ECOSENSE: IOT-DRIVEN POWER MONITORING AND CENTRALIZED CONTROL SYSTEM FOR ENERGY CONSERVATION

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ABSTRACT

The research study addresses the prevalent issue of high energy consumption at FAITH Colleges due to non-adherence to responsible practices, such as neglecting to turn off air conditioning units after use and unauthorized use of vacant rooms for leisure activities, resulting in significant energy wastage. To tackle this challenge, the study proposes the implementation of the ECoSense system, an Internet of Things (IoT)-driven power monitoring and centralized control system. The system utilizes a wireless sensor network to monitor energy consumption, which also includes real-time data collection, data analysis, data processing, automated control operation, database management, and data power visualization. Project implementation involved key components such as the PZEM-004T sensor, ESP8266, mini circuit breaker, MG996r Servo Motor, and Google Drive applications. Notably, ECoSense provides users with real-time data insights and automates air conditioning units' operational status based on user-defined schedules, significantly contributing to energy conservation efforts. The results demonstrate successful ECoSense implementation, highlighting its effectiveness in reducing energy consumption and cutting electricity costs.

1. 0 INTRODUCTION

Institutions such as the First Asia Institute of Technology and Humanities (FAITH Colleges) play a pivotal role in shaping the educational landscape, catering to the needs of thousands of individuals ranging from students to faculty and staff. The efficient operation and maintenance of facilities within these institutions are paramount to ensuring a conducive learning environment. However, the upkeep of such facilities often comes at a significant cost, particularly in terms of energy consumption.

FAITH Colleges, located in Tanauan City, Batangas, faces a pressing issue of escalating electricity costs, primarily attributed to the substantial energy consumption of air conditioning units across its campus. Engr. Jaime David IV, the administrator of the Physical Plant and Facilities Department, highlights the staggering monthly electricity bills, which average between 1.2 to 1.4 million pesos. Each classroom's average energy consumption of 3.5 kWh, with air conditioning units alone accounting for approximately 3 kWh, underscores the magnitude of the challenge. This translates to an estimated monthly expense of around 7 thousand pesos per air conditioning unit, accentuating the urgent need for intervention to address usage patterns and explore energy-efficient alternatives. Furthermore, the absence of effective measures to regulate air conditioning usage, compounded by negligent practices such as leaving units running unnecessarily, exacerbates energy wastage. Current attempts to manage usage, such as assigning teachers to oversee units, have proven ineffective due to students utilizing classrooms during non-scheduled hours. The complexity of college students' schedules and the absence of monitoring systems further complicate efforts to track and regulate appliance consumption accurately.

In response to these challenges, this proposed study endeavors to develop a comprehensive solution the "ECoSense: IoT-Driven Power Monitoring and Centralized Control System for Energy Conservation." This system aims to mitigate energy consumption issues while promoting conservation practices within the institution. Its key feature lies in its ability to automatically manage air conditioning units based on predefined schedules. By utilizing real-time data on electricity usage, the system will provide actionable insights to users, facilitating informed decisions to minimize energy consumption. Through the implementation of ECoSense, FAITH Colleges aim to not only reduce energy wastage but also foster a culture of responsible energy consumption and sustainability within their campus community.

Air conditioners primarily serve the purpose of providing comfort to individuals. In tropical regions, air conditioning plays a crucial role in cooling indoor environments to counter the oppressive heat. Nevertheless, the unregulated use of air conditioning leads to escalated energy consumption, higher electricity expenses, and an increase in carbon emissions released into the atmosphere[1]. According to present electricity consumption data, the most significant portion of power usage is attributed to heating and cooling air conditioners, which find extensive application in both residential and commercial structures. Therefore, it is of utmost importance to decrease the energy consumption of air conditioners in order to enhance the overall efficiency of power utilization from a global energy standpoint[2]. Excessive electricity consumption resulting from air conditioning usage poses a considerable risk of wasted energy if not managed effectively. Therefore, the ability to regulate air conditioning usage is of paramount importance for both electric power utilities and consumers[3].

While the studies proposed by Song et al. (2017) and Waluyo et al. (2022) offer innovative solutions for energy-saving air conditioning, they each possess certain limitations that necessitate the development of a more comprehensive system like ECoSense: IoT-Driven Power Monitoring and Centralized Control System for Energy Conservation. The IoT-based smart control system introduced by Song et al. (2017) provides remote monitoring and management capabilities but lacks the ability to automatically adjust air conditioning units based on real-time data[2]. Similarly, the automatic control system developed by Waluyo et al. (2022) utilizes motion sensors for activation and records essential data, yet it does not offer centralized control or real-time energy consumption analysis[4].

