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Monitoring and Control System for Energy Management Using Internet of Things

Anup Kumar Patel[1], Girija Shankar Sahoo[2], Shweta Dwivedi[3]
[1]Maharishi University of Information Technology
[2]Maharishi University of Information Technology
[3]Ambkeshwar Group Of Institute

Abstract: The use of technology has become an essential part of improving lifestyle, work efficiency, and a catalyst for economic growth. The benefit of the Internet of Things (IoT) and connected nodes has been on a steep incline in recent years. This paper aims to research, build, test and implement a low-cost energy monitoring and control system using IoT devices. Electrical appliances (e.g., air conditioning units and overhead lighting) can be controlled and monitored using IoT technology from any place in the world. In order to accomplish this goal, a complete front-end to back-end system that includes a smart device application (iOS platform), a cloud-based database, an Application Programming Interface (API), and a hardware development is proposed. A small programmable specialized computing device (e.g., Raspberry Pi) for preliminary testing. This smart node was chosen due to familiarity, and its capabilities, such as general purpose pins and built-in Wi-Fi chip. The end goal is to observe energy efficiency by monitoring and controlling air conditioning appliances and standard overhead lighting units. These smart IoT devices allow for the usage energy data from each unit to be collected and stored in a Cloud-based database that can be analysed and reported for energy conservation and analysis.
Keywords: Internet of Things (IoT), Energy Monitoring, Control System, Security.

I. INTRODUCTION

In 2016 the U.S. consumed 4,079,079 million kWh of energy, this number can be significantly reduced by decreasing energy waste through the Internet of Things (IoT) [1]. According to researchers, "*The IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to- computer interaction*"[2]. Many researchers have been studying the concept of IoT, its applications, and security of these applications using IoT [3, 4]. This project aims to implement a system in which electrical devices can be securely controlled and monitored using IoT technology on an international level (e.g., from any place in the world). Also, it deals with complete front-to-back aspects including
a mobile application, a cloud-based database, the creation of an API, and hardware development. The goal is to observe energy waste that may occur during the daily use of energy consuming appliances such as air conditioning units and standard overhead lighting units. These smart units are connected to Apple devices set up with iOS applications to control the unit's electrical status and monitor energy consumption, which is recorded in a database for analysis. Additionally, it consists of usage reports on the air conditioning units along with trends in consumption in kWh per unit time.

The United States, the largest economy in the world, consumed 12.96 million watt-hours per capita in 2014 [1, 5]. Despite energy consumption having a strong positive correlation with the economic development within a country, energy is not a free resource and has many environmental, social, and political dimensions associated. Data from March 2017 indicates that the United States energy consumption came primarily from petroleum and natural gas, sources that contribute to greenhouse gas emissions, which have been proven to increase global warming [6, 7]. This project is conducted at the Punta Leona Hotel y Club, Costa Rica, a resort and country devoted to the natural ecology of their region. Costa Rica aims to run primarily on renewable energy sources, where in 2016, 98.1% of electricity came from renewable sources [8, 9].

A. The Internet Of Things (IOT) System

The hardware aspect of this project requires a variety of components that had to be tested before ordering and implementing into the system. A small programmable specialized computing device, the Raspberry Pi v3, was used for preliminary testing. The Raspberry Pi v3 was chosen due to familiarity and its built-in capabilities for all aspects of the project, including general purpose pins and Wi-Fi capabilities. The Raspberry Pi v3 also had a variety of external attachments for monitoring and control purposes.

Following the preliminary testing phase of the project, this computational device was changed to the Raspberry Pi Zero Wireless due to its affordability, similar features, and smaller size, as seen in Figure 1.1.1 below.

