Development of Web-Based IoT Comfort Index and Electricity Consumption Estimation Monitoring Microcontroller System with Wireless Sensor Modules for Air-Conditioning System

Hazlina Selamat[1], Mohamad Fadzli Haniff[2,*], Aminudin Abu[2], Mohd Azlan Abu[3], Radhir Sham Mohamad[2], Muhammad Nur Azam Azizuddin[2]

[1] Laboratory of Thermal and Energetic Systems Studies (LESTE) at the National School of Engineering of Monastir, University of Monastir, Tunisia
[2] Malaysia–Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
[3] Pattern Recognition & Robotics Automation (PRA), Malaysia–Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia

ARTICLE INFO	ABSTRACT
	Nowadays, electricity consumption especially in Malaysia has increased by the year. One of the factors that led to the increase in electricity consumption of a building is the usage of air conditioners (AC). The inability of conventional AC remote controls to monitor indoor environment conditions of the building will lead to unnecessary extreme temperature setting, then causing unnecessary high electrical consumption. Also, the conventional AC remote control is not able to store and perform analysis on the environment condition data of the building for the use of energy management strategy. The conventional AC remote control is only able to show the temperature set point value of the system, which could not represent the comfort experienced by occupants. In this project, a new device which can monitor the indoor environment condition and estimated electricity consumption on a web server is developed. The device monitors a comprehensive thermal comfort index Predicted Mean Vote (PMV) representing the comfort experienced by the occupants. The device is equipped with wireless sensor modules for indoor and outdoor remote monitoring. The device can monitor the outdoor temperature, indoor temperature, and indoor relative humidity along with indoor PMV value and electricity consumption. This device can grant advance feature to conventional AC remote control without causing physical modification to the existing system.

1. Introduction

From the report extract of the Electricity Market Report of December 2020, Malaysia is ranked as the fourth largest percentage among the ten ASEAN countries after Indonesia, Vietnam and Thailand in terms of electricity consumption by its citizens [1]. The electricity consumption by all sectors in

---

* Corresponding author.
E-mail address: mfadzlihaniff@utm.my

Malaysia has been increasing annually since 1990 [2]. The electricity consumption in Malaysia is mostly contributed by industry, transport, and residential and commercial sectors [2]. As one of the rapidly developing second world countries, the density of the population of Malaysia is increasing over the years and is predicted to continue the trend in the future [3]. Increase in population will lead to increase of residentials or households, thus directly contributing to higher electricity consumption of Malaysia especially with the work from home (WFH) initiative that are starting to be practiced partially by some companies [4,5]. In residential buildings, air-conditioning (AC) contributes to highest electricity consumption among electrical appliances which are not used for 24-hour a day [6]. 68.7% of households in Malaysia own air-conditioning (AC) system units to cool down the temperature of the room in this warm climate country [7].

Although there are various kinds of AC systems developed and introduced in the market nowadays which are able to help in consuming less electricity, most of them are very costly and inconvenient to households with existing conventional AC systems. The conventional AC system remote control is very limited in terms of the functions and operation, where users can only set the temperature and fan speed of the AC system without being able to monitor the household indoor and outdoor environment along with the electricity consumption of the AC system [8]. Inability to monitor previously stated parameters lead to the user to set the AC system to unnecessary extreme cool temperature thus causing high electricity consumption [8-10].

Monitoring only the indoor temperature of a room is inaccurate to represent the comfort level experienced by the occupants inside the building. Comprehensive thermal comfort index called Predicted Mean Vote (PMV) is an index recommended by ISO 7730 which takes six indoor parameters values into one index value to represent the comfort experienced by occupants inside a building [8-10]. The six indoor parameters are activity (metabolism rate), air temperature, mean radiant temperature, air velocity, relative air humidity and clothing insulation.

Monitoring electricity consumption of an electrical appliance is usually done by measuring the voltage and current flowing inside the appliance which requires physical clipping of electrical wiring. Electricity consumption can be estimated by using equations such as from Zapater and Arroba [8,10]. The equation utilises the indoor and outdoor temperature along with the AC system BTU/h cooling capacity to calculate the coefficient of performance and then estimate the system electricity consumption.

The monitored indoor and outdoor parameters with the electricity consumption data should be stored and then analysed for the purpose of energy management strategy. Due to this, it is important for monitoring systems nowadays to have the capability to store the data in cloud storage.

This paper proposed a new AC system device which is able to monitor the indoor and outdoor parameters, PMV comfort levels and estimated electricity consumption of the AC system. The monitoring will also be done on a web server where the data can be stored and used for the user to come up with the household energy management strategy to maintain comfort without consuming high electricity. Section 2 discusses the algorithm used in this device. Section 3 explain about the device construction, IoT platform and the operational layout. Section 4 presents the monitoring results obtained by using the developed device. Lastly this paper is concluded in Section 5.

2. Algorithms

In this section, two algorithms used in this device will be discussed. First is the comfort index Predicted Mean Vote (PMV) used as the comfort indicator for the monitoring system. Second algorithm is an electrical consumption estimation algorithm proposed by Zapater and Arroba.

