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Switching On/Off Air Conditioner and Fan Alternately based on IoT Motion Detection and Room Temperature

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***Abstract*—The Internet of Things (IoT) connects electrical appliances that enable data transfer for communication without human intervention. IoT has evolved, and its implementation has been extended to residential areas. It can be said that all residents use fans as cooling appliances. In Malaysia, having a fan is not sufficient due to its hot temperature throughout the year. Therefore, most of the residents use air conditioners as an additional cooling appliance. Using air conditioners regularly could contribute to high energy consumption. Furthermore, excessive energy consumption occurs when an occupant of a residential building forgets to switch off electrical appliances such as fans and air conditioners. In addition, leaving electrical appliances turning on when nobody is at home just wastes energy. This work aims to develop an IoT-based smart home controlling system for minimizing energy consumption. This system enables automatic control that depends on room temperature and motion detection. Various types of sensors, such as temperature sensor, humidity sensor, and motion sensor, are used to switch on/off the air conditioner and fan. The air conditioner and fan will be alternately switched on and off depending on the ideal room temperature. The testing results show a significant reduction in energy consumption and a promising decrease in the electricity bill. Future works should be focusing on determining the over limit energy consumption. On top of that, this research would be best to try on simulation to get better results.**

***Keywords*—Internet of Things; energy consumption; alternately control; ideal temperature.**

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I. INTRODUCTION

A. Background of Study

Internet of Things (IoT) is a technological advancement that holds great promise for optimizing life via the use of internet-connected smart sensors and smart devices [1]. IoT-enabled solutions are designed to enhance the quality of life by utilizing automated technologies that can simplify and secure household management through mobile applications, telecommunications, and technologies [2]. It has been proven that IoT helps a person perform a variety of tasks in a timely, effective, and secure environment. IoT-based systems can significantly reduce homes' energy consumption and optimize energy efficiency.

The world population keeps increasing, and the lifestyle changes from having a fan as a cooling appliance to having an air conditioner. Thus, this increases the energy consumption of residential buildings. In Malaysia, residential buildings utilize 48% of the nation's total electrical production [3]. The previous study also revealed that almost 68% of the energy was used by residential buildings for heating, ventilating, and air conditioning systems [3].

Sometimes, people forget to switch off their cooling appliances, resulting in excessive energy consumption. A recent study in 2021 reported that air conditioners and refrigerators consumed about 70% of the building's electricity usage [3]. In Malaysia, refrigerators have the leading electricity power consumption, followed by air conditioners and ceiling fans [4]. To optimize electricity usage, the air conditioners should be turned off when the room temperature drops below ideal. In Malaysia, normal temperature ranges between 21°C to 32°C throughout the year [5], [6]. Therefore, the annual mean temperature can be said to be 27°C. Hence, if the usage of cooling appliances is controlled, energy consumption can be minimized. Consequently, a large amount of electricity consumption that contributes to lower electricity bills can be reduced.

Malaysia is a warm and humid tropical country located on the equator. The temperature is consistent and considered higher compared to the other countries not located on the equator. The annual mean temperature is 27°C, with an average daily high of 32°C and an average daily low of 21°C. The annual relative humidity value fluctuates between 74% and 86%. Thus, Malaysia enjoys a clear daytime sky throughout the entire year, about 3.7 to 8.7 hours every day [7]. On average, there are six hours of sunlight every day. It is undeniable that high air temperatures and relative humidity have a negative impact on the comfort and health of the occupants residing in a building without an adequate ventilation system [8].

The best or ideal temperature for a room depends on various factors such as location, season, design of the house, and even an occupant's preferences [9], [10]. Besides, several factors influence the ideal room temperature, including air temperature, mean radiant temperature, humidity, clothing, metabolism, and personal preference for the cooling system. Temperature impacts the amount of energy used to cool a building. Without a system to monitor room temperature, the energy consumption could be used unwisely, contributing to higher electricity bill. Many buildings in urban areas rely on air conditioners as cooling appliances to achieve the desired temperature. The Department of Standards Malaysia recommended that the ideal indoor temperature for Malaysian climates be between 23°C and 26 °C [11].