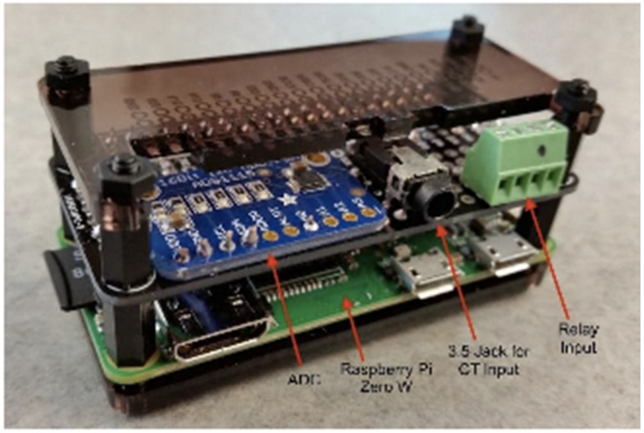

Figure 1.1.1. Architecture of One Smart Node

The electrical relay, an electronic switch that is activated by a current or signal between circuits, used in the preliminary testing was the SparkFun Beefcake mechanical Control kit which would attach to the Raspberry Pi v3 directly and become an intermediary for the electrical energy to flow through to the testing devices. The relay was later changed to 25 amp and 60 amp solid state relays due to variance in target appliances. The monitoring aspect involved a Current Transformer (CT) clamp, which uses a magnetic field to measure the current traveling through a wire. The analog signal output from the CT clamp was converted to digital signal by attaching it to a breadboard and then through a 4-channel Analog-to-Digital-Converter (ADS1115). Additional components such as 20 amp 125- volt duplex self –test slim GFCI outlets were used along with extension cords and component enclosures in the preliminary testing. Furthermore, once the hardware development was fully functioning in the testing phase, AC to DC, 5W power converter modules (transformers) were implemented to supply power to the Raspberry Pi via the source from the lighting, or A/C units. The completed preliminary hardware configuration is shown in Figure 1.1.2 below.

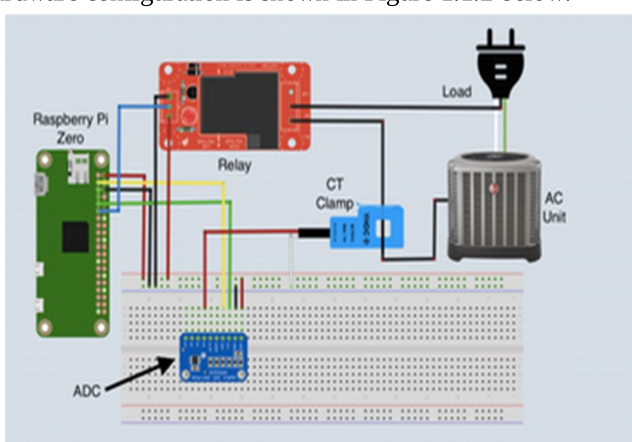

Figure 1.1.2. Hardware Wiring Diagram

The CT clamp measurements were calibrated against a clamp ammeter that measures current. The current was varied using a light dimmer serving as a potentiometer. The measurements were recorded, and a calibration curve was
generated, as shown in Figure 1.1.3. The calibration curve formula was implemented within the Python code on the Raspberry Pi for monitoring purposes. The python code written for the Raspberry Pi also referenced the voltage of the device to be monitored/controlled to generate an energy consumption power rating, seen in formulas (1) and (2) [10].

*Power=Current*Voltage* (1)

*Power=[Calibration Factor*CT Clamp Reading- Offset]*device_voltage_rating* (2)

