Jurnal Kejuruteraan 35(6) 2023: 1487-1500
https://doi.org/10.17576/jkukm-2023-35(6)-22

Internet of Things (IoT) Based Air Conditioner Monitoring System for Intelligent Facility Maintenance

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Received 8 May 2023, Received in revised form 18 May 2023
Accepted 18 June 2023, Available 30 November 2023

ABSTRACT

Office buildings often consume high energy to sustain building operations such as HVAC systems. A lack of proper decision-making approaches and a lack of maintenance planning will cause higher operational costs. This paper proposes data analytics for air conditioner's performance in laboratory by using Internet of Things (IoT)-based monitoring system to improve efficiency in facility maintenance. It provides a monitoring system, notification system and performance dashboard to enable data analytics. The data analytics methods used here are i) condition-based maintenance which includes thermal analysis and electrical analysis; and ii) Overall Equipment Effectiveness (OEE) approach. The pre-maintenance performance measured for AC-1 is adequate while AC-2 does not meet the requirement. After the reactive maintenance was performed on AC-2; there was a performance increment of 63.15%. Based on sensors data, it seems to correlate between current draw and low refrigerant. It aids facility maintenance for early failure detection, which helps in decision-making. The result from the OEE approach also suggested the same decision-making to schedule maintenance. Performance needs to balance out to leverage power consumption without hefty operational costs for maintenance strategies. In conclusion, the data analytics provide insight for the maintenance management to monitor and schedule preventive maintenance before air conditioner (AC) faults happen. Meanwhile, the modified OEE approach for ACs to measure performance takes into consideration speed to cool down air and cost to run the AC which has not been explored yet elsewhere.

Keywords: Data analytics; facility maintenance; IoT; decision-making; OEE

INTRODUCTION

Back in the 1980s, facility maintenance in the industry focused on scheduled maintenance based on the runtime of the machine (Cullum et al. 2018; Zou et al. 2019). Predictive and preventive maintenance are intuitive ways to reduce the likelihood of recurrent reactive maintenance which often causes higher maintenance costs and anomaly downtime. Random downtime will incur higher production losses for the facility. Some production lines possess monitoring systems that link directly from the machine to the control room (Aishwarya et al. 2020). Time-based maintenance (TBM) is mainly used in many industries such as palm oil, manufacturing, healthcare and construction industries; however, Industrial Revolution 4.0 (IR4.0) reduced challenges in condition-based maintenance (CBM) faced in the past to be considered functional (Ingemarsdotter et al. 2021). CBM accesses the assets based on various data acquired by sensors which allow users to schedule maintenance; different from TBM which favors time as the sole metric.

IR4.0 inevitably influences industries by providing advantages over improved work efficiency beneficial to conventional factories (Musthafa et al. 2020). Ubiquitous devices ease data acquisition without relying on manual data collection. Big data and the Internet of Things (IoT) synergy very well, resulting in smart healthcare, smart cities, disaster management, intelligent warning systems and etc. (Abdul Razak et al. 2022; Hajjaji et al. 2021). IoT enables data acquisition to be more connected, so any established system connected with IoT platforms will be able to monitor its application on the move. The sizeable amount of data in a database creates problems when processing big data due to the enormous amount of data and complexity.

The power consumption of public office buildings is often consumed ten times higher than residential buildings due to the size of the public office buildings being larger (Hou et al. 2017; Liu et al. 2015). The energy efficiency ratio (EER) plays an important role in power consumption; the higher the rating of the EER, the lower the power consumption of AC (Opoku et al. 2019). There is a study conducted in China, an IoT-based application on AC to monitor and predict the peak of the power consumption for smart controlling methods; the outcome of this study is to reduce the power consumption of the AC (Song et al. 2018).

Due to critical climate changes causing extreme temperatures in certain parts of the world; air conditioner (AC) systems are required to maintain thermal comfort in buildings. Large office buildings often consume more power to operate, which poses a higher threat to the environment (Amasyali & El-Gohary 2018). Energy consumption in office buildings is often scaled heavily on heat, ventilation and, air conditioning (HVAC) machines (Birkha Mohd Ali et al. 2021). The rising usage of AC systems in Malaysia has also caused a rise in energy usage where ACs are responsible for 53% of the total energy and the highest power consumption in office buildings in Malaysia (Aqilah et al. 2021; Toosty et al. 2022). Therefore, the initiative on energy conservation should be initiated to help tackle higher energy consumption in some countries which might end up generating more energy and worsening global warming (Birkha Mohd Ali et al. 2021). Thermal comfort speaks about the temperature in a particular space concerning the user's comfort while in the space. ASHRAE 55-2017 (American Society of Heating Refrigerating and Air-Conditioning Engineers - ASHRAE 2017) stated that the ideal thermal comfort for users in a room is between 19.44°C and 27.78°C while humidity is at 65% to reduce microbial activity. However, Taib et al (Taib et al. 2022) reported that the ideal mean temperature to achieve thermal comfort is 24.6 °C and that temperatures beyond 26°C show a decline in votes. Therefore, the temperature settings in AC should be 23 to 26°C.

In this IR4.0 era, research is needed in the development of predictive maintenance models using IoT and data analytics. By analyzing the data from sensors and other IoT devices, it can identify patterns and trends that help predict when an asset is likely to fail and allow management to schedule preventive measures. Moreover, it helps optimize facility maintenance schedules by analyzing data on asset performance and maintenance history; to develop more efficient maintenance schedules that reduce unexpected downtime and extend asset life cycles.

The purpose of this paper is to design and develop data analytics for AC performance in the laboratory by using an IoT-based monitoring system to improve efficiency in facility maintenance to monitor ACs in the CAISER Laboratory at UKM and analyze the effect of ubiquitous sensors on ACs to increase the efficiency of facility maintenance. The two data analytic methods proposed are the CBM and OEE approaches. CBM uses thermal and electrical analysis to analyze the IoT sensors to aid facility maintenance. The OEE approach uses 3 parameters, such as availability, performance, and quality, to measure the efficiency of the AC asset. The expected result from the implementation of IoT into the AC monitoring system allows management to monitor sensors anywhere and anytime with mobile phones or computers when the internet connection is accessible.

METHODOLOGY

IOT DASHBOARD TOPOLOGY

Figure 1 shows the proposed topology for the data monitoring system. The topology starts with 1) the operation of the AC; 2) the IoT sensors measuring the data accordingly. 3) IoT sensors send data to the IoT gateway, which stores the data in a JavaScript Object Notation (JSON) format and every 10 minutes, it will send the JSON data in POST URL format to the ThingsSentral Cloud application programming interface (API). 4) The API will process the POST URL and register the JSON data into 5) the ThingsSentral database. The ThingsSentral platform is an IoT platform that provides several functions, such as registering sensor data, database to store data, displaying data in graphs or dials, and monitoring the data in a customized performance dashboard (Md Saad et al. 2021). 6) Users can access the Web GUI from the integrated-sensor monitoring system (I-SMS) to monitor the data and uses the performance dashboard to see the relevant chart plots.