In contrast, ECoSense addresses these shortcomings by seamlessly integrating IoT technology with power monitoring and centralized control features. By automatically managing air conditioning units based on predefined schedules and utilizing real-time data insights to optimize energy usage, ECoSense offers a superior solution for reducing electricity consumption. Furthermore, the ECoSense system also acts as a plug-and-play device, functioning as a block box that boasts ease of portability. This feature allows for seamless integration with various devices, enhancing its versatility and convenience in managing energy consumption across different settings. In summary, while the initial studies provide valuable contributions to the field, the development of ECoSense represents a significant advancement in energy-saving technology, offering a holistic solution that addresses the limitations of existing systems and provides a more efficient and sustainable approach to energy conservation.

2. 0 REVIEW OF RELATED WORK

Refer to 1.0 Introduction.

3.0 METHODOLOGY

3.1 Monitoring and Control System

The study employs a prescriptive approach, integrating the 5-stage model and the research paradigm to provide actionable solutions for energy conservation. Figure 1, the research paradigm is based on the IPO model, which visualizes the sequential flow of inputs, processes, and outputs. Inputs include essential elements like air conditioning units and class schedules, while processes involve data collection, integration, and energy consumption analysis. The outputs feature automated control of air conditioning units, database management, and data visualization for real-time monitoring and long-term analysis. This framework underscores the study's approach to sustainable energy management, promising effective power conservation and environmental responsibility.

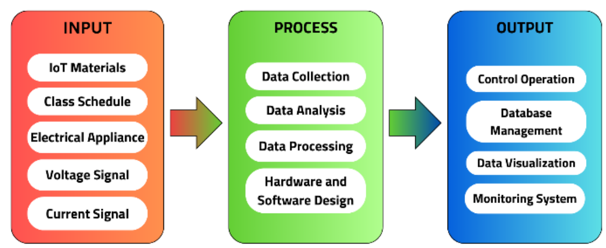


Fig 1. Research Paradigm

Figure 2 is the system's flowchart where it begins with initializing the hardware and software components, followed by establishing an internet connection. Once connected, the system starts collecting, processing, and displaying data. It then checks the class schedule; if a class is scheduled, it energizes the socket; if not, it de-energizes the socket. This process continuously loops back to checking the internet connection to ensure seamless operation.

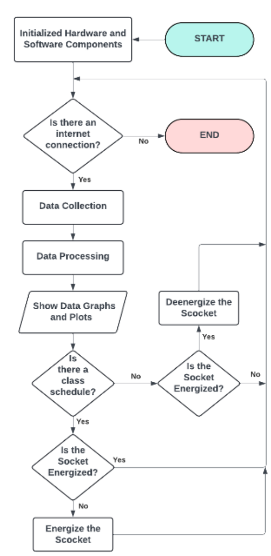


Fig 2. Flowchart

The study presents a meticulously designed system with various functionalities aimed at efficient energy management. Power is sourced directly from the AC socket, facilitated by AC to DC converting modules. Key components, such as the PZEM-004T Sensor, enable accurate real-time data collection, capturing metrics like voltage, current, power, and energy consumption. Connectivity is ensured through the ESP8266 microcontroller, allowing seamless integration with Wi-Fi networks and communication with the IoT platform, Google Sheets. Automation features, including the mini circuit breaker and MG996r Servo Motor, enable automatic control of air conditioning units based on user-defined schedules. A user-friendly graphical interface provides real-time data and scheduling information for efficient energy usage. Data storage and analysis are conducted securely through Google Drive, enabling historical analysis for better energy management strategies. The system also includes safety features like a master switch for shutdown during updates or troubleshooting. Operating continuously, it adapts to class schedules, ensuring devices are powered on only when needed, thus promoting energy conservation.

As for the components to be used, a generation of alternatives was done through research and assessment. Then, each alternative was evaluated through pairwise comparison chart and decision matrix. This became the basis of having the hardware components as the system's main components referred to in Appendix A.

