads and Figure 18 shows the load comparison.



Project Details :

Objective : To monitor the power and energy consumption and Factor influence energy consumption in Level 17 Faculty Of Electrical Engineering (F&E)
Location : Level 17 FKE
Load Monitored : 1. Three Phase Air Conditioner 2. Lighting Load 3. Plug Load

System Load Detail :

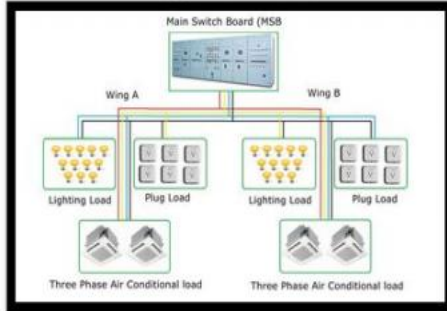


Figure 13: Homepage of the energy monitoring system



Figure 14: Air conditional power consumption

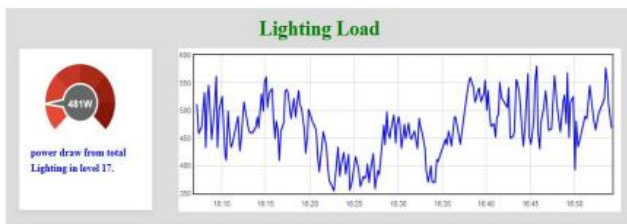


Figure 15: Lighting power consumption



Figure 16: Plug load power consumption

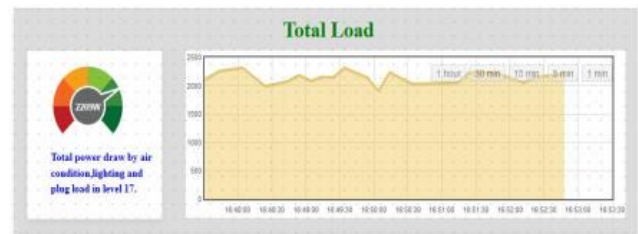


Figure 17: Total power consumption



Figure 18: Load Comparison

Other than the real time power, the web page also displays the energy performance of the building. This energy performance includes real-time energy (kWh), estimated annual energy (kWh) and energy index (kWh/m²). These energy performance are calculated in the OEM using the real-time power (kW) measured by Arduino board. Real-time energy shows how much energy have been consumed on that time. The graph of total energy can be zoomed into daily, weekly, monthly and yearly energy consumed. The bar graph is used to visualize this energy data. Figure 19 shows the sample of total energy use on 27th May and 28th. From the daily energy consumed per day, estimated annual energy can be calculated. The estimated annual energy, calculated energy index and CO₂ emission are shown in Figure 20. The value of temperature and humidity are shown in Figure 21. The CO₂ emission is calculated using Peninsular Malaysia's Green House Gas Grid Intensity of 0.6747 kg CO₂/kWh.