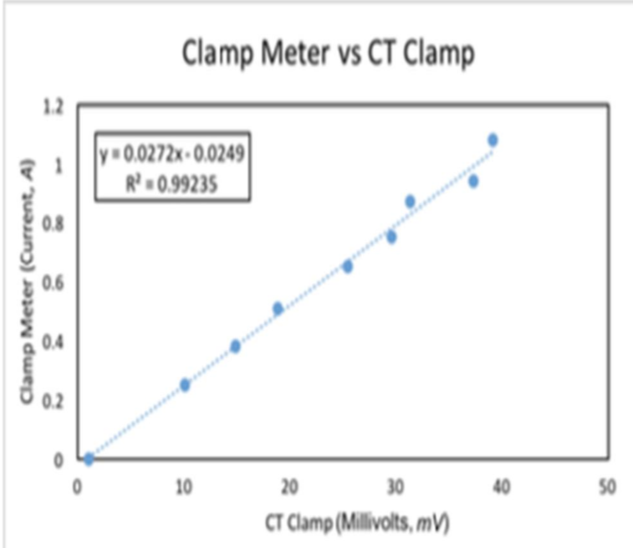

Figure 1.1.3. Calibration of Current Transformer Clamps

The smart nodes were designed to communicate with the various hardware components for the intention of sending energy data in hourly intervals to a MySQL relational database instance hosted on Amazon Web Services. Once the data is inserted and stored in the database, it can then be read from the iOS application. Additionally, the iOS application has the functionality of sending data to the database to change a device's status (e.g., On/Off), which the smart nodes can then interpret and respond in order to satisfy the request as shown in Figure 1.1.4.

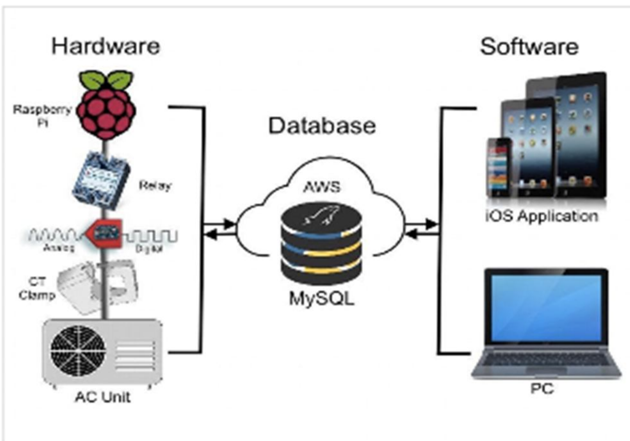

Figure 1.1.4. THE ARCHITECTURE DIAGRAM OF THE IOT MONITORING AND CONTROL SYSTEM

II. PRIOR WORK

As the limited work is done on cloud computing for scientific analytics, let us first discussed some impotent work done previously. Rocha et al [1] have introduces a unified approach that can combine many features and classifiers that requires less training and is more adequate to some problems than a naïve method, where all features are simply concatenated and fed independently to each classification algorithm. Raghupathi [2] has described the nascent field of big data analytics in healthcare, discusses the benefits, outlines an architectural framework and methodology. Burghard [3] has described Big Data and Analytics Key to Accountable Care Success. Dembosky [4] has described the promise and potential of big data analytics in healthcare. Feldman et al [5] have described Big Data in Healthcare Hype and Hope. Fernandes et al [6] have explained Big data, bigger outcomes. IJHT [7] has described Transforming Health Care through Big Data Strategies for leveraging big data in the health care industry. Frost and Sullivan [8] have *Drowning in Big Data? Reducing Information Technology Complexities and Costs for Healthcare Organizations.*

III. METHODOLOGY

A. Development and Implantation

Before the installation began, the specific install locations were assessed upon arriving in Costa Rica. Information was gathered about the Wi-Fi reliability, A/C unit specifications, equipment/tools and materials necessary for the installation [11, 12]. This process also involved making inquiries for extra hardware components that would be required for the installation to be successful. This inquiry was conveyed to the electrician that worked at the resort about some of the unit specifications and with the IT staff about the networking configuration before proceeding. Prior to the installation, mock wiring schemes were developed in order to fully understand how the various electrical components would be interconnected. These wiring schemes were later digitalized and can be seen in Figures VI and VII. The implementation consisted of 18 total units, which included 8 A/C units with energy monitoring capabilities, 4 lighting units that did not include energy monitoring capabilities, and 6 spare units in the event of malfunction or damage to a smart node. All units were switchable through an iOS application from any location. The data flow for controlling any specific device can be seen in Figure 3.1.1 below