B. Related Works

IoT is closely related to a smart home, an automated system. Smart home was created to improve device communications at home, such as controlling devices wirelessly [12]. A smart home consists of multiple devices connecting for communication and conveying information. The input devices of the smart home received instructions to control and monitor home devices such as lights, doors, and temperature. This can be done using smartphones via mobile application or from different systems at home [13], [14]As the demand for electricity increases daily, smart homes are a new research area allowing users to access their household appliances remotely using IoT.

Researchers focus on four basic categories of smart homes: safety, health care, energy efficiency, and entertainment. Besides smart homes, smart campuses have an attention to the researchers, especially in creating an environmentally friendly and energy-saving campus [15], [16]. According to the World Energy Outlook (IEA) 2023 report [17] that energy is used to heat and cool buildings and industries. Fossil fuels meet roughly 65 percent of this demand. About a third of all energy used in the world goes to powering buildings. It is presumed that, in the long term, people will need more energy. Smart home automation could be seen as a way to reduce energy consumption.

Several studies have shown that home automation systems can save up to 30% of a building's energy [18], [19]. Smart sensors in the buildings let people see and control their energy usage in real-time, including how much energy they have used for the electrical or cooling appliances. The occupants can see and monitor how their homes use energy and plan how their systems work efficiently. Smart homes also use smart plugs, smart cooling, and smart lighting systems to keep track of energy use. Smart homes allow the occupants to save energy by automatically keeping the home comfortable and even at the desired setting [20], [21]. After all, the main target is to achieve energy efficiency, which is about cutting down the usage and cost of energy usage, eco-friendly as well, as sustaining the energy without affecting the services provided [22].

It is well-known that an air conditioner is a cooling appliance that manages the temperature of a room. According to reference [23], an air conditioner attempts to keep the indoor temperature within a fixed range of temperature values that the occupants specified. This is done by turning the compressor on and off. For example, when the room temperature is higher in hot weather, the occupants select a cooling temperature, so the compressor will blast cold air until the room temperature reaches the cooling temperature. Then, the compressor will be turned off while the fan will be turned on to keep the air circulation consistent inside the house. Consequently, this makes the energy used more efficient.

Besides air conditioners as cooling appliances, ceiling fans are commonly used at home in Malaysia. They are low-cost and yet cost-effective options for consumer comfort. According to reference [24], a series of survey studies were conducted where a total of 78% of participants admitted to routinely using fans at home. In fact, 68% of the survey participants had air conditioners installed in their homes. Turning off the air conditioning system and depending only on the ventilation system in conjunction with the ceiling fans did not significantly increase the amount of energy consumed by the ceiling fans. Therefore, the amount of energy used by ceiling fans did not exceed one percent of the overall energy consumption. As a result, a ceiling fan may help create a sustainable atmosphere at the lowest possible cost of power, resulting in increased energy efficiency.

Therefore, various studies were carried out about smart controlling systems for minimizing energy consumption [13], [25] such as a controlling system via a smartphone to help the occupants control the air conditioner [23], [26], [27], [28]. The studies implemented cloud servers via Wi-Fi connection. Other than that, other studies proposed systems to remotely control energy consumption from excessively used, which also allowed the system to monitor the energy used from apart [29], [30]. Here, relays were deployed to regulate the appliances to be on and off based on specific criteria [23].

To optimize energy efficiency, the authors in [13] [13] developed a mobile application for a smart home to reduce electricity usage and minimize energy waste. In the proposed system, Raspberry Pi (Master) was a front-end interface to any web browser, providing data processing and decision-making capabilities. In comparison, Raspberry Pi-powered Arduino was used as a slave. The Arduino collected sensor data and controlled the light-emitting diode (LED) and alternating current (AC) circuits as needed. The messages, appliance status, and sensor readings were all on one liquid-crystal display (LCD).