3.2 Delphi Method

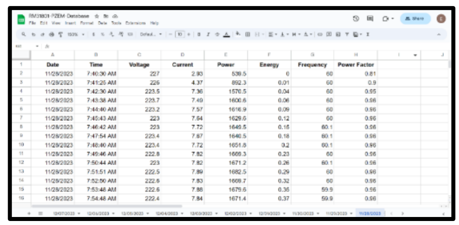
The Delphi method involves structured, iterative rounds of expert consultation to gather and refine insights on the system's feasibility, effectiveness, and potential challenges. Experts in IoT, energy conservation, and related fields provide feedback through questionnaires, which are analyzed and synthesized to inform the development of recommendations and strategies. This process ensures a comprehensive understanding of technical factors and system limitations. Refer to Appendix B for its flow.

4.0 RESULTS AND DISCUSSION

4.1 Deployment setup and data collection of the system

Fig 3 displays the deployment setup of the monitoring system implemented in room 318, operating continuously throughout the gathering phase via a portable pocket Wi-Fi connection for data transmission. The setup was conducted in two distinct ways: initially with a power meter for accuracy testing, ensuring precise measurements, then without the power meter for the gathering phase to collect comprehensive data from the monitored appliances as shown in figure 4. The collected data, parameters such as voltage, current, power, energy, frequency, and power factor at one-minute intervals, offer insights into appliance operation and consumption behavior, establishing the backbone of the monitoring system for efficient management and performance optimization. Furthermore, rigorous testing with various home appliances assessed the system's adaptability and performance across different scenarios.

Fig 3. Deployment Setup of the system



Date	Time	Voltage	Current	Power	Energy	Frequency	Power Factor
11/28/2023	7:40:30 AM	227	2.93	539.5	0	60	0.81
11/28/2023	7:41:25 AM	226	4.37	892.3	0.01	60	0.9
11/28/2023	7:42:30 AM	223.5	7.36	1570.5	0.04	60	0.95
11/28/2023	7:43:38 AM	223.7	7.49	1600.6	0.06	60	0.96
11/28/2023	7:44:40 AM	223.2	7.57	1616.9	0.09	60	0.96
11/28/2023	7:45:43 AM	223	7.64	1629.6	0.12	60	0.96
11/28/2023	7:46:42 AM	223	7.72	1649.5	0.15	60.1	0.96
11/28/2023	7:47:54 AM	223.4	7.67	1640.5	0.18	60.1	0.96
11/28/2023	7:48:40 AM	223.4	7.72	1651.8	0.2	60.1	0.96
11/28/2023	7:49:46 AM	222.8	7.82	1669.3	0.23	60	0.96
11/28/2023	7:50:44 AM	223	7.82	1671.2	0.26	60.1	0.96
11/28/2023	7:51:51 AM	222.5	7.89	1682.5	0.29	60	0.96
11/28/2023	7:52:50 AM	222.6	7.83	1669.7	0.32	60	0.96
11/28/2023	7:53:48 AM	222.6	7.88	1679.6	0.35	59.9	0.96
11/28/2023	7:54:48 AM	222.4	7.84	1671.4	0.37	59.9	0.96

Fig 4. Data Collection of the system

4.2 Interface of the monitoring system

Fig 5 represents the graphical user interface (GUI) of the monitoring system, acting as a visual representation of the data collected in figure 4. The graphs displayed primarily emphasize the power consumption patterns of the appliance, offering a clear insight into its energy usage over time. Additionally, this GUI provides functionality beyond mere observation, enabling users to control the appliance's operation. It includes features such as setting usage limits, thereby restricting access to the appliance beyond scheduled hours. Users can also navigate the display of the GUI to their desired date of consumption for detailed analysis and comparison of energy usage over different time periods. Moreover, alongside the consumption data, class schedules for specific rooms on particular days are also displayed within the interface. This integration of monitoring and control capabilities enhances the system's utility, allowing for efficient management of energy consumption and adherence to predefined usage schedules.

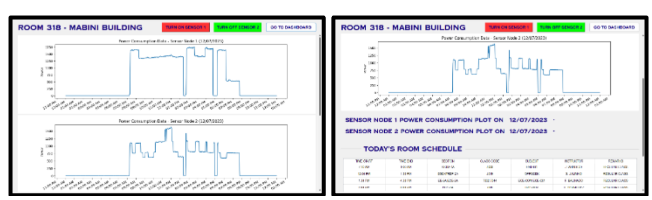


Fig 5. System's displayed GUI for Monitoring

4.3 Evaluation of the performance of the system in terms of accuracy, reliability, effectiveness, functionality, and adaptability

This section evaluates the system's performance across five key metrics: accuracy, reliability, effectiveness, functionality, and adaptability. The results provide a comprehensive understanding of the system's strengths and areas for improvement.