2.1 Predicted Mean Vote (PMV) Algorithm

PMV is a thermal comfort index recommend in ISO 7730 introduced by Fanger in 1970 which considers six parameters; activity or metabolism rate (M) in unit of Met, indoor air temperature (T_{in}) in °C, mean radiant temperature (T_{mrt}) in °C, air velocity (v_a) in m/s, relative air humidity (RH) in % and clothing insulation (I_{cl}) in clo [11,15-17]. PMV is a one value parameter but yet comprehensive comfort parameters when compared to IAQ which have big numbers of parameters. PMV value ranges from -3 (cold) to +3 (hot) with 0 being neutral as shown in Figure 1. The recommended comfortable value of PMV is between -0.5 to +0.5. PMV can be calculated by using Eq. (1).
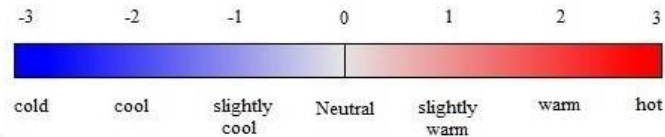

Fig. 1. Configuration 1 and mixed boundary conditions

$$PMV = (0.303 * e^{-0.036M} + 0.028) * L \tag{1}$$

$$\begin{aligned} L = M - W &- 3.05 * 10^{-3} * (5733 - 6.99 * (M - W) - p_a) - 0.42 * ((M - W) - 58.15) \\ &- 1.7 * 10^{-5} * M * (5687 - p_a) - 0.0014 * M * (34 - T_{in}) \\ &- 3.69 * 10^{-8} * f_{cl} * ((T_{cl} + 273)^4 - (T_{mrt} + 273)^4) - f_{cl} * h_{cl} * (T_{cl} - T_{in}) \end{aligned} \tag{2}$$

$$\begin{aligned} t_{cl} = 35.7 &- 0.028 * (M - W) - I_{cl} * (3.69 * 10^{-8} * f_{cl} * ((T_{cl} + 273)^4 - (T_{mrt} + 273)^4) \\ &- f_{cl} * h_{cl} * (T_{cl} - T_{in}) \end{aligned} \tag{3}$$

$$p_a = \frac{p_s RH}{100} \tag{4}$$

$$\ln p_s = \frac{C_1}{T} + C_2 + C_3 * T + C_4 * T^2 + C_5 * T^3 + C_6 * \ln T \tag{5}$$

where

$C_1 = -5.8002206 * e^3$
$C_2 = 1.3914993$
$C_3 = -4.8640239 * e^{-2}$
$C_4 = 4.1764768 * e^{-5}$
$C_5 = -1.4452093 * e^{-8}$
$C_6 = 6.5459673$
$T = T_{in} + 273.15$

$$h_{cl} = \begin{cases} 2.38(T_{cl} - T_{mrt})^{0.25} & 2.38(T_{cl} - T_{in})^{0.25} < 12.1\sqrt[2]{v_a} \\ 12.1\sqrt[2]{v_a} & 2.38(T_{cl} - T_{in})^{0.25} > 12.1\sqrt[2]{v_a} \end{cases} \tag{6}$$

$$f_{cl} = \begin{cases} 1.00 + 0.2I_{cl} & I_{cl} < 0.5clo \\ 1.05 + 0.1I_{cl} & I_{cl} > 0.5clo \end{cases} \tag{7}$$

Due to the uncertainties and complexity, it is important and necessary for some parameters to be assumed instead of measured directly as in [10,12,13]. So in this project T_{mrt} will be assumed as the average between on T_{in} and T_{out} instead of measured using complex configuration as in [10].

2.2 Electrical Consumption Estimation Algorithm

Zapater and Arroba introduced a way to estimate or calculate the hourly electricity consumption (Watt per hour, W/h) of AC system only just by knowing limited information such as outdoor temperature (T_{out}), indoor temperature (T_{in}) and the cooling capacity of the AC unit in BTU/h [14]. First, the maximum coefficient of performance (COP_{max}) of the AC system need to be determined by based on T_{in} and T_{out}. Then the hourly electricity consumption can be calculated based on the BTU/h and assuming the AC system operate at $0.1 \times COP_{max}$. The equations to be used in estimating the hourly electricity consumption is as below

$$Electricity\ Consumption, \frac{W}{h} = \frac{\frac{BTU}{h}}{3.41 \times (0.1 \times COP_{max})} \quad (8)$$

$$Maximum\ Coefficient\ of\ Performance, COP_{max} = \frac{T_{in}}{T_{out} - T_{in}} \quad (9)$$

3. PMV and Estimated Electricity Consumption Monitoring Device

This section will present the schematics for the monitoring device which are divided into Wireless Sensor Modules and Main Control Device. The IoT based platform ThingSpeak Web Server will also be presented. Then the project operational layout will also be presented later to show how the system will operate in a building

3.1 Wireless Sensor Modules

This module enables the data monitoring of temperature and humidity using DHT22 sensor to be done remotely further from the Main Control Device by using the wireless transmission of data. Microcontroller NodeMCU ESP32 (programmed with Arduino IDE) is used for this sensor module with the addition of NRF24L01 which able to transmit and received data by using radio frequency signal within 2.5Ghz frequency range and 10-meter communication range. In this device the NRF24L01 will function as data transmitter sending the temperature and humidity data to Main Control Device as shown in Figure 2. Two units of Wireless Sensor Modules is developed for remote indoor and outdoor monitoring. Figure 3 shows the schematic connection of the components for this module. When this module is turned ON, it will continuously be measuring and then transmitting the data.
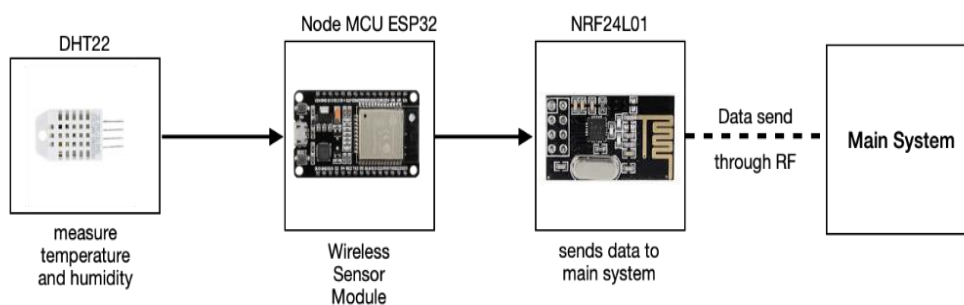