Based on the previous studies, it can be said that developing an IoT-based system to control air conditioners and fans alternately (and switching them on and off alternately) is essential because it would lead to lower energy consumption. This would also benefit the occupants, especially those who live in huge homes or have trouble keeping track of cooling appliances. The occupants could also monitor the room temperature and would be kept notified even though they were not at home.

Therefore, this paper proposes a system design that controls an air conditioner alternately switched on/off with a fan based on room temperature and motion detection. When the current room temperature is higher than ideal, the air conditioner will be automatically turned on, and the fan will be automatically turned off. However, when the current room temperature is lower than ideal, the air conditioner will be automatically turned off, and the fan will be automatically turned on. Furthermore, if the motion sensors detect no motion, the air conditioner and the fan will be turned off. This ensures that the energy consumption of cooling appliances is at optimum usage.

The proposed system is hoped to lead to more research in IoT-based energy-saving approaches for cool appliances. IoT enables data collection for room temperature and monitors the cooling appliances. The rest of this paper is structured as follows: Section II further explains the main components used and the proposed system design. Next, Section III describes the results and discusses them. Finally, Section IV outlines the conclusion.

II. Materials and Method

This section explains further the main components used, the proposed system design, and the method implemented.

A. Main Components

The design consists of two main sensors: (1) a Humidity and Temperature sensor for sensing the room temperature and (2) a Passive Infrared (PIR) sensor for detecting the occupants' existence. The other main components and the descriptions are presented in Table I.

TABLE I
MAIN COMPONENTS

Component	Description
NodeMCU ESP8266	It is a microcontroller with Wi-Fi capability. It is an open-source firmware and development kit used to develop IoT products.
Humidity and Temperature Sensor (DHT22)	It is used to sense temperature and humidity. Its accuracy is ±0.5ºC for temperature sensing and ±1% point for humidity sensing.
Passive Infrared (PIR) Sensor	It is also known as a motion sensor. It detects and collects infrared (IR) light produced by objects within its range of vision, which means it detects human movement within a specific range.
Infrared (IR) Transmitter Module	It is used for communication between devices. It controls the device from a short distance with a clear sight line.
Current Sensor Clamp (SCT013)	A current sensor can be clamped around an electrical load supply line to measure current. This current sensor can measure up to 50 amps for monitoring energy usage.
Voltage Sensor (ZMPT101B)	It is a voltage transformer to measure AC voltage.

B. Proposed System Design

The proposed system's main components, such as Humidity and Temperature Sensors, an IR Transmitter Module, and PIR Sensors, are connected to the microcontroller (NodeMCU ESP8266). Fig. 1 shows the main components' connections, while Fig. 2 shows a schematic diagram of the main components.

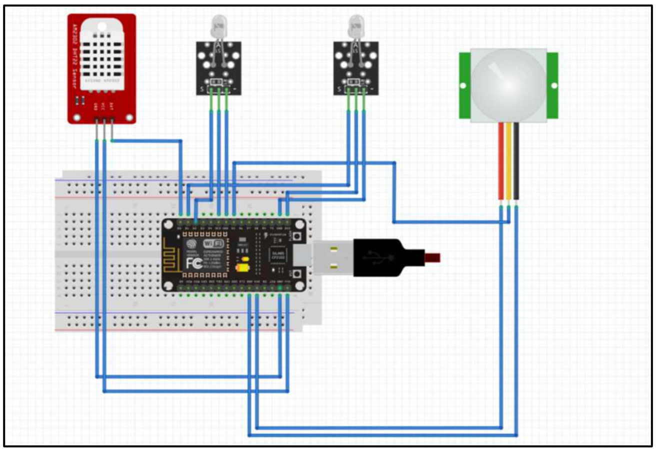

Fig. 1 Connection between Humidity and Temperature Sensor, IR Transmitter Module, and the PIR Sensors