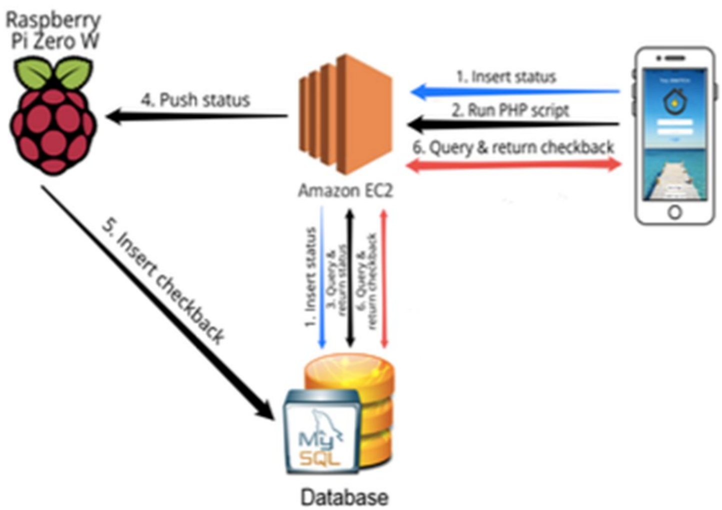

Figure 3.1.1. Development and Implementation Flow Diagram

The final preliminary installation element that was performed was to verify that the specifications for each A/C unit, previously received from the Punta Leona staff, matched that of the physical machine specifications. It became apparent that some of the given ratings for the A/C units were not accurately recorded, but not by such a factor that could have prevented further implementation. Installation began with one single unit in order to ensure the procedure could be replicated onto the additional A/C units. The associated wiring diagrams are shown in Figures 3.1.2. and 3.1.3.

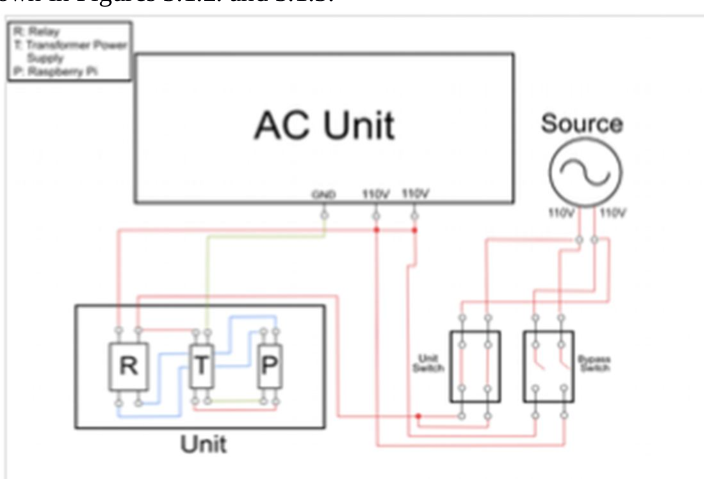

Figure 3.1.2. Hardware Wiring Diagram after Implementation

With this developed methodology, a successful installation was performed on all A/C units. The diagram of the setup (Figure VI) encapsulated the physical wiring of all components involved for the controlling method alone. Energy monitoring was done using current transformer clamps installed on the lead wires running to the A/C units, which were then connected to the smart node units. The clamps transmitted analog data to an analog-to-digital converter, which could then be processed by the Raspberry Pi, as seen in Figure VII below. The lighting units' installation followed a similar method, with the exception of the voltage value. The lighting units provided a source voltage of 120V vs. 220V and therefore made use of a 30A solid state relay and 120V bypass and pass-through (unit) switches. Although data was not designed to be collected from the lighting units, the CT clamps were still used in the configuration for error detection and control assurance.