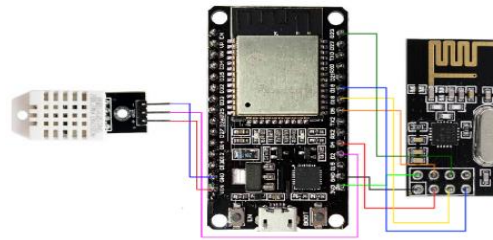**Fig. 2.** Wireless sensor module data transmission

Fig. 3. Schematic connection of wireless sensor module

3.2 Main Control Device

The Main Control Device is where all the data from the wireless sensor modules will be gathered and processed as PMV value and estimated electricity consumption value. As shown in Figure 4, the data transmitted from remote indoor and outdoor monitoring using NRF24L01 will be received by Main Control Device which also uses NRF24L01 as the receiver device. After the PMV value and estimated electricity consumption value is processed, all the measured and processed value will be sent by the NodeMCU ESP32 to the IoT platform through Wifi connection for web-based monitoring and also displayed on the LCD display. This device is also equipped with keypad to set certain parameters before operating. Figure 5 shows the schematic connection of the components in this device.
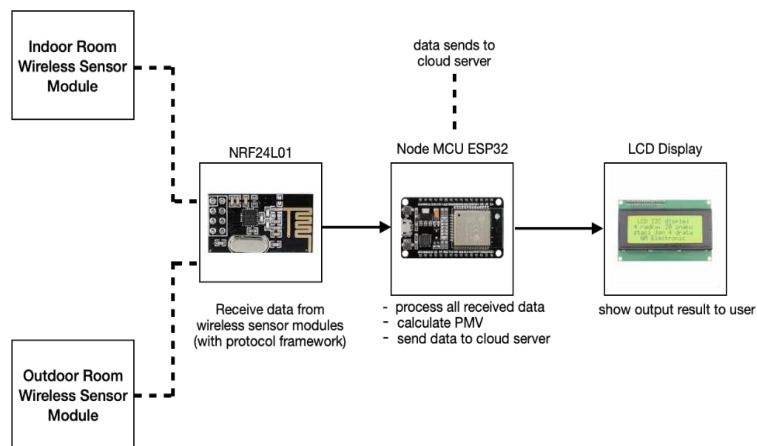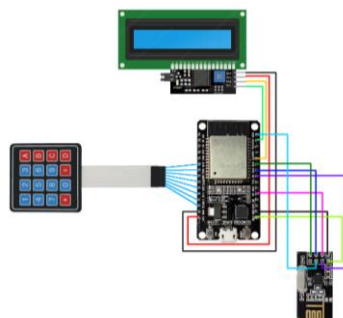

Fig. 4. Main control device data movements

Fig. 5. Schematic connection of main control device

Before the system can start monitoring, some parameters need to be set or configured first; which are the cooling capacity (BTU/h), metabolism rate (M), air velocity (v_a) and clothing insulation (I_{cl}). Among the five parameters to be set, M, v_a and I_{cl} were divided into 3 categories to simplify the selection as shown in Table 1.

Table 1
M, v_a and I_{cl} categories

Category	M		v_a		I_{cl}	
	Description	Value (Met)	Description	Value (m/s)	Description	Value (clo)
1	Seat, Working	1	Favourable	0.2	Light	0.47
2	Seat, Working, Talking	1.4	Awareness	0.5	Medium	0.731
3	Walking	2.5	Annoyance	1	Heavy	1.25

3.3 ThingSpeak Web Server

Thingspeak was originally created by MathWorks, is a website for Internet of Things (IoT) cloud platform where we can use devices that are embedded with tools that enables it to connect to the internet to send and store sensor data to cloud database servers. In this web server, all the measure data will be displayed, and user can see the data progressing from the time to time.
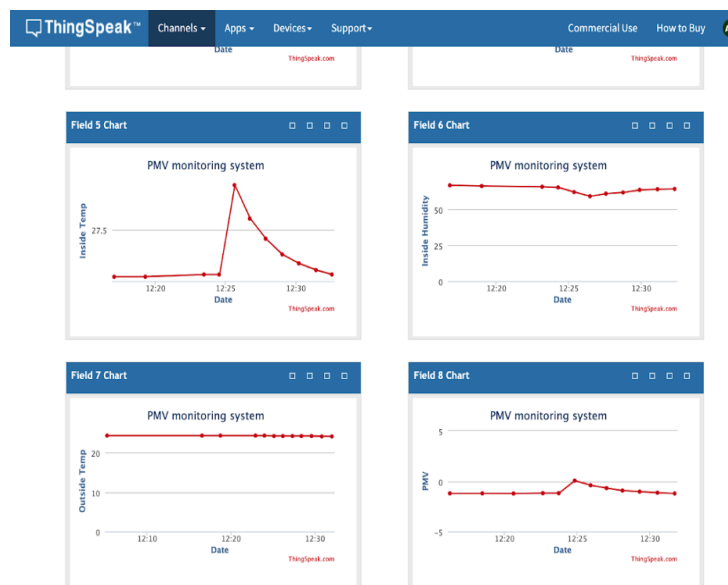

Fig. 6. Monitoring measure and calculated parameters in Thinkspeak

3.4 Project Operational Layout

The two wireless sensor modules will be located indoor and outdoor each in the position suitable for measurement without any disturbance from other thermal element. The main control device can be placed anywhere in the building easy for the user to access. The full project operational layout can be seen in Figure 7 below.
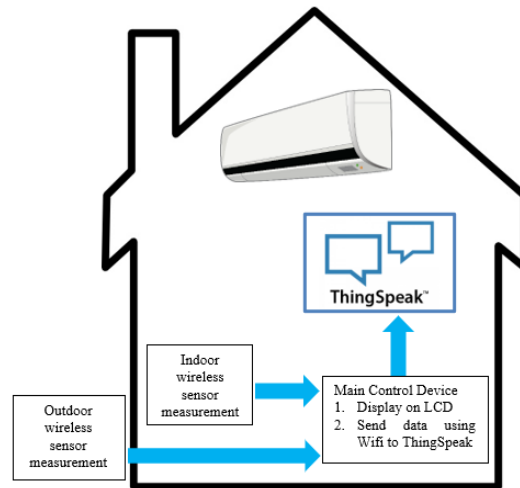
Fig. 7. Project operational layout