The proposed system in this paper, namely the Integrated-Sensor Monitoring System (I-SMS) platform uses several types of IoT sensor nodes temperature and humidity (T/H) sensors and power meters.

Referring to Figure 2, the current power meter, temperature and humidity sensors, were deployed as IoT ubiquitous sensors to monitor the condition of the ACs in the CAISER laboratory at UKM. There are in total 2 temperature and humidity sensors and 2 power meters to measure temperature, humidity and the current draw of the

AC. The system uses IoT sensor nodes and gateways designed by Enomatrix Solution Sdn Bhd. CA-RTU (CAISER RTU XXXX) is the model for the gateway used to link all IoT sensor nodes.

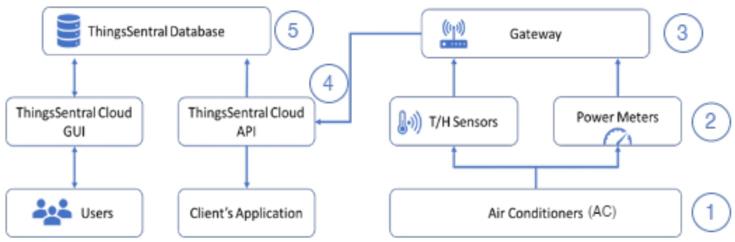

FIGURE 1. Monitoring System IoT Platform Topology

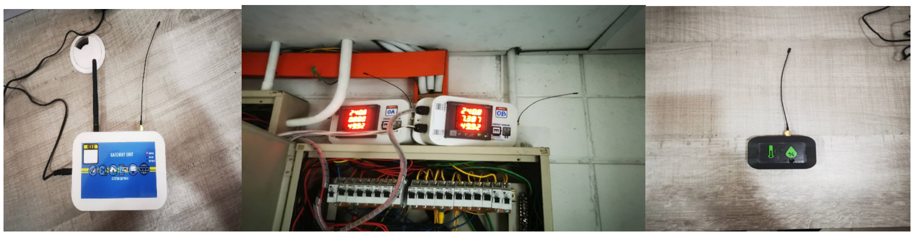

FIGURE 2. (a) Temperature and humidity sensor; (b) Power meter sensors; (c) IoT gateway.

WEB API DATA REGISTRATION

Figure 3 shows the overall operation flowchart for the web API from ThingsSentral. It uses a Graphical User Interface (GUI) and API to receive and access the data. The API will process the incoming URL sent to it and process it based on the condition set. The URL sent to the API can come from the IoT Gateway or Postman Canary a postman agent software. The API is hosted on a ThingsSentral server that continuously listens to any HTTP URL request and processes GET & POST requests based on the URL string form. A validation process will take place after reading the HTTP URL from the sender; it can be to retrieve data or register data in the database. The handle URL from the API will read the URL and split it on the '#' delimiter to segregate the request type, the data values, and the token; moreover, JSON payload does not require multiple splits because JSON is stored in the body of the URL. The API will extract the parsed data from the JSON payload and register the parsed data into the ThingsSentral database.

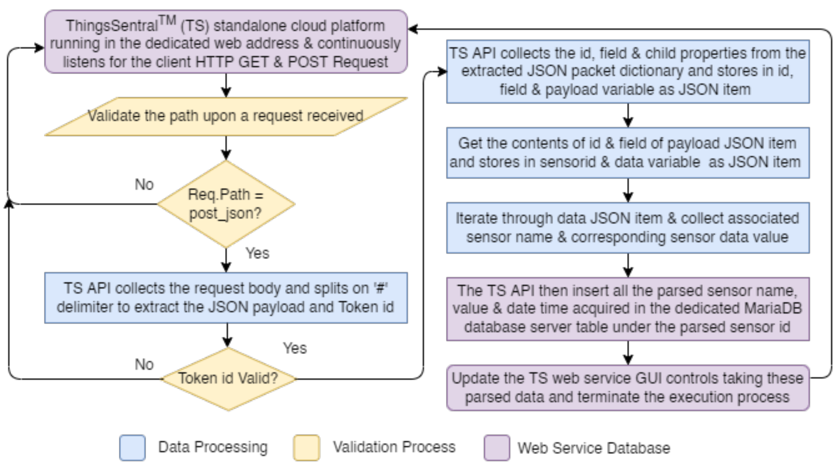

FIGURE 3. Overall Web API flowchart for ThingsSentral IoT Platform

IOT SENSORS DATA REGISTRATION AND WEB GUI DASHBOARD SYSTEM

Figure 4 shows that ThingsSentral's Web API handles incoming requests from the gateway; the wireless sensor node (WSN) measures the surrounding based on the sensor configurations. WSN uses a radio frequency (RF) channel to communicate with the Gateway Node; the gateway receives measurement data from the WSN and constructs the data into JSON format. If the web API is online, the gateway will make contact with the web API via HTTP POST request; if the web API is offline, the gateway will reroute and terminate the connection. The web API process the parsed JSON data packet; it will connect to ThingsSentral's database and register WSNs parsed data into it under the dedicated sensor identification (ID). Web GUI retrieves stored WSN data from the ThingsSentral's database under the respective sensor ID. Web GUI controls updates and displays the data in widget style and charts in the browser. The Web GUI will continuously retrieve data from ThingsSentral's database after a few minutes to refresh the data with real-time data.