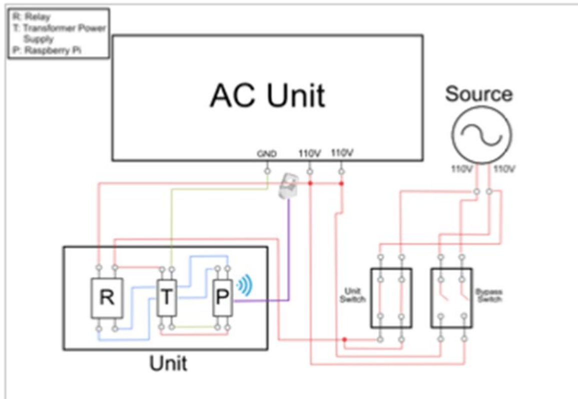

Figure 3.1.3. Hardware Wiring Diagram including Energy Monitoring System after Implementation

The monitoring and energy consumption on the smart node was done by using scripts written in Python coding language. These scripts were written and tested before deployment and pre-installed on all Raspberry Pi units. Some minor changes were made to the control code, for example the addition of a check-back procedure to ensure any device to be controlled would return to its previous power state upon restart, as well as additional error detection features.

B. Quality Control

While in Costa Rica, various improvements were necessary to enhance the quality of the overall product. During this time, it was made apparent that the status (e.g., On/Off) indicator would change despite the fact the true status of the component had not been altered. After deliberation on the issue, the decision was made to verify, in the iOS application, if the status received from the database was indeed the correct check-back from the smart node and not one sent from a previous transaction. As a result, a time stamp verification was added to the Python script on a smart node to determine if the check-back was received within an acceptable time frame following an attempt to change a component status. When the check-back was not within an acceptable time frame, due to the newly implemented time stamp verification, it was clear that the check-back was stale and the Raspberry Pi did not send the check-back during the current transaction. Through the addition of this time stamp procedure, connection interruption issues were revealed by means of stale transactions between the database and smart node. A few smart nodes also utilized port forwarding in order to adapt to the desired security mode of the connected network. By adding port forwarding, it allowed the smart nodes to connect to WPA2 personal routers and receive packets from the server (EC2) on Amazon Web Services. Additionally, it was observed that when a power outage occurred, all devices would be powered down, reboot and the node would not return the A/C or lighting unit to the last status in the database. This caused a discrepancy between the previous state of the unit and the power status the iOS application returned from the database. To resolve this, a Python script was implemented to pull the current status of the unit every time the smart node rebooted.

To minimize the amount of physical modification to walls or Air Conditioning units, a non-invasive installation was exercised such that the hotel could have the option to remove or exchange units. Additional steps were implemented to add quality to the product and the installation performed by securing all exposed wire used in the installation process and to ensure that weatherproof tubing and enclosures protected all outside wiring. When the installation of the smart nodes neared completion, any cables that were associated with the nodes were zip-tied together for a proper wiring configuration. Another considerable quality control process implemented during this time was when a new model of A/C unit was presented. A new mock wiring diagram would be developed and approved by the hotel's electrician before execution of the configuration would continue.

1) Mobile App Interface

The iOS mobile application was the primary graphical user interface (GUI) for the product. This interface allowed users to manipulate the power status of electronic devices. The application provided the component status and check-backs on whether or not the component was successfully able to respond to the requested change in power status. The iOS application was first written in English and then translated into Spanish, per the request of the sponsors of who natively speak Spanish.

The app also allows for hourly data to be interactively displayed on the screen and in various time increments. The data can be viewed per unit and in an increase of hours for the duration of one day, week, or month as shown in Figure 3.2.1.1. Additionally, the graphs can be manipulated by touching your fingers to the screen using simple scaling finger gestures. The X-axis is dynamic in the fact that one can zoom in and out to change the X-axis scale. The mobile application has an 'all off' button to allow a user to turn off all components in a specific section. The components were separated by component type (e.g., A/C or lighting) in the application. PHP, a server-side scripting language designed for web development, was utilized on the Amazon server instance (EC2) for the inter-component integration. Various PHP scripts were written and stored in files on the EC2 instance in order to communicate with the database for sending and receiving data.