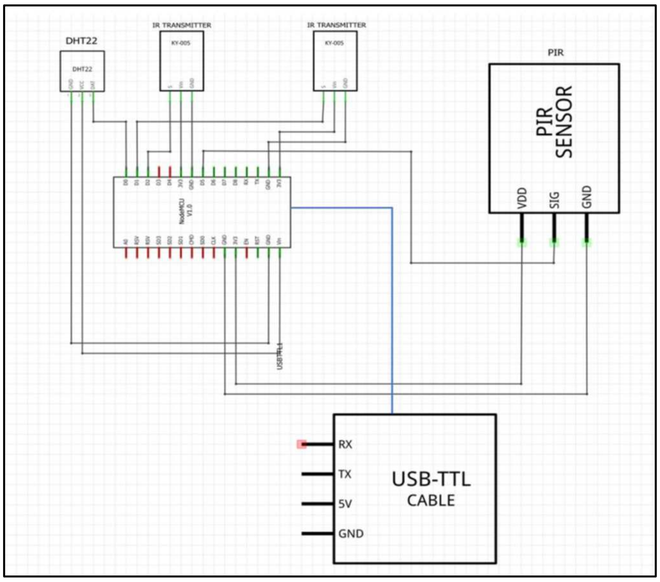

Fig. 2 Schematic Diagram of the Proposed Design

Fig. 3. shows the detailed proposed design. The PIR and the temperature sensors received inputs from the environment. In this case, the Humidity and Temperature sensor detected the room temperature while the PIR sensed an occupant's motion existing in the room. However, the IR Transmitter Module gave on or off input to the air conditioner. The input data went to the microcontroller for processing such as determining whether to switch on the air conditioner or the fan. The data is also kept in the Blynk Cloud for other processing such as calculating the energy consumption and electricity bill. The result, then, can be used for displaying and manipulating data.

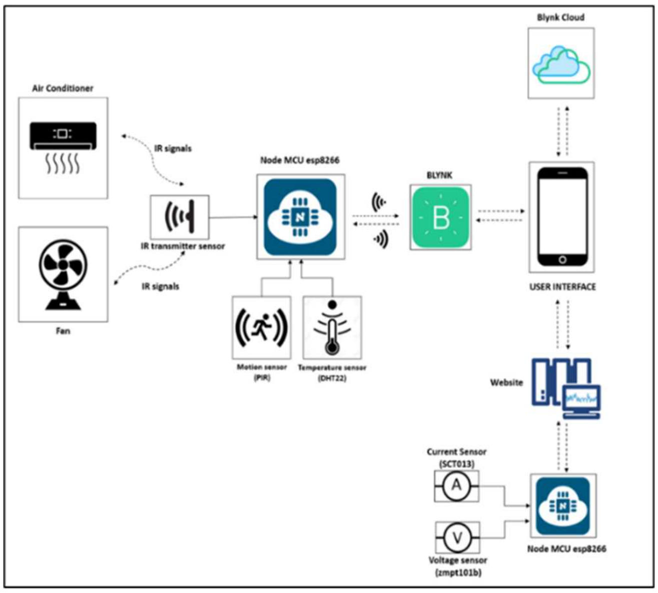

Fig. 3 Proposed Design

C. Proposed Algorithm

Referring to Algorithm 1, the PIR sensor senses motion. If motion is detected, the DHT22 is activated to read the room's temperature. If the temperature exceeds 26°C, the air conditioner will be turned on while the fan will be turned off. Otherwise, if the temperature is lower than or equal to 26°C, the air conditioner will be turned off while the fan will be turned on.

Algorithm 1: The Proposed Algorithm

```
  Start
    Get input (motion) from PIR sensor
    If (motion == 1)
      Get the room temperature from DHT22
      If (temperature > 26)
        AirCond = 1
        Fan = 0
      Else
        AirCond = 0
        Fan = 1
      End
End
```

Fig. 4. illustrates the overall proposed layout diagram with the installed components. First, the proposed system senses the occupants' movement in the room. Once the movement is detected, the signal is sent to the microcontroller, and the temperature sensor is activated to detect the room temperature. Depending on the room temperature, the air conditioner and fan will be turned on or off. As explained before, Malaysia's ideal indoor room temperature is between 23°C and 26°C [11]. As the threshold value, the ideal temperature is set to be 26°C. Therefore, when the room temperature exceeds 26°C, the system will automatically turn on the air conditioner and turn off the fan. However, when the room temperature is less than or equal to 26°C, the fan will be turned on, and the air conditioner will be turned off. This process is repeated until no motion is detected. Turning the air conditioner and the fan on and off is executed by the IR transmitter sensor. Finally, the user can remotely monitor and control the system using a developed mobile application. This would improve energy utilization efficiency.