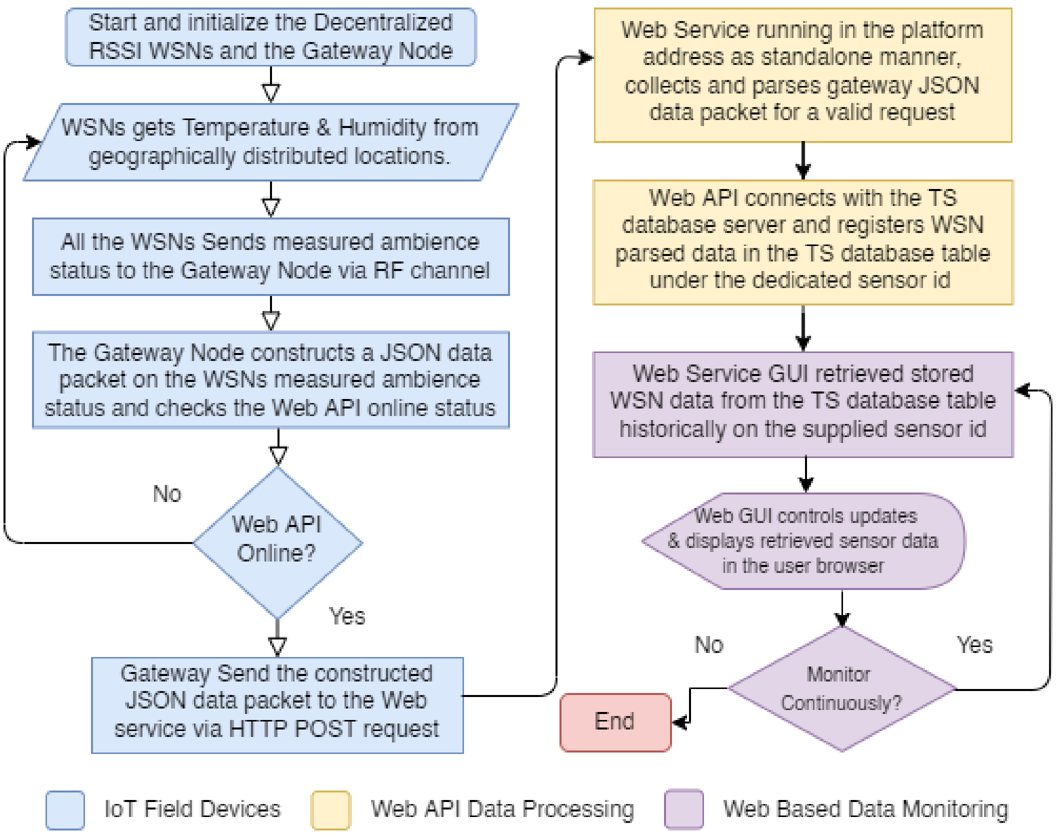

FIGURE 4. The IoT sensor monitoring system flowchart to measure and display sensor data.

NOTIFICATION PLATFORM USES TELEGRAM

Figure 5 shows the overall application flowchart for the sensor monitoring system and notification system to measure, monitor, display and notify users. A status notification desktop application was developed to prompt the person in charge of the targeted location to investigate any anomaly based on the rules established. The Telegram Bot API needs to generate a token as authentication that links to the user; the notification system will connect to ThingsSentral's database. The notification system makes a structured query language (SQL) query to ThingsSentral's database and retrieves the WSN data based on the sensor ID. A validation is made for the date time acquired of the sensor value; if the validation is more than 25 minutes in real time then it will send a HTTP POST request to the Telegram Bot API. From the Telegram Bot API, it will send a message with content based on the HTTP POST request. The notification system will terminate upon receiving an acknowledgement from the Telegram Bot API response. The person in charge will receive a message from Telegram notified with messages containing problems encountered by the WSNs.

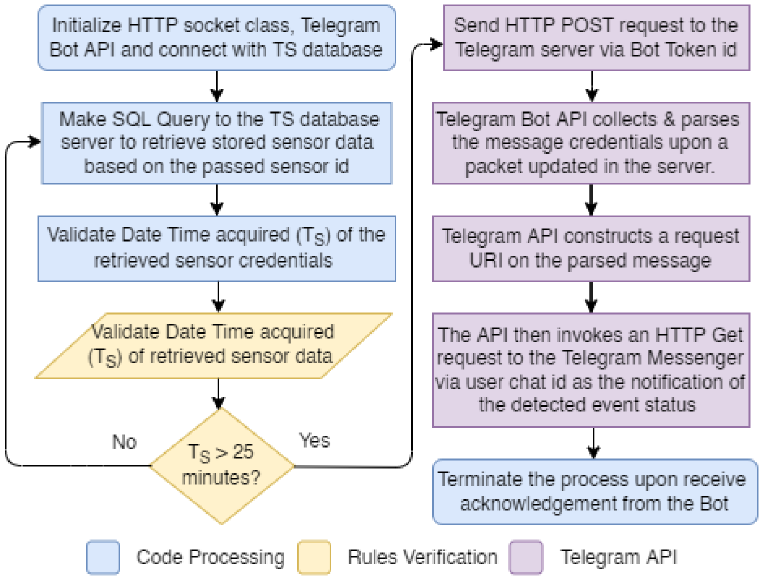

FIGURE 5. The notification system flowchart to notify user when IoT sensor data acquisition not working.

DATA ANALYTICS

Based on the IoT sensor reading, thermal and electrical analysis were performed to analyze the temperature and power consumption based on the current draw from the AC to study the plots and assist in decision-making and early failure detection. Decision-making often required historical data to analyze and increase accuracy in deciding and improving maintenance strategies to improve AC efficiency. The performance indicator for the AC needs to be established in order to compute the performance of the AC. To correlate the performance indicator with IoT sensor data; the time taken for the AC to facilitate the air temperature in the laboratory represents the percentage of performance. Summation of the average time taken to reach the ideal temperature and the average power consumption of the AC with a ratio of 50:50 to compute the performance (*P*) based on Equation 1.

$$P = \left[0.5\left(\frac{power\ rated - \mu_{power\ consumption}}{power\ rated}\right) + 0.5\left(1 - \frac{\Delta t_{min}}{60}\right)\right] x100\% \quad (1)$$

Performance measurement on the AC is based on the time taken for a room to cool down to a certain temperature, such as 26°C as suggested (Taib et al. 2022). The performance indicator percentage is calculated based on the time taken to cool the temperature below 26°C within 1 hour. Observe performance data to facilitate decision-making and optimize maintenance schedules to improve preventive maintenance. The IoT sensor data acquisition was performed in the CAISER Laboratory at UKM. There are two ACs operating in the lab. There are 3 case studies created to fully cover the two ACs; the first case study operates AC-1, the second case study operates AC-2 and the third case study operates AC-1 and AC-2. Each case study operates for three consecutive days to collect the average IoT sensor value. Maintenance for AC-1 and AC-2 will be scheduled and repeated measurements will be taken after maintenance based on the 3 case studies again to compare the AC's performance before and after maintenance. Location setup for IoT sensors, IoT power meters and AC's locations are shown in Figure 6.

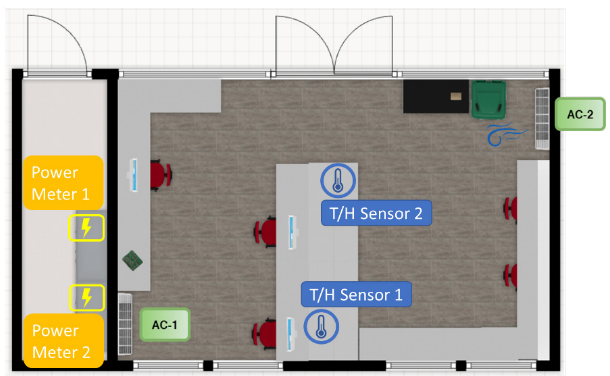

FIGURE 6. Laboratory layout of the AC and IoT Sensors.

RESULTS AND DISCUSSION

WEB DASHBOARD DEVELOPMENT

Based on the proposed method in methodology, the development of the web application for the web dashboard and the desktop application uses XOJO 2021 R3.2 (Zhang et al. 2020). The development of the web application for I-SMS in Figure 7 shows the dashboard to monitor the condition of the laboratory and the power consumption of both ACs. The web dashboard is capable of displaying various parameters and plotting charts by clicking the parameter's value as demonstrated in Figure 7.