4. Results and Discussion

In this paper, two kinds of tests were done using two sets of the systems, first is the monitoring comparison of turning ON and OFF AC system, the second is testing the Early ON and Early OFF effect. The same experiment setting is used for both tests. The activity or metabolism rate (M) set for both room is seating and working (1 met or 58 W/m^2) , clothing insulation is light (0.47 clo), air velocity is 0.2 m/s, set temperature is 21℃, BTU/h of the AC system is 10,000.

4.1 Difference between turning ON and OFF AC systems (Outdoor Temperature, Indoor Temperature, Relative Humidity, PMV and Hourly Electricity Consumption)

A monitoring test was done at the same day (0800h to 1700h) on two identical room located side by side; Room A with its AC system turned OFF and Room B with its AC system turned ON. The data collected are outdoor temperature (T_{out}), indoor temperature (T_{in}), relative humidity (RH), predicted mean vote (PMV) and hourly electricity consumption (Wh).

Figure 8 shows the T_{out} of the test day. It is shown that the temperature increases from 0800h to 1100h, then it fluctuates within 33℃ to 42℃ until around 1400h. After 1400h, the temperature starts to decrease then fluctuates within 33℃ to 36℃. The fluctuation is caused by the movement of cloud that shaded the building and reduce the temperature exposed to the outdoor wireless sensor module. It is expected, lesser fluctuation of temperature will occur during night-time due to the absence of direct sunlight and effect of cloud movement.
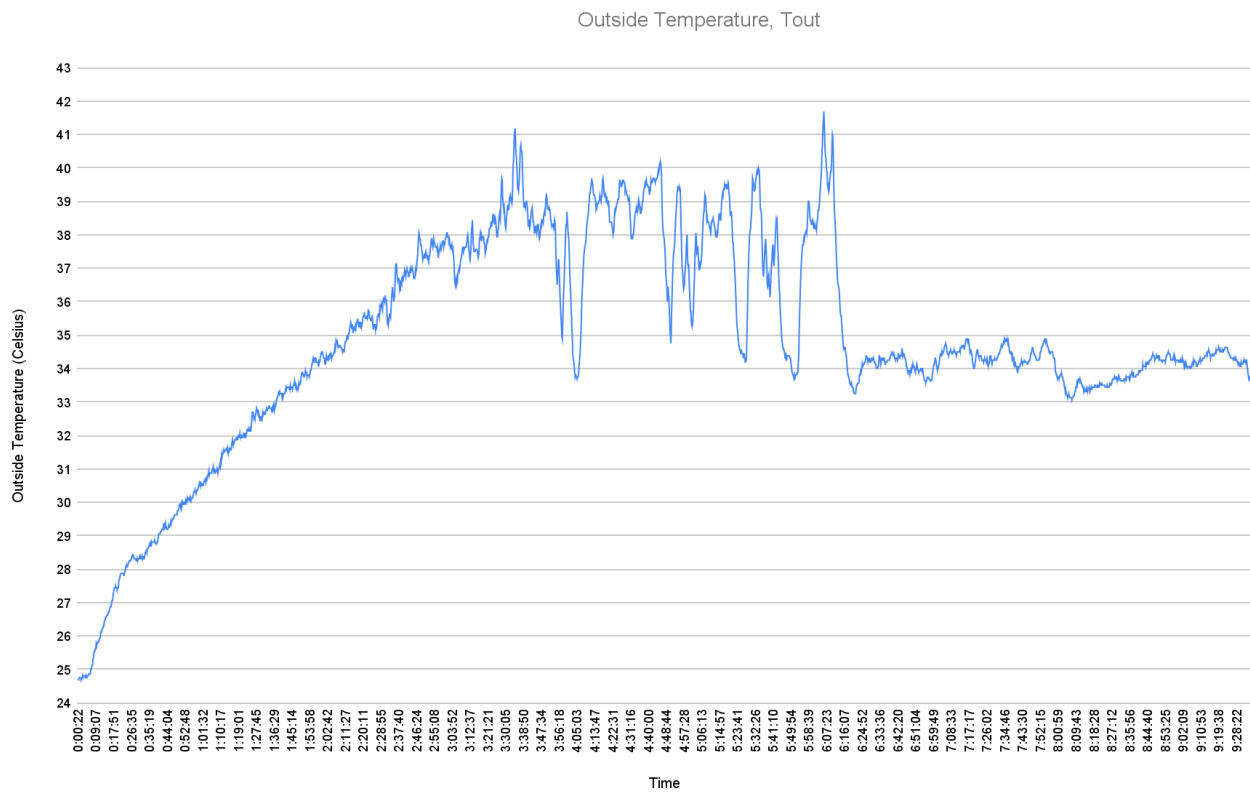
Fig. 8. Outdoor temperature (T_{out}) from 0800h to 1700h