4.3.1 Accuracy Testing

Table 1 provides a comprehensive overview of the results obtained from an extensive evaluation, comparing the prototype's measured values against the actual values recorded by the power meter. This evaluation was meticulously conducted at a consistent 1-minute interval, spanning a duration of 158 minutes, equivalent to approximately 2 hours and 38 minutes. Notably, the assessment reveals a range of percentage errors for both the power and energy parameters, with values fluctuating from -5.764% to +6.0857% for power and from -15.3846% to +7.4074% for energy. Calculating the average percentage error further elucidates the system's performance, yielding negative means for both parameters, measuring at -0.829% for power and -0.728% for energy. The negative percentage error signifies a shortfall in the measured values compared to the true or expected values, indicating an underestimation or lower measurement than anticipated.

Table 1. Accuracy Test Results

Time Interval	Power			Energy		
	Measured Value (PZEM)	Actual Value (Power Meter)	% error	Measured Value (PZEM)	Actual Value (Power Meter)	% error
1	232.2	232.9	0.301	0	0	0
2	754.4	753.3	-0.146	0.01	0.01	0
3	1149.2	1148	-0.105	0.03	0.026	-15.385
4	853	852.8	-0.023	0.04	0.041	2.439
5	867.3	861.2	-0.708	0.05	0.054	7.407
…	…	…	…	…	…	…
154	556.9	551	-1.071	1.58	1.557	-1.477
155	830.6	819.1	-1.404	1.59	1.57	-1.274
156	563.8	539.6	-4.485	1.6	1.584	-1.010
157	809.9	816.1	0.760	1.61	1.595	-0.940
158	560.1	552.1	-1.449	1.62	1.607	-0.809
	Average Percentage Error (Power):		**–0.829%**	**Average Percentage Error (Energy):**		**–0.728%**

4.3.2 Reliability Testing

The monitoring system has been deployed to oversee the operation of two air conditioning units within the room, designated with device numbers 31801 and 31802. Table 2 offers insights into the system's reliability in monitoring these appliances. Initially implemented during online class schedules from November 6 to November 10, 2023, the system gathered data for a total duration of 4 days, 14 hours, and 20 minutes. Subsequently, it was deployed during face-to-face classes from November 28 to December 8, 2023, resulting in gathered data durations of 10 days, 3 hours, and 52 minutes for device 31801 and 10 days, 3 hours, and 48 minutes for device 31802. Despite slight variations in results likely attributable to installation and removal processes, the system demonstrated its reliability during implementation by consistently monitoring the status of the air conditioning units without any interruptions.

Table 2. Reliability Test Results

Device Number	Date Implemented	Total Duration
Device 31801	Nov. 6 – Nov. 10, 2023	4 days, 14 hours, 20 minutes
	Nov. 28 – Dec. 8, 2023	10 days, 3 hours, 52 minutes
Device 31802	Nov. 6 – Nov. 10, 2023	4 days, 14 hours, 20 minutes
	Nov. 28 – Dec. 8, 2023	10 days, 3 hours, 48 minutes

4.3.3 Effectiveness Testing

Fig 4 provides a comprehensive comparison of power consumption data over a 3-day period between the Unscheduled-Based Operation and Scheduled-Based Operation Monitoring modes of the two devices. This visual representation offers valuable insights into the effectiveness of scheduling operations in managing energy usage. Furthermore, Table 3 supplements this analysis by presenting a detailed breakdown of consumed energy, revealing significant savings achieved through the integration of the system. Specifically, energy savings of 5.09kWh, 9.06kWh, and 3.85kWh were recorded over the monitoring period. Cumulatively, these savings amount to a total of 18kWh, underscoring the system's efficacy in conserving energy and optimizing operational efficiency.