Figure 8 is the desktop application programmed to monitor the status of sensor data received in ThingsSentral's database. It will prompt a message to the telegram when the sensor data are missing in the database for more than 25 minutes. The relevant person in charge can check out the sensors to identify and rectify the problem. It monitors ThingsSentral's web API as well to make sure the web API is always online to receive the sensor data sent by the gateway.

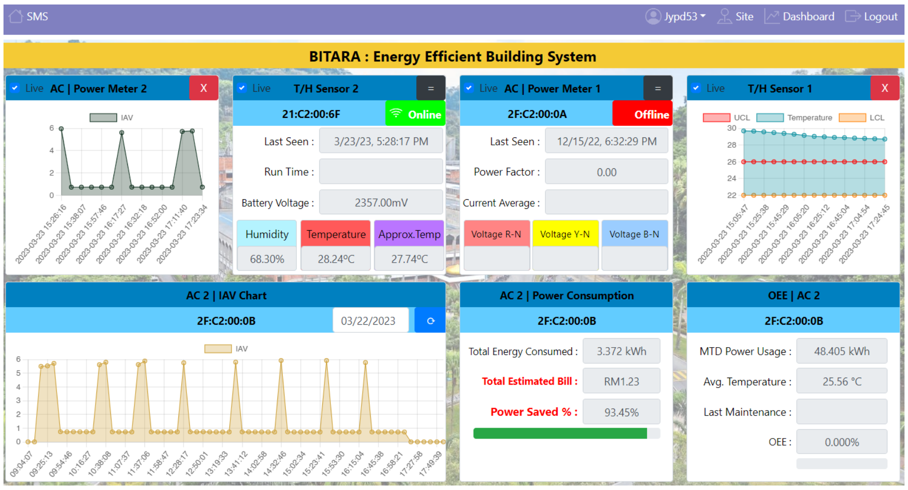

FIGURE 7. Application of sensor monitoring system and sensor widgets with graph to show the trend of the parameters.

FIGURE 8. I-SMS Status Notification Desktop Application

THERMAL AND ELECTRICAL ANALYSIS FOR FACILITY MAINTENANCE

Referring to Table 1, the first case study shows the average time taken to cool down the laboratory in 25 minutes with a 3.6°C temperature reduction which yields a 57.22% performance. However, it took around 52 minutes to achieve thermal comfort with a 2.02°C temperature reduction for the right portion of the laboratory with AC-2 turned off. The second case study shows that AC-2 is not capable of cooling down the laboratory which operates from 9:00 to 18:00; yielding 0% performance. Due to the poor performance observed, maintenance is scheduled for AC-2 which will undergo inspection and repair if any anomalies are detected. The AC maintenance team managed to identify problems and repaired AC-2. There is a performance increase observed after maintenance was done on AC-2. Therefore, AC-2 performance increased from 0% to 63.15% major increment with an average of 22.1 minutes to cool down to 1.54°C and the left portion of the laboratory took 50.11 minutes to cool down to 2.58°C while AC-1 was turned off. The third case study shows the initial performance for AC-1 is 80% with an average of 12 minutes to cool down to 4.17°C but AC-2 is rated at 0% with an average of 64.6 minutes to cool down to 2.42°C. However, maintenance was done on AC-2 after the second case study; performance drastically increased. Therefore, AC-1's performance was measured at 78.33% with an average of 13 minutes to cool down to 3.04°C and AC-2's performance increased from 0% to 65.19% with an average of 20.9 minutes to cool down to 2.25°C.

TABLE 1. Tabulated result in multiple case studies for AC performance indicators in percentage.

Case Study	Before Maintenance		After Maintenance	
	AC-1*	AC-2**	AC-1*	AC-2**
1	57.22 %	13.52%	-	-
2	0 %	0 %	16.48 %	63.15 %
3	80 %	0 %	78.33 %	65.19 %

Based on three case studies conducted in the laboratory; the result showed that AC-2 does not perform well enough due to the temperature does not cool down to the expected temperature which is between 18°C to 26°C. Case study 2 operates only AC-2 but AC-2 does not have the capability to cool down the laboratory even when it operates from 9:00 am to 17:30 pm.

1. Performance of AC-1 before Maintenance: Throughout the observation period, AC-1 did not receive any sort of maintenance due to the performance computed and tabulated in Table I showing results ranging from 57.22% to 80%. Based on Figure 9, the time taken to cool the temperature down to 26°C is 28 minutes which yields 53.33%. However, the current draw for AC-1 is high due to the compressor consistently operating to supply chilled air to the lab room. The average current draw throughout the 9 hours is 8.18A and the power consumption is 17.67kWh which results in RM6.45 based on the medium voltage general commercial tariff at the rate of 36.5sen/kWh set by Tenaga Nasional Berhad (TNB) (TNB 2020).

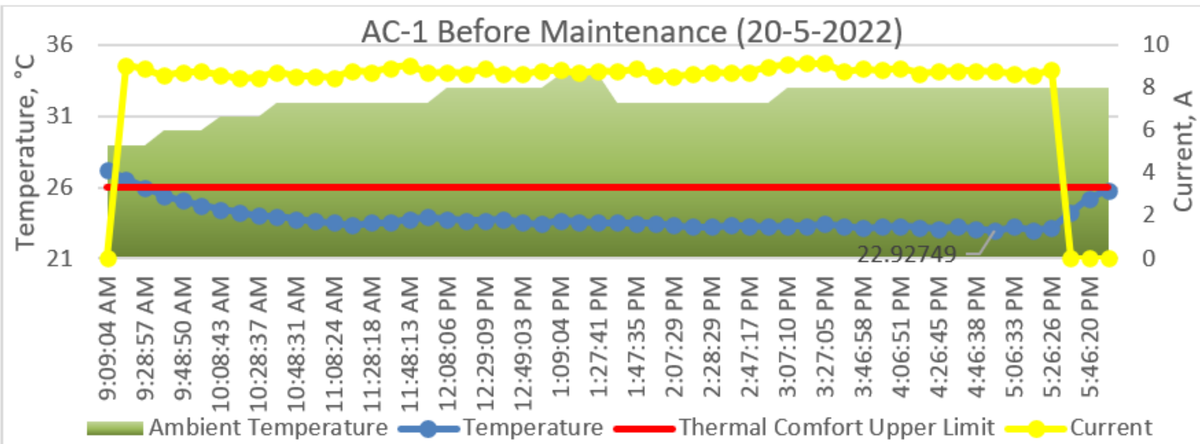

FIGURE 9 Temperature and Current Data for AC-1 before Maintenance on 20/05/2022.

Performance of AC-2 Before and After Maintenance: Figure 10 and Figure 11 shows the temperature and current data readings charts for AC-2 before and after maintenance. There is a significant difference compared between the temperature maintained under 26°C before and after maintenance was performed on AC-2. The maximum current reading recorded is 6.26A for AC-2 before maintenance and 9.031A for AC-2 after maintenance. In terms of the average current draw throughout 9 hours are 2.018A and 2.49A for AC-2 before and after maintenance respectively. In terms of kWh, after the maintenance task was done on AC-2; the power consumption increased by 23.39% which is 1.02kwh. Based on Table 2, the maximum current draw from AC-2 before maintenance is lower than AC-2 after maintenance. There is a slight increment in the average current draw throughout office hours.