Figure 9 shows the T_{in} of both Room A and Room B. It can be seen that the temperature in Room A is following the trend of T_{out} where it increased until 1400h and then reduced slightly and stay within a certain ranged of temperature. T_{out} affect T_{in} due to the thermal transfer from outside wall to inside wall. Then the inside wall increases the indoor temperature. The fluctuation of temperature can't be seen in T_{in} due the time taken for the thermal transfer is not immediate, so the cloud movement is not able to give significant impact to T_{in}. Meanwhile T_{in} in Room B is decreased at first until 1000H, then started to fluctuate between 18℃ to 22℃. This shows that the conventional AC system is cooling the room but not with constant value. After certain temperature is achieved, the compressor is working in higher efficiency (to store cool air at lower temperature) and lower efficiency (stored cool air assisting providing comfort until the desired temperature) in relay thus causing this T_{in} fluctuation. Here it can be seen that the AC system is maintaining around 4℃ range of fluctuation near the desired temperature 21℃.
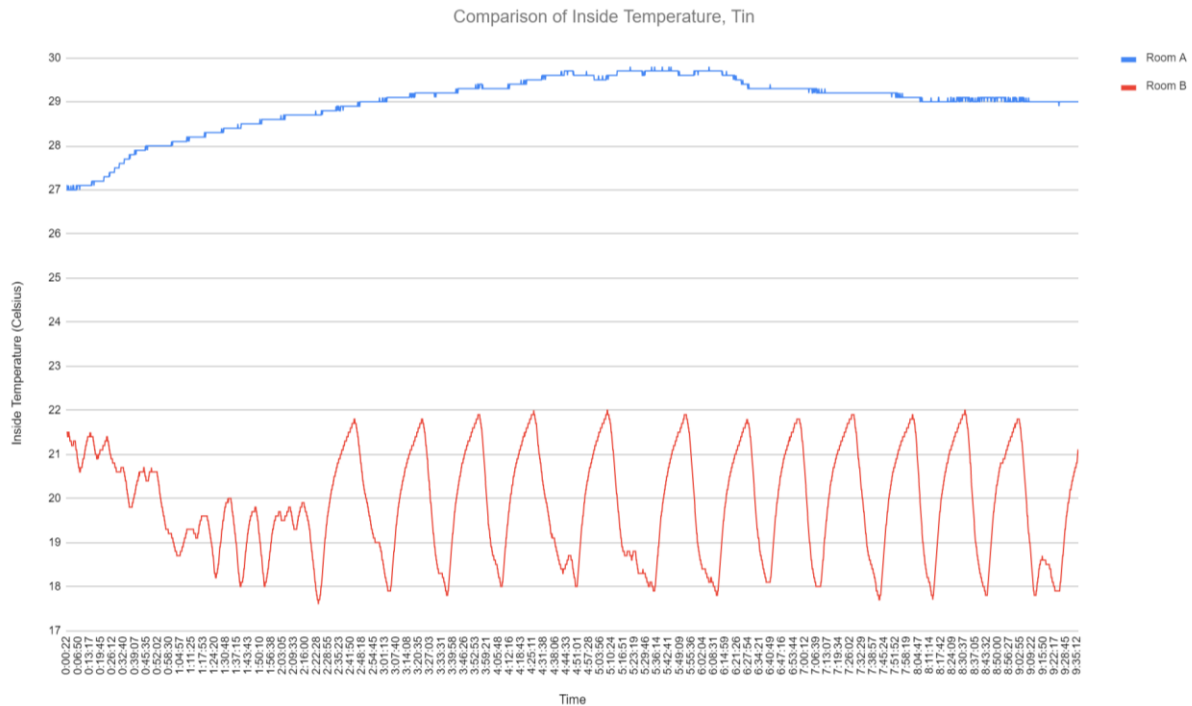
Fig. 9. Indoor temperature (T_{in}) from 0800h to 1700h

Figure 10 show the RH of both Room A and Room B. RH in Room A seem to decrease throught the day, with the lack of humidity provided to the room, the room is getting dryer as the day goes by. But in Room B, the humidity increased slightly until 1000H and the start to fluctuates between 62% to 82%. The humidity provided by conventional AC system seem is also based on the compressor higher and lower performance relay operation.
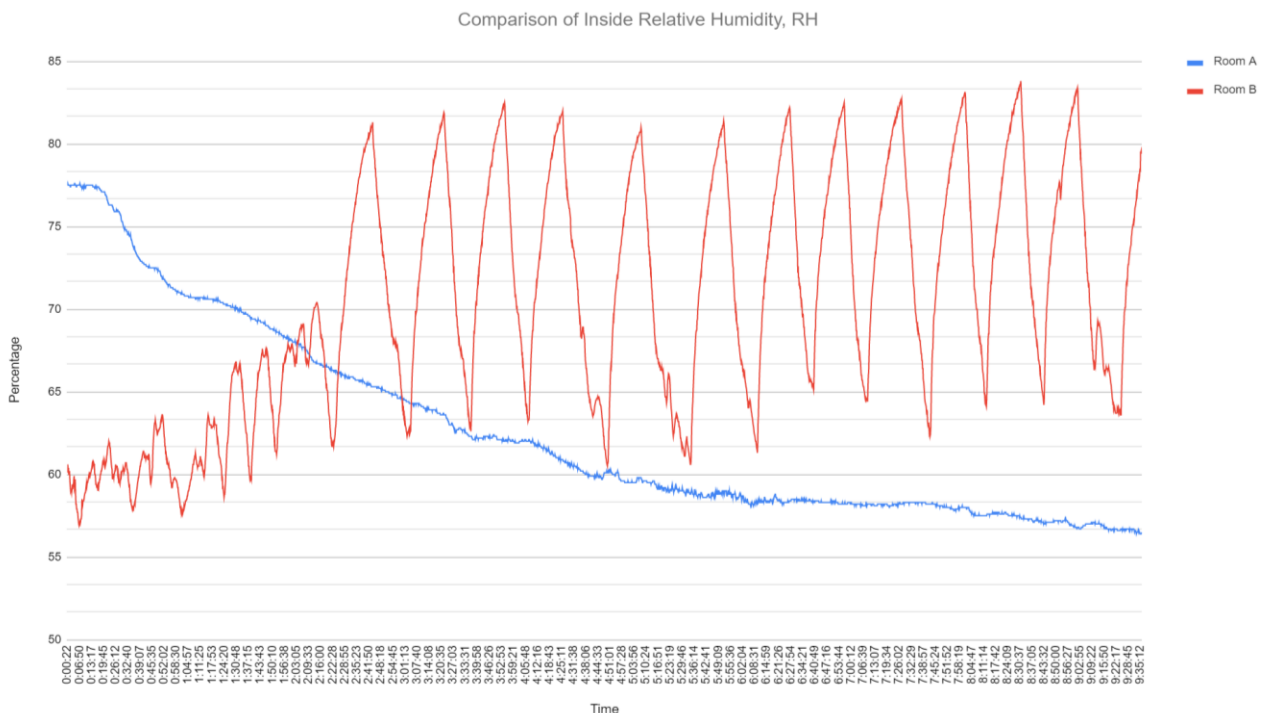