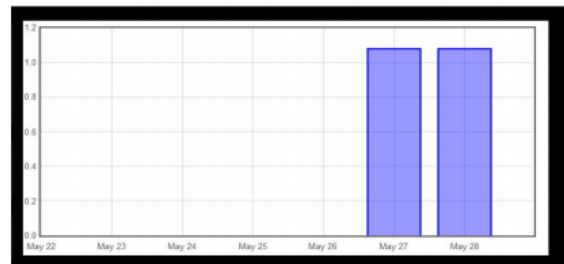


Figure 19: Real-time energy consumed

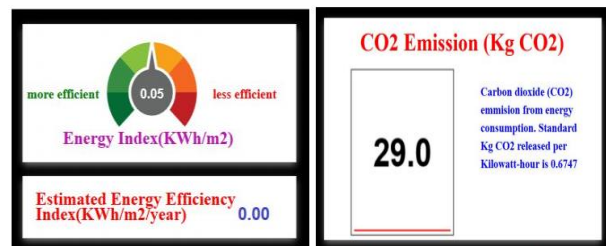


Figure 20: Energy index (right) and CO₂ Emission



Figure 21: Temperature and humidity

D. Device Calibration

Figure 23 shows the plot of energy, kWh reading between the proposed monitoring system and Fluke 485 for a week and Table 1 shows the tabulated results. It is observed that for the one week calibration period, the system is able to provide reading with average error of 2.04% as compared with commercial Fluke 485 meter. Meanwhile, Figure 24 and Figure 25 show the graphs of hourly energy use on weekday and weekend. GERC has 16kW photovoltaic system installed on the roof top of parking area [9]. During the weekend, it can be seen that the energy use is negative. This shows that the energy generated using the photovoltaic system is greater than the energy use by the building in the weekend.

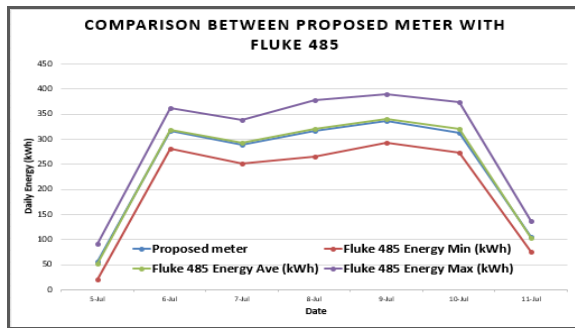


Figure 23: Plot of energy reading between proposed device and Fluke 485.

Table 1

Calibration results between proposed device and Fluke 485

Date		5-Jul	6-Jul	7-Jul	8-Jul	9-Jul	10-Jul	11-Jul
Proposed meter	daily Energy (kWh)	56	317	289	318	336	314	106
	Energy Min (kWh)	21	282	253	265	293	273	77
Fluke 485	Energy Ave (kWh)	53	319	293	322	341	321	104
	Energy Max (kWh)	92	363	340	379	390	374	137
Relative error %		6	1	1	1	1	2	2
Absolute Error (kWh)		3	3	4	4	5	7	2
Average Error %		2.036						

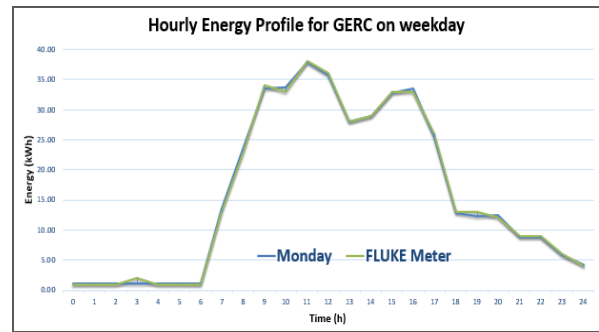


Figure 24: Hourly energy use in GERC during weekday.

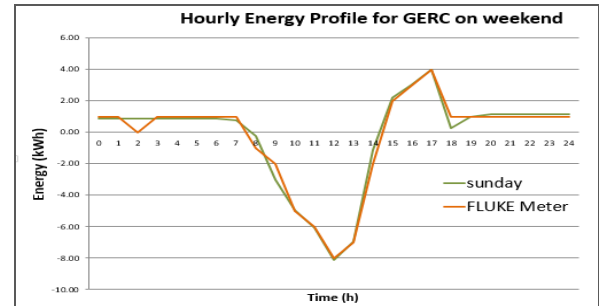


Figure 25: Hourly energy use in GERC during weekend.

V. CONCLUSION

As market recovers and organizations seek to take advantages of rising demand, energy efficiency offers one of the best opportunities to reduce operating expenses. Real time energy monitoring system proposed in this paper is able to measure and display the energy consumption pattern in a building with good accuracy. The real power consumption calculated by Arduino from instantaneous current and voltage measured by the CTs and voltage adapter is displayed through web server, LCD screen and saved in the SD card. The system has been tested at level 17, FKE, UiTM Shah Alam.

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