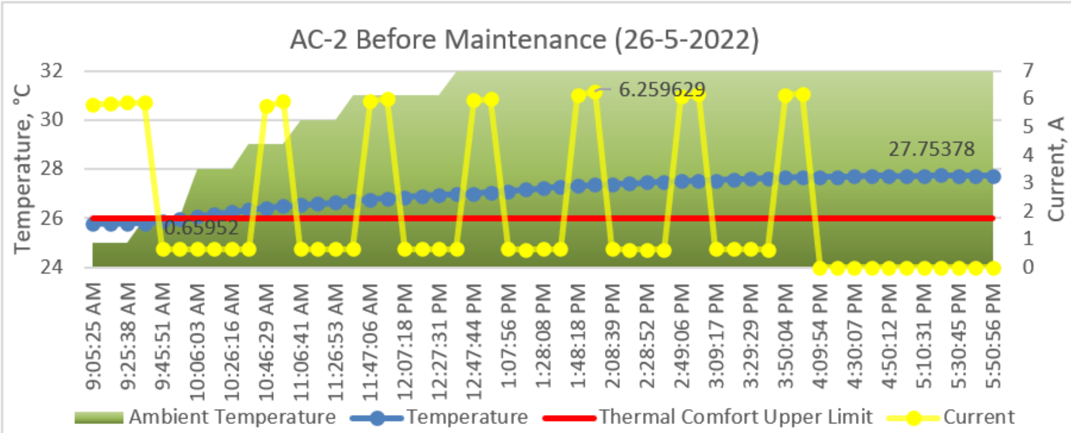

FIGURE 10. Temperature and Current Data for AC-2 before Maintenance on 26/05/2022.

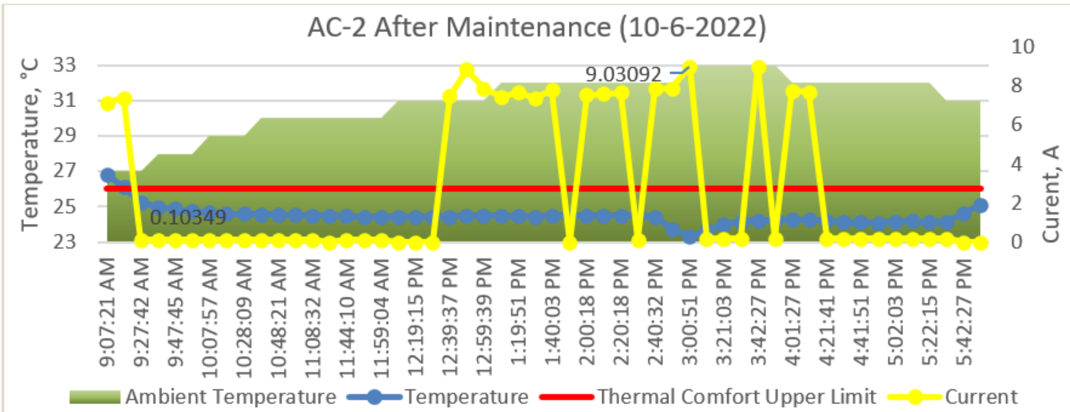

FIGURE 11. Temperature and Current Data for AC-2 after Maintenance on 10/06/2022

TABLE 2. AC-2 before and after maintenance task affect current draw detailed data.

AC-2	Before Maintenance			After Maintenance		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Date	26/5/22	27/5/22	28/5/22	10/6/22	11/6/22	12/6/22
Max.Ampere (A)	6.26	6.315	6.269	9.031	7.731	7.816
Average Ampere (A)	2.018	2.052	1.887	2.49	1.908	2.46

Monitoring the performance of AC-2 can show positive improvements and meet the needs of laboratory users by providing a good working environment. Even though the average power consumption increased in AC-2 and it operated well compared to AC-2 with low average power consumption but poor performance, it shows that the use of AC-2 should reach a certain level of thermal comfort to ensure that electricity is not wasted.

After the first maintenance was carried out on June 10, 2022, continuous monitoring of AC-2 was carried out until the end of the year 2022. AC-1 and AC-2 were found to be facing repetitive shutdowns from 20 August 2022 until 23 August 2022. Both ACs face power trips on the entire floor of the building. The IoT gateway does not work and the temperature and electric current data in the laboratory cannot be sent to the database. The notification system deployed on the server sent several notification messages to users to investigate the problem encountered in the laboratory. Figure 12 shows Telegram notification messages received by users to provide an alert as soon as possible as a warning. A notification message informed the user that the IoT sensor data could not be received by the database. The notification system allows users to identify problems experienced by the laboratory such as power outages, internet access being cut off, sensors not working, sensors running out of battery, etc. The Telegram notification message in Figure 12 states that all IoT sensors are inactive due to data not being registered in the database. It means there is a power outage for the entire floor of the building because all the IoT sensors are inactive compared to selective IoT sensors that are offline. However, many possibilities cause the notification system to send notification messages to the user. It will also notify users when IoT sensor data transmission returns to normal operation.

The management decided to stop the operation of the AC-1 to reduce the risk of a power outage in the building after an inspection was carried out in the distribution box; the management suspected that the AC-1 suffered a circuit faulty that caused a short circuit. The operation of the AC-2 is not affected by any short circuit failure and it can continue to operate in the CAISER laboratory.