Fig. 10. Relative humidity (RH) from 0800h to 1700h

In Figure 11, the PMV for both Room A and Room B is shown, where it can be seen that the PMV of Room A for the test duration increased from +0.5 to a peak value +2 and then dropped to +1.5. This shows that the occupants in the space will experience between slightly warm and warm environment. Meanwhile in Room B, the value of PMV is constantly changing within the range of -1 to 0, which means the environment in the room is between slightly cold to neutral. Although both rooms have a PMV value which not following the recommended ±0.5 value, the PMV in Room B is less extreme than Room A in term of the PMV violation. This indicate that the AC system is able to provide a better comfort in the room.
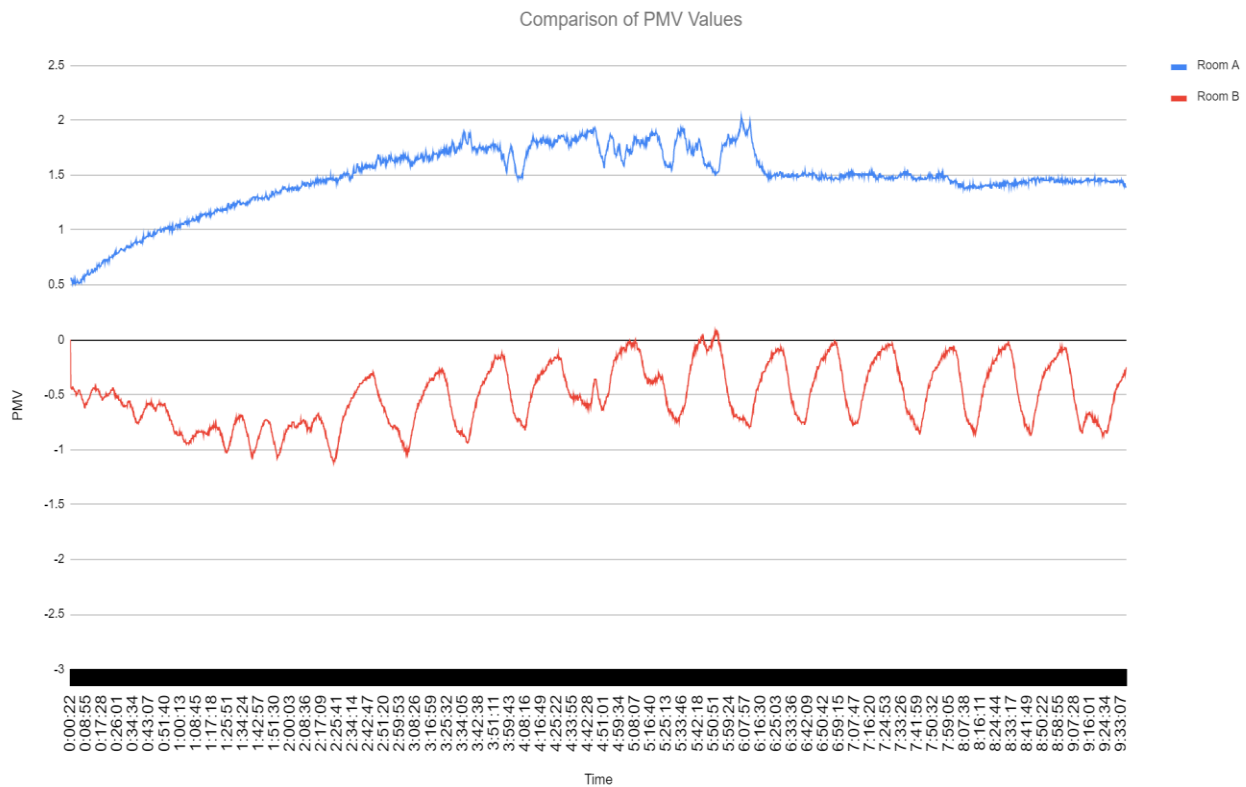

Fig. 11. Predicted Mean Vote (PMV) from 0800h to 1700h

The electricity consumption of AC unit in Room B is shown in Figure 12 in the unit of Wh. By comparing with Figure 8, as T_{out} increase, the electricity consumption will also increase, based on the equation in Section 2.2. The total electricity consumption during the test period is estimate at 16.14 kWh.