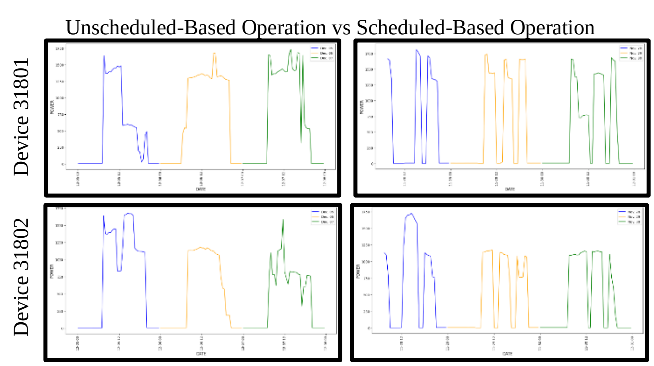


Fig 4. Power Consumption Graphs for Effectiveness (Saved Energy)

Table 3. Energy Consumption Comparison for Effectiveness (Saved Energy)

Day	Date	Device No.	Unscheduled-Based Operation	Scheduled-Based Operation	Saved Energy
Tuesday	November 28, 2023	31801	---	8.9 kWh	5.09 kWh
		31802	---	10.41 kWh	
	December 5, 2023	31801	9.59 kWh	---	
		31802	14.81 kWh	---	
Wednesday	November 29, 2023	31801	---	11.25 kWh	9.06 kWh
		31802	---	9.37 kWh	
	December 6, 2023	31801	17.45 kWh	---	
		31802	12.23 kWh	---	
Thursday	November 30, 2023	31801	---	12.53 kWh	3.85 kWh
		31802	---	10.45 kWh	
	December 7, 2023	31801	16.03 kWh	---	
		31802	10.8 kWh	---	
Total			**80.91 kWh**	**62.91 kWh**	**18 kWh**

4.3.4 Functionality Testing

Table 4 presents a Likert scale analysis of student responses across various questions evaluating the system's effectiveness in terms of functionality, with a notable trend of "Strongly Agree" prevailing throughout. The weighted means for questions 1 through 5 range from 4.38 to 4.62, reflecting high agreement levels. This data, collected from 50 student respondents in the experimental room, offers a robust overview of their perspectives.

Table 4. Students' Evaluation of the system for Functionality

Statement	5 – Strongly Agree	4 – Agree	3 - Neutral	2 – Disagree	1 – Strongly Disagree	Weighted Mean	Interpretation
1. The ECoSense system consistently follows programmed schedules.	33	12	5	0	0	4.56	Strongly Agree
2. The system is responsive to changes in classroom schedule or usage.	27	16	6	1	0	4.38	Strongly Agree
3. The ECoSense system has raised my awareness of energy conservation.	35	11	3	0	1	4.58	Strongly Agree
4. Unnecessary usage of the classroom by students is reduced/limited due to the ECoSense system.	28	15	7	0	0	4.42	Strongly Agree
5. The ECoSense system effectively reduces unnecessary energy wastage in the classroom.	34	13	3	0	0	4.62	Strongly Agree

4.3.1 Adaptability Testing

Fig 6 exhibits the power and energy consumption data recorded by the ECoSense device while connected to various appliances, such as a hair dryer, printer, electric fan, rice cooker, another brand of AC unit, and a refrigerator. This data underscores the system's effectiveness in terms of adaptability, highlighting its ability to monitor and enhance energy utilization across a diverse range of appliances.