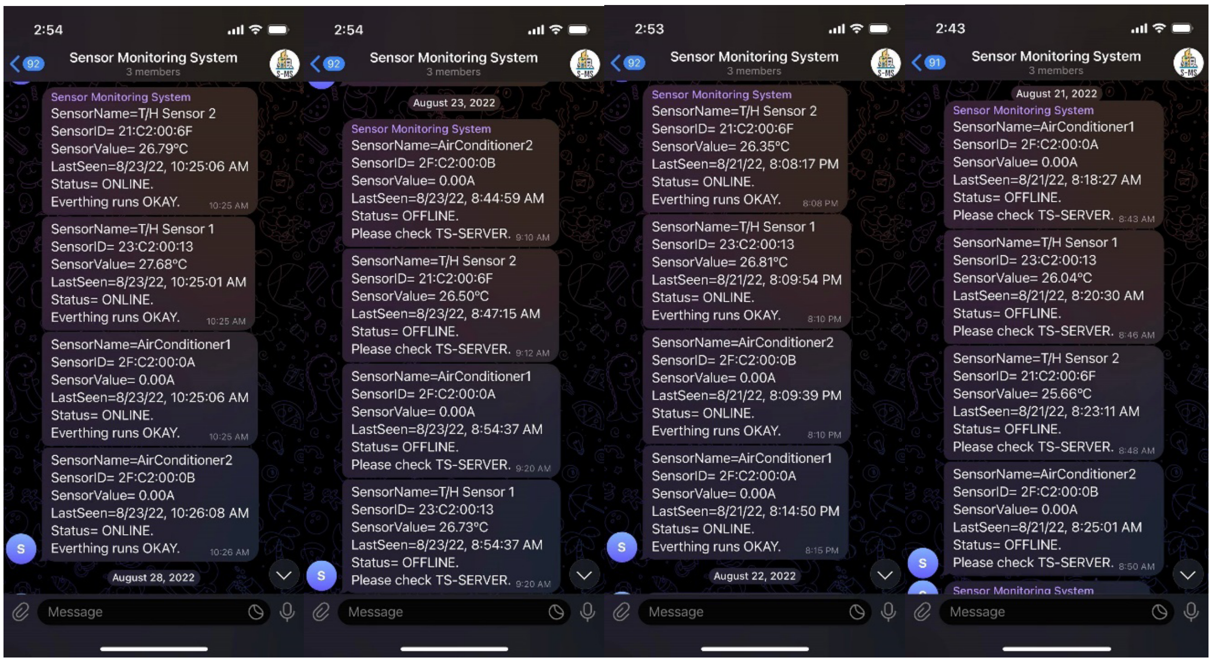

FIGURE 12. Notifications Platform using Telegram with I-SMS to manage and monitor IoT gateways, IoT sensors and assets.

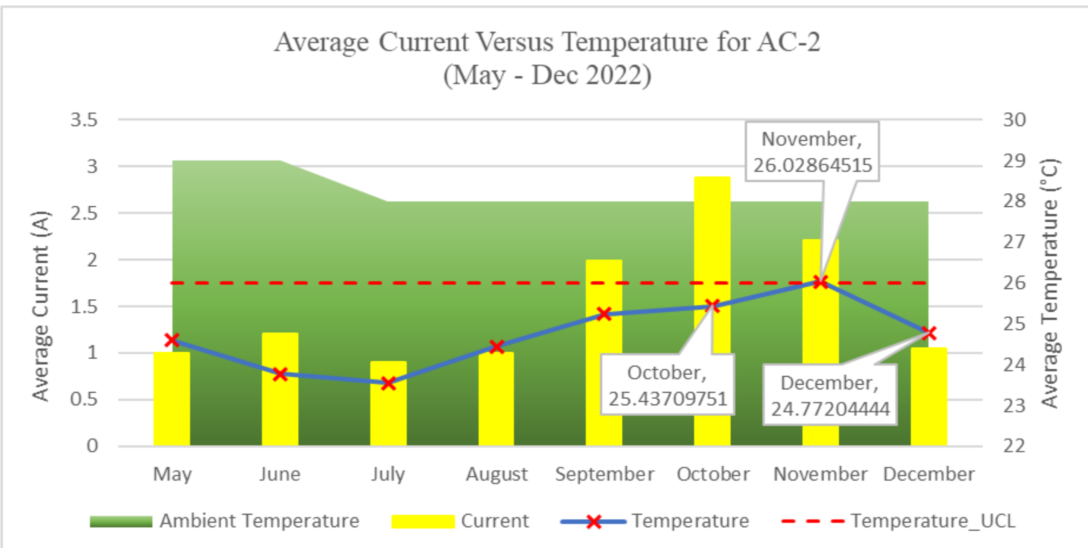

FIGURE 13. Chart of average current versus temperature for AC-2 from May 2022 to Dec 2022

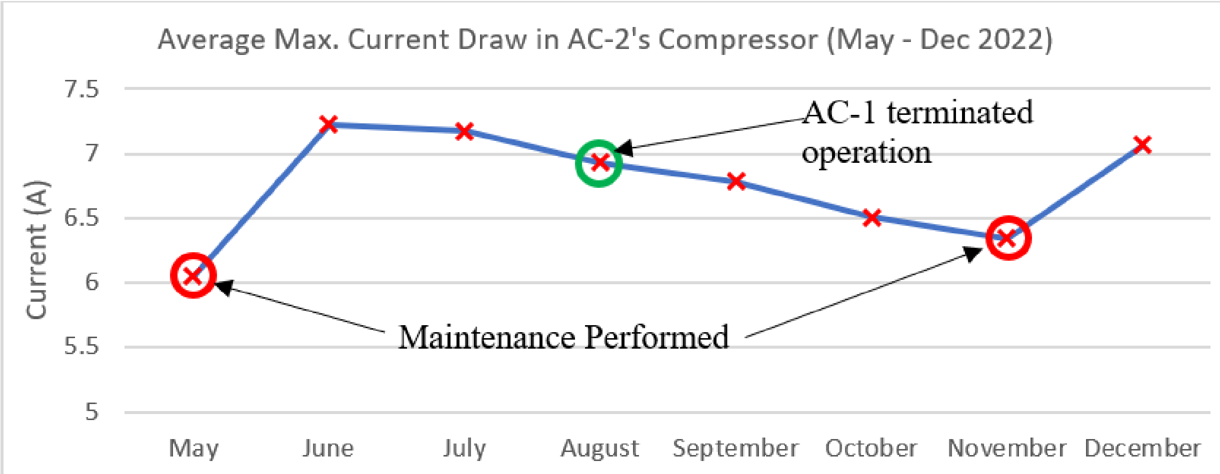

FIGURE 14. Chart of average power consumption on AC-2's Compressor from May 2022 to Dec 2022

Refer to Figure 13, which shows a graph of the electric current versus the temperature of AC-2 from May 2022 until the end of December 2022 in the CAISER Laboratory. According to Figure 13, starting from May 2022, the average temperature for that month is below 26°C; however, there is maintenance scheduled for that month even though the temperature is below the upper control limit of temperature. The reason is that AC-1 and AC-2 are running simultaneously which resulted in the temperature being within the acceptable range while AC-2 was not performing well which was discussed earlier. After maintenance was carried out for AC-2, the average temperature dropped by more than 1°C for June and July 2022. On August 2022, there is a slight increase in the average temperature due to AC-1 no longer operating. The average temperature continued to increase in September 2022 with a slight increase in October 2022. Meanwhile, October 2022 marked the highest average current draw across the whole study duration. November 2022 marks the incapability of AC-2 to cool down the air in the laboratory where the average temperature crossed the upper control limit temperature at 26.03°C. A detailed investigation carried out in that particular month showed that the performance of AC-2 started to decline. Later, maintenance was scheduled and carried out on 29th November 2022; the problem was low in refrigerant and the possible fault due to low refrigerant is a leak in the cooper pipes in the system. After the maintenance, the average temperature and current dropped into the desired range for December 2022.