Based on the test done, it shows that AC system can provide better PMV comfort which slides toward negative range of the index. It also shows that AC system compressor will not work constantly at high performance in providing the cool air based on the set temperature, instead if will switch between high and lower performance in order to utilize the stored cool air inside the room during high performance to assist providing comfort during lower performance. Due to this, T_{in}, RH and PMV also oscillates at certain range instead of being a constant value.
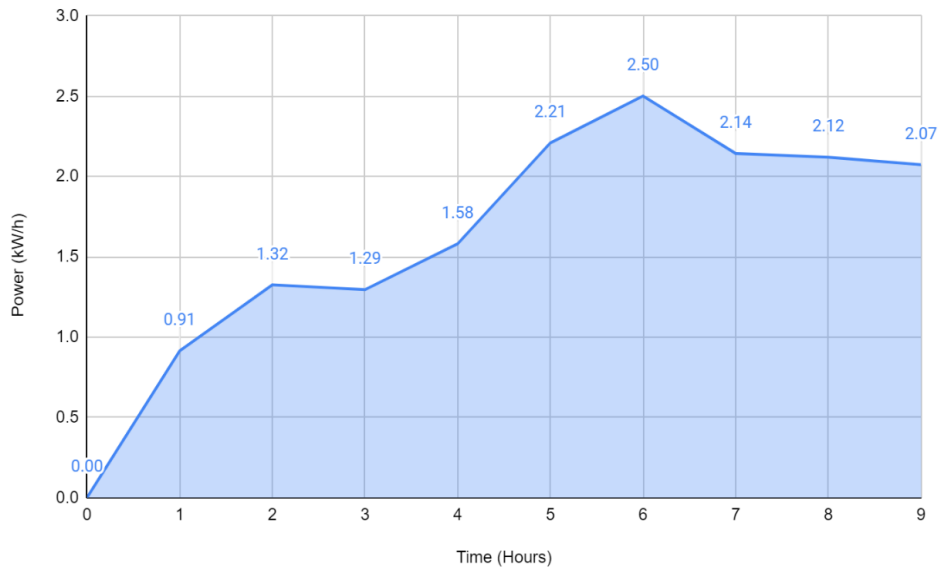
Fig. 12. Electricity Consumption from 0800h to 1700h

4.2 Effect of Early ON and Early OFF of AC System to PMV

In this section, two kind of tests were done on one room with conventional AC system for two different days. First test is to observe how long will it take for conventional AC system to bring down the PMV value inside the room to be within recommended ±0.5 range. Occupants of a building expects to feel comfort as soon as they enters the room, which means the AC system need to be turned ON early. Second test is to observe how long will the room able to maintain its comfort within acceptable ±0.5 range after the AC system is turned OFF. Turning OFF the AC system earlier than the actual end of occupancy period will be able to reduce the electricity consumption of the system without violating the comfort.

Figure 13 show the two days Early ON test results. In both day, the PMV of the room dropped to +0.5 within around 30 minutes after the AC system is turned ON at 0800h. 5 to 8 minutes later, the room PMV dropped to neutral comfort value of 0. This duration is affected by T_{out} during the test. The T_{out} during Day 1 is slightly higher than Day 2 in general, which is why the time taken for the PMV to go down to 0 in Day 1 is slightly longer than Day 2. Based on this results, if the occupants want to feel neutral PMV comfort right after entering the room, the AC system need to be set to turn ON at least on 0722h earlier.

The PMV performance during Early OFF is shown in Figure 9. In this test, the room PMV was at -0.6 before the AC system is turned OFF at 1500h. The Figure shows that for both day, it takes about 10 minutes for the comfort value to increase to neutral 0. In general the PMV for Day 1 increase faster than Day 2 because of higher T_{out} during the test on Day 1. It is also shown that even after 40 minutes, the comfort inside the room is still within the ±0.5 recommend range. Based on this results, even if the AC system is turned OFF at 1415h the PMV inside the room will not be violating the recommended range by ISO 7730. A great amount of electricity can be reduced.

Based on the Early ON and Early OFF test done on the room, it can be concluded that the occupants should turn ON the AC system earlier than their occupancy schedule in order to feel immediate comfort. In order to reduce the electricity consumption without violating the comfort recommendation, the AC system can be turned OFF earlier than the end of their occupancy schedule. If the violation PMV value is +0.5, the short Early ON period will not consume too high electricity and longer period between Early OFF and PMV violation will reduce the electricity consumption greatly.
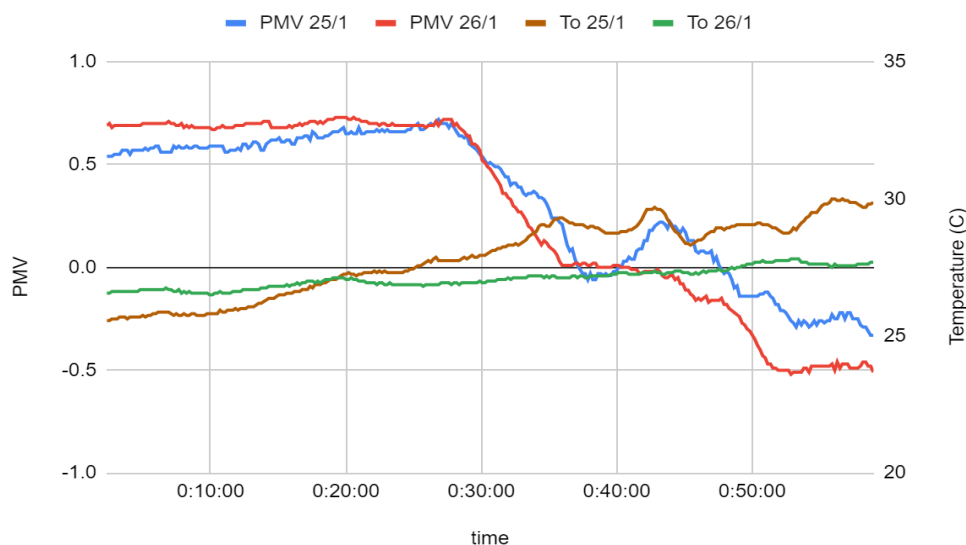
Fig. 13. PMV value during Early ON

5. Conclusions and Future Works

In this project, the objective of developing an IoT based monitoring system for comfort and estimated electricity consumption when using AC system is achieved. They system can monitor the outdoor temperature (T_{out}), indoor temperature (T_{in}), relative humidity (RH), predicted mean vote (PMV) and hourly electricity consumption (Wh). With the wireless sensor module, the device is able to do monitoring of indoor and outdoor environment remotely.