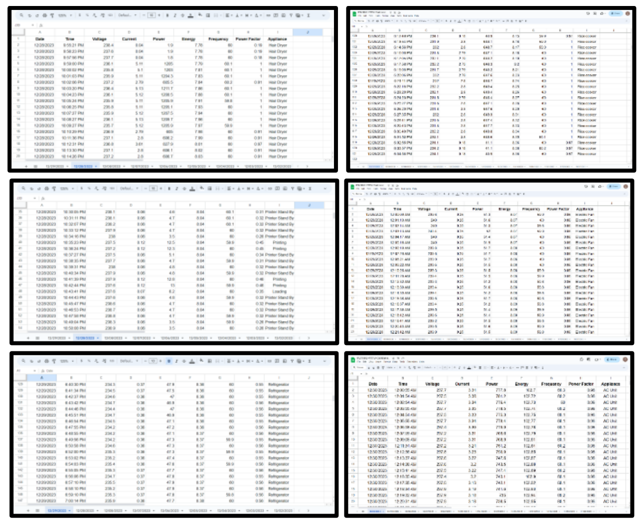


Fig 6. Power Consumption of other appliances for Adaptability

4.4 Overall performance of the system

Table 5 serves as a comprehensive summary of the prototype's overall performance across various metrics. Notably, the accuracy of measuring power and energy stands at an impressive 99.17% and 99.27%, respectively, underscoring the system's precision in capturing these crucial parameters. Additionally, the reliability of the two devices is demonstrated through consistent monitoring durations of 10 days, 3 hours, and 52 minutes, and 10 days, 3 hours, and 48 minutes, respectively. Furthermore, the system's effectiveness in conserving energy is evident, with a remarkable saving of 18kWh recorded over a 3-day period. These results affirm the functionality and adaptability of the prototype, highlighting its capability to deliver accurate measurements, maintain reliability, and optimize energy usage, thereby validating its utility in practical applications, as approved by the beneficiary.

Table 5. Overall performance of the prototype

Metrics	Results	
Accuracy	Power	99.17%
	Energy	99.27%
Reliability (longest period)	Device 31801	10 days, 3 hours, 52 minutes
	Device 31802	10 days, 3 hours, 48 minutes
Effectiveness	Saved Energy	18kWh (3 days)
	Functionality	Strongly Agree
	Adaptability	Yes

5.0 CONCLUSION

The researchers successfully implemented a wireless sensor network to measure and acquire real-time power consumption data from air conditioning units. This data was then utilized by graphing it through the created user-friendly graphical interface (GUI) for monitoring energy consumption, analyzing power wastage patterns, and implementing scheduling features. Additionally, the system's performance was evaluated through effectiveness, accuracy, and reliability assessments. Moreover, the system demonstrated commendable accuracy and reliability over a continuous five-day period, further solidifying its effectiveness. The ECoSense project strategically addresses challenges related to non-adherence to responsible energy practices within the institution, offering real-time monitoring capabilities and scheduled-based operation to overcome inefficiencies of manual management. This comprehensive approach not only fulfills primary objectives but also positively influences user behavior and contributes to sustainable practices. In essence, the ECoSense system emerges not just as a technological solution but also as a catalyst for positive change and responsible energy management within the institution.

6.0 RECOMMENDATIONS

Upon completing the system, the researchers provide a set of recommendations for future contributors in the engineering field. Emphasizing the importance of maintaining a stable internet connection, the researchers highlight its crucial role in the device's successful operation and reducing the risk of system bypassing. Integrating a human counter within rooms plays a crucial role by enabling the device to precisely determine the maximum number of air conditioners required for optimal operation, thus markedly improving energy conservation efficiency, especially during class hours when early dismissal may result in unoccupied rooms. Moreover, analyzing how the device's data correlates with student behavior in classrooms to identify occupancy patterns, activity levels, and preferences is essential. This analysis informs optimizations, leading to a deeper understanding of energy usage dynamics in educational settings. Lastly, recommending the addition of a mobile application version of the GUI to provide users with convenient control and monitoring of devices, offering a user-friendly interface for seamless management through mobile devices.

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8.0 REFERENCES

1. Azman, N., Ismail, M. B., & Ramli, N. A. (2020). Control and monitoring air conditioner: perspective of internet of things. Test Engineering and Management, 83, 8215-8220.

2. Song, W., Feng, N., Tian, Y., & Fong, S. (2017). An IoT-based smart controlling system of air conditioner for high energy efficiency. In 2017 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData) (pp. 442-449). Exeter, UK. doi:10.1109/iThings-GreenCom-CPSCom-SmartData.2017.72.
3. Wardana, N. S., & Garniwa, I. (2019). Design of low-cost energy metering device for direct load control and air conditioning energy monitoring. In 2019 IEEE International Conference on Innovative Research and Development (ICIRD) (pp. 1-4). Jakarta, Indonesia. doi:10.1109/ICIRD47319.2019.9074772.
4. Waluyo, Andre Widura, Febrian Hadiatna, & Ridwan Syamsul Fikri. (2022). IoT-based air conditioning control system for energy saving. Department of Electrical Engineering, Institut Teknologi Nasional Bandung, Jl. PHH Mustafa No. 23, Bandung, 40124, Indonesia.

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10.0 APPENDIX

Appendix A – System Components

Components
ESP8266
PZEM-004T Sensor
Mini Circuit Breaker
MG996R Servo Motor
LED Light
Google Drive

Appendix B – Delphi Method