The result on the average power consumption in AC-2's Compressor chart shows the average maximum current recorded throughout daily readings. Every compressor has its own rated operational power; the electrical analysis analyzes the current drawn from the compressor to identify the anomaly readings, which slow the abnormal operation of the compressor when it runs above or lower than rated power. Based on Figure 14, the average maximum current draw on May 2022 was recorded at 6.05 A and AC-2 at that time was incapable to cool down the temperature. After the first maintenance scheduled, the maximum current draw increases to 7.2 A. The chart shows the trend gradually dropped to below 6.4 A in November 2022; however, on October 2022 experience dropped too which gives off an early failure sign. On November 2022, the AC-2 was not able to cool down the temperature. A second maintenance was scheduled at the end of November 2022; after the second maintenance is done, the average maximum current draw increases to 7.05 A which is desirable. Figure 15 shows the temperature and current data the next day after the second maintenance took place. AC-2 is capable to cool down the air in the laboratory; however, it seems that AC-2 is not able to cut off the compressor when the desired temperature set at 25°C reached where it keeps cooling down the temperature to 19.5°C which is quite cold for average users. Meanwhile, it also consumes more power at 9.37kWh for 9 hours to keep the compressor running when the compressor should cut off when the desired temperature is reached by the thermostat in AC-2. However, after a week from the second maintenance took place; the compressor was able to cut off when the desired temperature is reached to conserve energy at 7.49 kWh and the lowest temperature at above 23°C based on Figure 16.

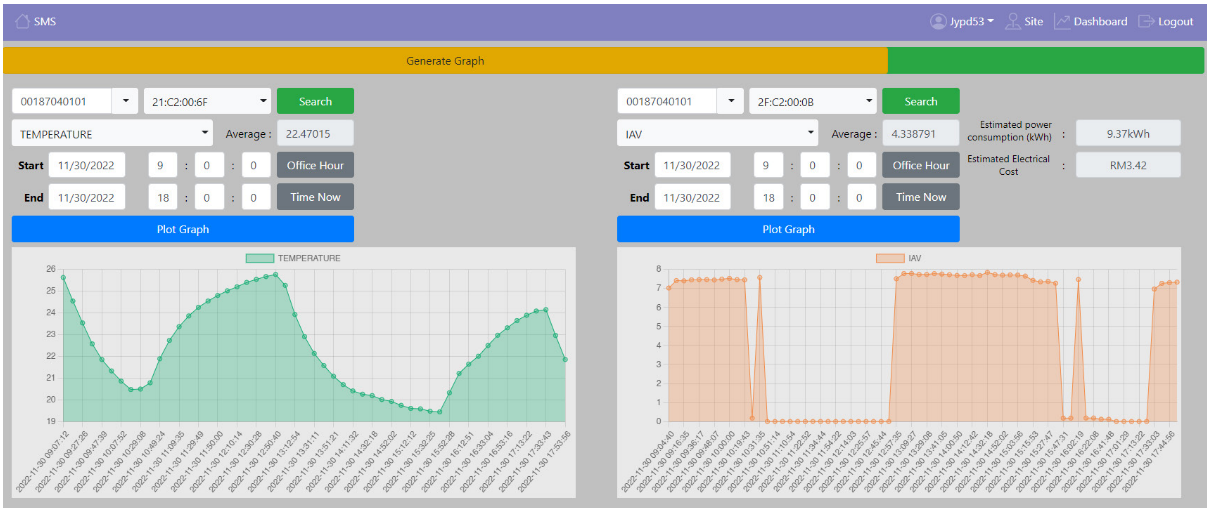

FIGURE 15. After predictive maintenance effort on 30th November 2022

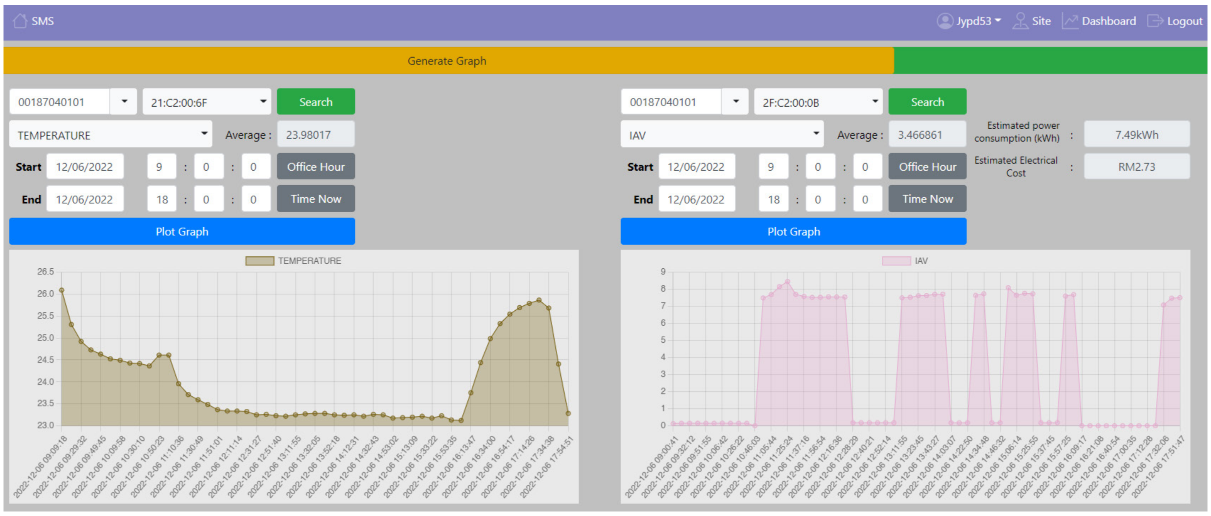

FIGURE 16. A week after predictive maintenance effort on 6th December 2022.

According to the results shown earlier, AC-1 performance fluctuated from 57.22% to 80% due to the ambient temperature varying every day. The weather for each day will directly affect the performance of the AC especially one of the laboratory walls the façade wall. Temperature differences were observed in the morning, afternoon and evening time. The door activity has a minor impact too as it introduces extra exfiltration of the cool air from the laboratory which results in inconsistent temperature. With the I-SMS in place, the monitor period can be extended to after office hours. It allows management to monitor and reduce unsupervised electrical consumption beyond working office hours. Telegram notification is capable of prompting messages to notify management if the current reading picks up from the power meter which identifies as an anomaly operation. Therefore, management can instruct one of their executives to carry out an investigation into that location and turn off the AC to reduce further unprecedented power consumption. In short, I-SMS unlocks measure, register, monitor and notification functionality. Operating both AC-1 and AC-2 yields a good performance result in terms of speed to cool down the whole laboratory space. However, the power consumption used to operate both ACs comes at a higher price. Therefore, management needs to consider the operational cost to run both ACs to achieve excellent performance but higher power consumption or adequate performance with lower power consumption.

AC-1's performance showed the capability to cool down the space in the laboratory. However, the current draw for the AC-1's compressor is high, compared to the current draw for Figure 9 and Figure 11, both ACs operated independently but we observed a significantly lower current draw despite both of the AC being the same specification in terms of Horsepower. In this condition, AC-1 inability to cut off the compressor when the desired temperature is achieved in the laboratory even though the temperature is set at 26°C; that is why the temperature reaches its lowest at 22.92°C refer to FIGURE 9. From the maintenance perspective, AC-1 experience good performance but the power consumption is high. However, it has to justify the maintenance cost whether to repair AC-1 by replacing the thermostat to cut off the compressor when the desired temperature achieves or to bare the additional electrical consumption cost which cost about RM4.00 per working day. Due to this outcome, it is also important to reiterate the performance formula for the OEE approach to include power consumption and; a balance between the performance and power consumption that directly affects the operational cost.