From the tests done, the results shown were able to help the user to understand how AC system works in providing comfort. The data obtained from the monitoring can be used for the user to strategize their AC system usage. Early ON and Early OFF methods could be the basic energy management strategy to be used in this case. The user can study how early should the AC system should be turned ON to experience immediate recommended comfort and how early it should be turned OFF to reduce electricity consumption without violating the comfort in the room.

In the future, this project could be extended with an AC system temperature control feature which able to automatically control the comfort level within the recommended or desired range. The device will enable the advance use of conventional AC system without any physical modification to the system.

References

[1] Regional. Southeast Asia. "Electricity Market Report - December 2020 – Analysis. 2020." IEA.
[2] Malaysia. Suruhanjaya Tenaga, Putrajaya/Energy Commission. *Malaysia Energy Statistics. Suruhanjaya Tenaga Putrajaya/Energy Commission*, 2020.
[3] Statista. "Total population of Malaysia 2026." Statista. November 3, 2021.
[4] Institute of Energy Policy and Research. *The Impact of COVID-19 on Electricity Consumption in the Residential Sector. Policy Brief*, 2021.
[5] Malay Mail. "Residential electricity usage soared 23pc during MCO, says the Energy Ministry. Malaysia |" May 30, 2020. Malay Mail.
[6] Mohammed, Nabil, Kumeresan A. Danapalasingam, and Ahmed Majed. "Design, control and monitoring of an offline mobile battery energy storage system for a typical malaysian household load using PLC." *Int J Power Electron Drive Syst* 9, no. 1 (2018): 180-188. https://doi.org/10.11591/ijpeds.v9.i1.pp180-188
[7] Aqilah, Naja, Sheikh Ahmad Zaki Shaikh Salim, Aya Hagishima, Nelidya Md Yusoff, and Fitri Yakub. "Time series data measurement on electricity consumption for selected domestic appliances in typical terrace house of

Malaysia." *Bulletin of Electrical Engineering and Informatics* 8, no. 3 (2019): 1144-1153. https://doi.org/10.11591/eei.v8i3.1601

[8]   Othman, Norzalina, Mohamad Fadzli Haniff, Hazlina Selamat, Tuan Muhammad Syahmi Tuan Saha'Arif, Muhammad Al'Hapis Abdul Razak, Mohd Usairy Syafiq Sama'in, and Julaida Abdul Jalil. "Air Conditioning System Comfort Level and Power Consumption Monitoring Device with RF-Based Wireless Sensor Modules and Android Mobile Application." In *Progress in Engineering Technology IV*, pp. 255-272. Cham: Springer International Publishing, 2022. https://doi.org/10.1007/978-3-030-93250-3_22

[9]   Selamat, Hazlina, Mohamad Fadzli Haniff, Zainon Mat Sharif, Seyed Mohammad Attaran, Fadhilah Mohd Sakri, and Muhammad Al'Hapis Bin Abdul Razak. "Review on HVAC System Optimization Towards Energy Saving Building Operation." *International Energy Journal* 20, no. 3 (2020).

[10] Haniff, Mohamad Fadzli, Hazlina Selamat, Nuraqilla Khamis, and Ahmad Jais Alimin. "Optimized scheduling for an air-conditioning system based on indoor thermal comfort using the multi-objective improved global particle swarm optimization." *Energy Efficiency* 12 (2019): 1183-1201. https://doi.org/10.1007/s12053-018-9734-5

[11] ISO, ISO7730. "7730: Ergonomics of the thermal environment Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria." *Management* 3, no. 605 (2005): e615.

[12] Rani, Mohd Rahairi, Hazlina Selamat, Hairi Zamzuri, and Fauzan Ahmad. "PID controller optimization for a rotational inverted pendulum using genetic algorithm." In *2011 Fourth International Conference on Modeling, Simulation and Applied Optimization*, pp. 1-6. IEEE, 2011. https://doi.org/10.1109/ICMSAO.2011.5775461

[13] Sandhu, Fargham, Hazlina Selamat, S. E. Alavi, and Vahid Behtaji Siahkal Mahalleh. "FPGA-based implementation of Kalman filter for real-time estimation of tire velocity and acceleration." *IEEE Sensors Journal* 17, no. 17 (2017): 5749-5758. https://doi.org/10.1109/JSEN.2017.2726529

[14] Zapater, Marina, Patricia Arroba, José Luis Ayala Rodrigo, Katzalin Olcoz Herrero, and José Manuel Moya Fernandez. "Energy-Aware policies in ubiquitous computing facilities." *Cloud computing with E-science applications* 2015 (2015): 267-284. https://doi.org/10.1201/b18021-13

[15] Djabir, Djabir Abdoulaye, Azian Hariri, Mohamad Nur Hidayat Mat, and Md Hasanuzzaman. "Thermal Comfort of Indoor Open Spaces at University Library in Malaysia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 94, no. 2 (2022): 142-165. https://doi.org/10.37934/arfmts.94.2.142165

[16] Revichandran, Rajeanderan, Jaffar Syed Mohamed Ali, Moumen Idres, and A. K. M. Mohiuddin. "A Review of HVAC System Optimization and Its Effects on Saving Total Energy Utilization of a Building." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 93, no. 1 (2022): 64-82. https://doi.org/10.37934/arfmts.93.1.6482

[17] Allah, Mohammad Zaraa, Azian Hariri, and Haslinda Mohamed Kamar. "Comparison of Thermal Comfort Condition of Naturally Ventilated Courtyard, Semi-Outdoor and Indoor Air-Conditioned Spaces in Tropical Climate." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 101, no. 1 (2023): 45-58. https://doi.org/10.37934/arfmts.101.1.4558