Figure 3.2.1.1. MOBILE APP INTERFACE

Figure 3.2.1.2 provides an example of how the raw data was analyzed. Out of the eight A/C units, two were identical units, and the rest were dedicated to an event room with 6 five-ton A/C units of the same model. Figure IX displays the frequency distribution of two office units when the air conditioning unit was in the 'ON' state. To determine if the unit was on or off, a usage value of 0.1 kWh or higher was used at any given hour for two employees working on the same schedule. One would expect the usage would be similar, however, these employees work schedules varied due to their position and individual working schedules per week.

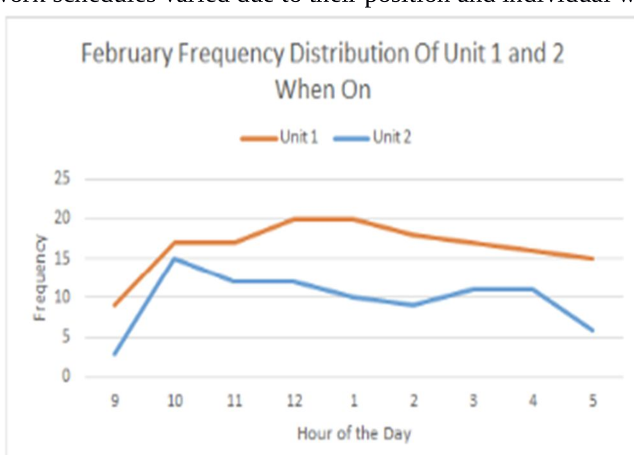

Figure 3.2.1.2. FREQUENCY DISTRIBUTION OF TWO UNITS IN THE MONTH OF FEBRUARY 2018 FROM 9:00 AM TO 5:00 PM

Figure X displays the total energy consumption of the two office units. For any given hour, Unit 1 had higher total energy consumption; therefore, if the employees of these offices were on a regular schedule, one could conclude that there is significantly more energy consumption from the employee using Unit 1 as opposed to the employee using Unit 2. Although their work schedules differ, looking at Figures IX for 10:00 AM, Unit 1 was only active for a few more hours than Unit 2, yet Figure X displays that Unit 1 consumed over two times the amount than that of Unit 2. The sum of all readings at 10:00 AM in February was 22.07 kWh for Unit 1 and 10.15 kWh for Unit 2.

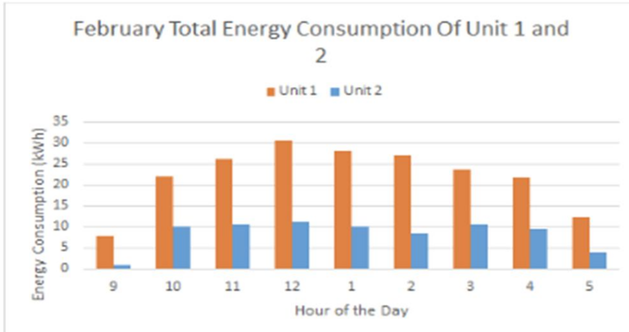

Figure 3.2.1.3 TOTAL ENERGY CONSUMPTION OF TWO UNITS IN THE MONTH OF FEBRUARY 2018 FROM 9:00 AM TO 5:00 PM

Figure 3.2.1.4 displays the two office units' average energy consumption when the unit was active. The average reading for Unit 1 was 1.12 kWh, which is 41.8% greater than that of the 0.79 kWh reading from Unit 2. We can conclude that the employee using Unit 1 is consuming 0.33 kWh more than the employee using Unit 2 at any given moment. The difference can be attributed to the preference between the two employees. However, the office where Unit 1 is located has twice the square footage of the office where Unit 2 is located. Additionally, Unit 2 is right above employee 2, whereas Unit 1 is across the room from the first employee.