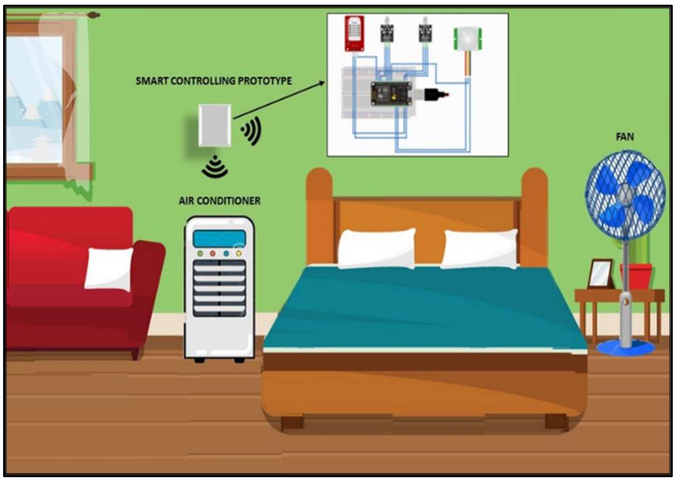

Fig. 4 Layout Diagram

This system starts running once the 'auto' mode is activated, as shown in Fig. 5. When the motion sensor detects the occupant's presence, the signal will be transmitted to the system. Simultaneously, the temperature sensor detects the room temperature, shown on the screen in Fig. 5. If the temperature is higher than the ideal temperature, the air conditioner will be turned on, and the fan will be turned off. This is shown on the developed user interface in Fig. 5. However, if the temperature is lower than ideal, the air conditioner will be turned off, and the fan will be turned on.

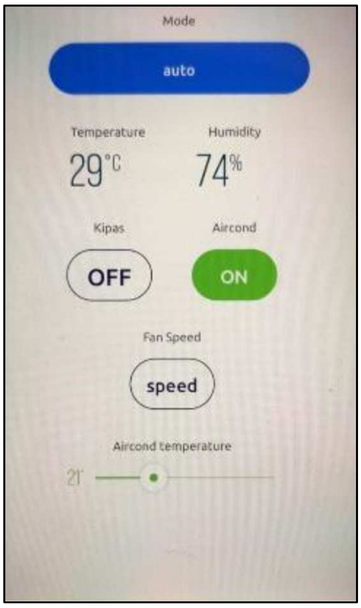

Fig. 5 User Interface

III. Results and Discussion

This section discusses and analyses the proposed solution's capability to minimize energy consumption. The proposed solution system was tested on two different days. On Day 1, it was installed, while on Day 2, it was not installed. The clamp current and voltage sensors were used to read the power consumption.

Fig. 6 shows the proposed system detecting the occupants' presence within 24 hours. No motion was detected between 8:00 a.m. and 5:00 p.m. The reason was that the occupant left for work at 8:00 a.m. and returned home at 6:00 p.m. The system detected motion during that period since the occupants were at home from 6:00 p.m. until 7:00 a.m. (the next morning). However, no results were obtained for Day 2 because no system was installed.