AC-2 pre-maintenance yields 0% performance; direct maintenance is scheduled and performed on it. According to Figure 10, the graph showed the inability of AC-2 to cool down the laboratory but the power consumption is very low. AC-2 is the opposite of AC-1's performance; low performance and low-power consumption compared to high performance and high-power consumption. However, management often prefers performance over power consumption. Therefore, AC-2 does not meet the requirement and reactive maintenance was scheduled. Post-maintenance AC-2 indicated the main fault to succumb to such performance is low refrigerant and capacitor failure at the outdoor split unit. However, AC-2 post-maintenance results in higher power consumption but was justified by the lack of refrigerant present in AC-2 which causes lower power consumption in pre-maintenance. The compressor in AC-2 required less energy to compress a low volume of refrigerant to high pressure to achieve the superheated state. Therefore, monitoring the current draw in the AC system enables the prediction of the health state of AC. The low average current in AC systems while cooling indicates low refrigerant occurrence and it acts as early failure detection for management and assists in maintenance strategy decision-making.

OEE APPROACH

Based on the I-SMS system, allows the calculation of the OEE reading based on several metrics such as temperature, electric current, operating time and downtime of the AC. OEE monitors on assets allow executives to observe OEE trends and react responsively if OEE is below the threshold. Figure 17 shows the OEE trend for AC-2 in the CAISER laboratory. Refer to Figure 17, May and Nov 2022 obtained the lowest OEE rates of 43.43% and 37% respectively. There was a maintenance task scheduled done on June 2022 and it caused the OEE to increase in that month. Five months after the maintenance was done, the OEE rate started to drop to 61% in August 2022 but recovered immediately to 85.7% on September 2022. On August 2022, there are several instances that the power supply trip in the building occurs which causes the AC-1 and AC-2 to shut down unexpectedly; it resulted in the availability rate dropping a little. The following month faced the same drop to 63.1% on October 2022 similar to August 2022; however, it continued to drop to 36% for the month of November 2022. Therefore, maintenance was scheduled to check and identify the possible faults that caused the OEE to drop dramatically.

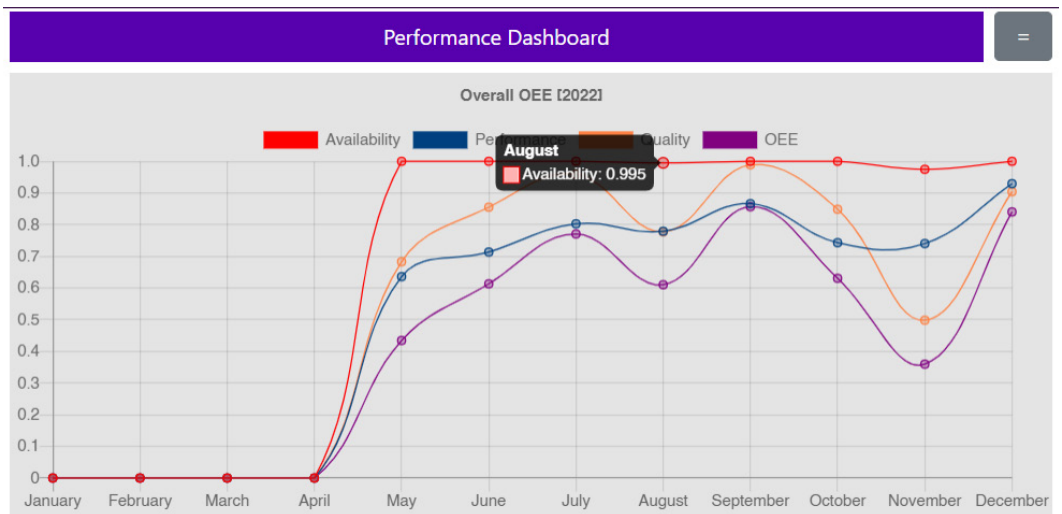

FIGURE 17. Performance Dashboard for OEE in CAISER Laboratory

After the maintenance carried out on 29th November 2022, the performance of the AC-2 was able to cool the temperature in the laboratory. However, Figure 17 is not able to show the OEE improvement on that particular day, please refer to Figure 15 to see the improvement in AC-2's performance. Meanwhile, in December 2022 experienced a significant increase in OEE up to 84%. It states that the maintenance carried out has improved the performance of the AC-2.

CONCLUSION

In conclusion, the research provides a designed monitoring system able to assist facility maintenance to achieve intelligent facility maintenance by implementing an IoT platform. It increases management productivity in terms of eliminating the hassle of measuring environmental parameters and equipment parameters. Display data in the simplest way for users to understand the big data and historical data through a real-time data dashboard and performance dashboard. To assist in facility maintenance, the data analytics discussed showed several case studies that I-SMS designed to pick up the anomaly to aid the decision-making for facility maintenance to schedule maintenance.

AC-1 offers good performance compared to AC-2 for the pre-maintenance state. However, post-maintenance for AC-2 achieves 63.15% improvement which provides adequate performance for the laboratory. Therefore, in terms of performance, operating AC-1 and AC-2 post-maintenance simultaneously offers the best performance to cover both areas in the laboratory which yield 78.33% and 65.19% respectively. In terms of power consumption, AC-2 shows the balance between performance and power consumption. AC-1 consumes 3 times more power than AC-2 throughout 9 hours of office hours. After AC-1's operation terminated on August 2022; AC-2 operated alone in the laboratory. With the monitoring system in place, it is able to provide early failure detection on AC-2 where it detects refrigerant leaks in the system and scheduled maintenance to rectify the problem.

In terms of data analytics, from thermal and electrical analysis, it is noticeable that the power consumption is different from pre-maintenance and post-maintenance for AC-2. The noticeable difference in the power consumption in an AC provides good information for maintenance management to take precautions and schedule preventive maintenance. The monitoring systems enable big data; data always give out meaning when data analysis is done properly.

The contribution of this paper provides data analytics for facility maintenance based on an IoT monitoring system to measure, register and display sensor data in the dashboard. Moreover, the data analysis of the big data acquired in the database from the IoT sensors showed significant results to provide early failure detection for decision-making to improve the efficiency of facility maintenance; the modified OEE approach for AC was used and the result is similar to CBM approach with thermal and electrical analysis; the modified OEE focus on the performance where it takes in consideration of the speed to cool down air and the power needed to run the AC.

ACKNOWLEDGEMENT

The authors would like to thank the Institute of IR 4.0 (IIR4.0) for supporting this research through the GPK-4IR-2020-017 grant code and Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM) for providing the research facilities.

DECLARATION OF COMPETING INTEREST

None

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