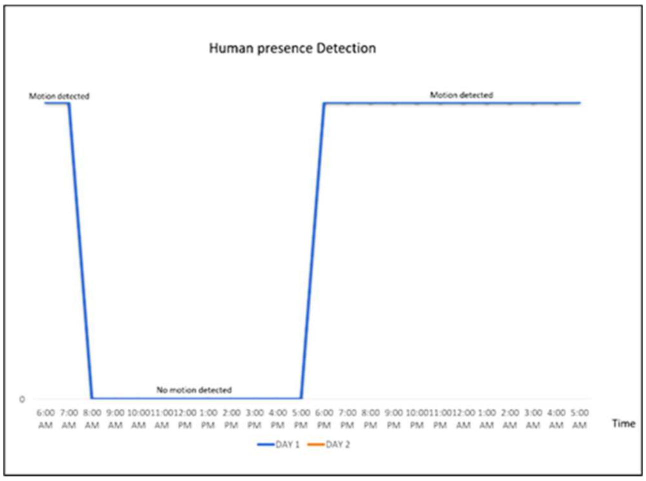

Fig. 6 Human Presence

Fig. 7 shows the average room temperature over a two-day period for 24 hours. The proposed system was configured to obtain the hourly temperature and humidity readings. The room temperature was 26°C on both Day 1 and Day 2.

The power consumption of the electrical appliances is calculated as follows

$$p = v \times c \tag{1}$$

where p is the power consumption in watts, v is the voltage, and c is the electricity current in amperes (amp). The energy consumption is calculated as follows

$$e = \frac{p \times t}{1000} \tag{2}$$

where, e is the energy in kilowatt per hour (kW/h), and t is the duration of the electrical appliances in operation.

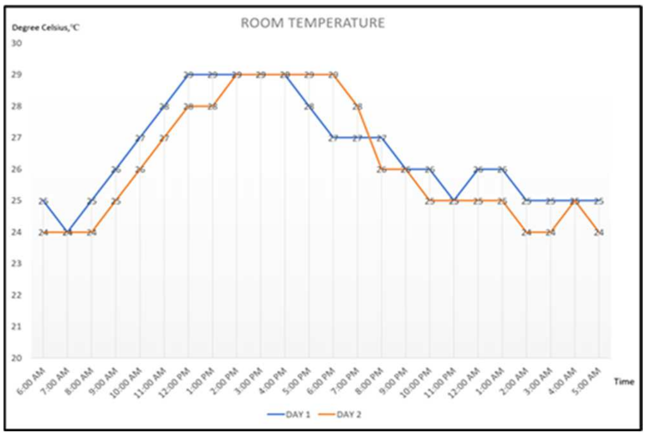

Fig. 7 Room Temperature

The electricity cost in Ringgit Malaysia (RM), ϵ, is calculated as follows.

$$\epsilon = \frac{e \times r}{100} \tag{3}$$

where, r is the tariff rate. Table II shows the power consumption for Day 1 (the proposed system that was in use) and Day 2 (the proposed system that was not in use).

TABLE II
AVERAGE ENERGY CONSUMPTION

	Day 1 (Using Automatic Control System)				Day 2 (Not Using Automatic Control System)			
	Air conditioner		Fan		Air conditioner		Fan	
Time	**Status**	**Power used, W**	**Status**	**Power used, W**	**Status**	**Power used, W**	**Status**	**Power used, W**
6:00 am	OFF		ON	45	ON	1,210	OFF	
7:00 am	OFF		ON	42	ON	1,320	OFF	
8:00 am	OFF		OFF		ON	1,310	OFF	
9:00 am	OFF		OFF		ON	1,315	OFF	
10:00 am	OFF		OFF		ON	1,300	OFF	
11:00 am	OFF		OFF		ON	1,280	OFF	
12:00 pm	OFF		OFF		ON	1,270	OFF	
1:00 pm	OFF		OFF		ON	1,270	OFF	
2:00 pm	OFF		OFF		ON	1,260	OFF	
3:00 pm	OFF		OFF		ON	1,250	OFF	
4:00 pm	OFF		OFF		ON	1,245	OFF	
5:00 pm	OFF		OFF		ON	1,250	OFF	
6:00 pm	ON	1,100	OFF		ON	1,250	OFF	
7:00 pm	ON	1,210	OFF		OFF	1,250	OFF	
8:00 pm	ON	1,320	OFF		OFF		ON	41
9:00 pm	OFF		ON	45	OFF		ON	41
10:00 pm	OFF		ON	43	OFF		ON	43
11:00 pm	OFF		ON	43	OFF		ON	45
12:00 am	OFF		ON	41	OFF		ON	45
1:00 am	OFF		ON	42	OFF		ON	43
2:00 am	OFF		ON	43	OFF		ON	43
3:00 am	OFF		ON	43	OFF		ON	42
4:00 am	OFF		ON	44	OFF		ON	42

	Day 1 (Using Automatic Control System)				Day 2 (Not Using Automatic Control System)			
	Air conditioner		Fan		Air conditioner		Fan	
Time	**Status**	**Power used, W**	**Status**	**Power used, W**	**Status**	**Power used, W**	**Status**	**Power used, W**
5:00 am	OFF		ON	45	OFF		ON	43
Average power consumption per hour, W	1,210		43		1,272		43	
Total hours 'On'	3		11		13		10	
Energy consumption, kWh	3.63		0.47		16.54		0.43	
Total energy consumption by day, kWh	4.1				16.97			
Electricity cost (RM) per day	First 200 kWh (1-200 kWh) per month: (4.1 * 21.8) / 100 = RM 0.98				First 200 kWh (1-200 kWh) per month: (16.97 * 21.8) / 100 = RM 3.70			

During Day 1, the air conditioner was turned on between 6:00 p.m. and 8:00 p.m. because the motion sensors detected human presence, and the room temperature was above the ideal temperature. However, the fan was turned on between 9 p.m. and 5 a.m. because the motion sensors detected human presence below the ideal temperature. Therefore, the total energy consumption was 4.1 kWh while the electricity cost was RM 0.89. During Day 2, another scenario was tested where the occupant forgot to turn off the appliances before leaving for work from 6 a.m. to 6 p.m. Consequently, the appliances (the air conditioner and the fan) remained running even though nobody was present. The total energy consumption was 16.97 kWh, while the electricity cost was RM 3.70. The difference between Day 1 and Day 2 is RM 2.81. If this happens continuously until the end of the month, much more energy consumption could be obtained on Day 2, and this could cause higher electricity bills. Fig. 8. shows an output sample where the power consumption can be monitored via a web-based interface. In summary, implementing the proposed IoT-based system, which could be closely controlled and monitored by the occupants, could reduce energy consumption and electricity bills.

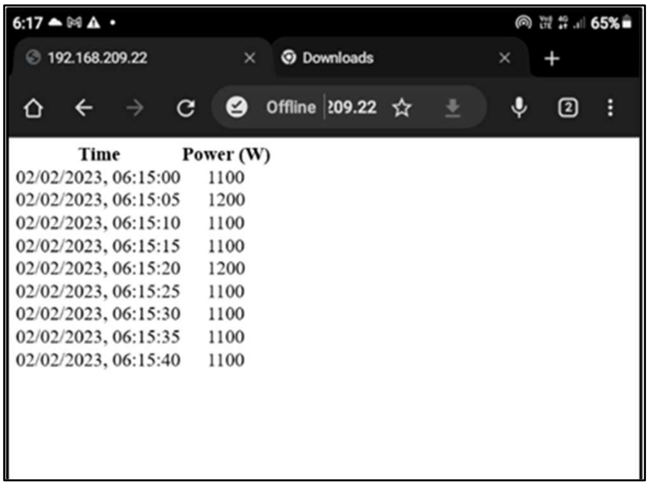

Fig. 8 Output Sample for Monitoring Power Consumption

IV. Conclusion

In this paper, we have proposed an automatic system to alternately switch on/off an air conditioner and a fan based on motion detection and room temperature. The proposed system switched off the air conditioner and switched on the fan when the room temperature was below an ideal temperature and if the occupant was present. The results proved that energy consumption and electricity bills could be reduced. The developed mobile application displayed energy consumption and room temperature for monitoring purposes. Besides, the on/off state can be controlled by using the mobile application. As for future work, the proposed system could be improved by determining over-limited energy consumption. On top of that, this research would be best to try on simulation to get better results.

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