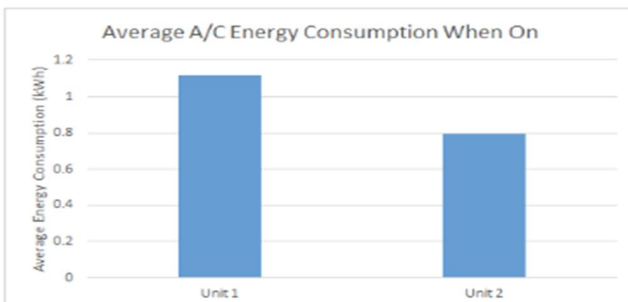

Figure 3.2.1.5. AVERAGE A/C UNIT ENERGY CONSUMPTION WHEN THE UNITS ARE ON

The consumption of the 6 A/C units in the event room varied greatly. This is due to fact that the room is used more often and for longer periods of time, and mostly on the weekends. The data is summarized in Figure XII for the total energy consumption in a given month for 4 of the A/C units. One of the two excluded units, A/C Unit 7, had an issue with a transformer on the A/C itself and thus was never used. Unit 6 experienced issues with Wi-Fi connectivity due to the location of the room access point and the strength of the smart nodes.

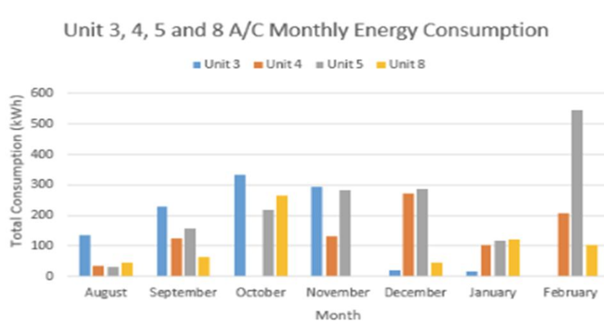

Figure 3.2.1.6. TOTAL ENERGY CONSUMPTION FOR EVENT ROOM UNITS PER MONTH

Figure 3.2.1.6 displays the consumption of the 4 units. The event room (when used) was not always at full capacity which meant that when an event was occurring, one or two A/C units would be used, as shown in August for Unit 3 and in December Units 4 and 5. Ideally, these units should be consuming the same amount of energy in a given month to avoid having to deal with maintenance problems that can be due to the usage of one unit over another. Transitioning to February, Unit 5 consumed 545.2 kWh, which was 209.8 kWh greater than the next highest, being Unit 3 in October, which had a total consumption of 335.4 kWh. This variation is attributed to an extended event in February and the preference of using A/C Unit 5 for the event attendees.

IV. CONCLUSION

In this paper, a method of building a cyber-physical system utilizing IoT for energy monitoring and control of electrical devices was presented and installed at a resort in Costa Rica, where a sample of data analysis was also conducted. In February, results show a pattern of energy consumption in the office environment from a time interval ranging between 9:00 AM to 5:00 PM. During this time, it could be observed the most energy consumption throughout the day was around 12:00 PM (Noon) for Unit 1 and fairly constant throughout the day for Unit 2. This information directly correlated with the frequency distribution of the two units showing how often, during any single hour, a unit was reported in the 'ON' state. As a result of the lower energy consumption for Unit 2 within the office environment, it was observed Unit 2 had a lower energy impact per hour when in the 'ON' state. The hourly storage and ease of access to energy data accomplished through this project support the concept of energy awareness and conservation. As energy data is collected, greater trends can be derived, thus providing the consumer with the means in which to understand and consciously make changes to excessive energy use in an effort to reduce consumption. During the implementation in Costa Rica, many challenges were observed and subsequently adapted to, including low Wi-Fi bandwidth, dated networking technologies, frequent power outages and low Wi-Fi network range throughout the resort. Through an understanding of these issues, strategic elements and measures were implemented to ensure the projects longevity post departure. Future goals include the development of an interactive map of the facilities at Punta Leona Hotel y Club and web app/Android functionality for controlling and monitoring applications. Further future goals include Wi-Fi improvements to increase responsiveness, such as upgrading to the latest Wi-Fi technologies and increasing the range of Wi-Fi signal on site (i.e., additional access points, repeaters, etc.) [13, 14]. Finally, the addition of IoT technology for various other applications such as integrated temperature control and various 'modes' for scheduled operation would create a more versatile product.

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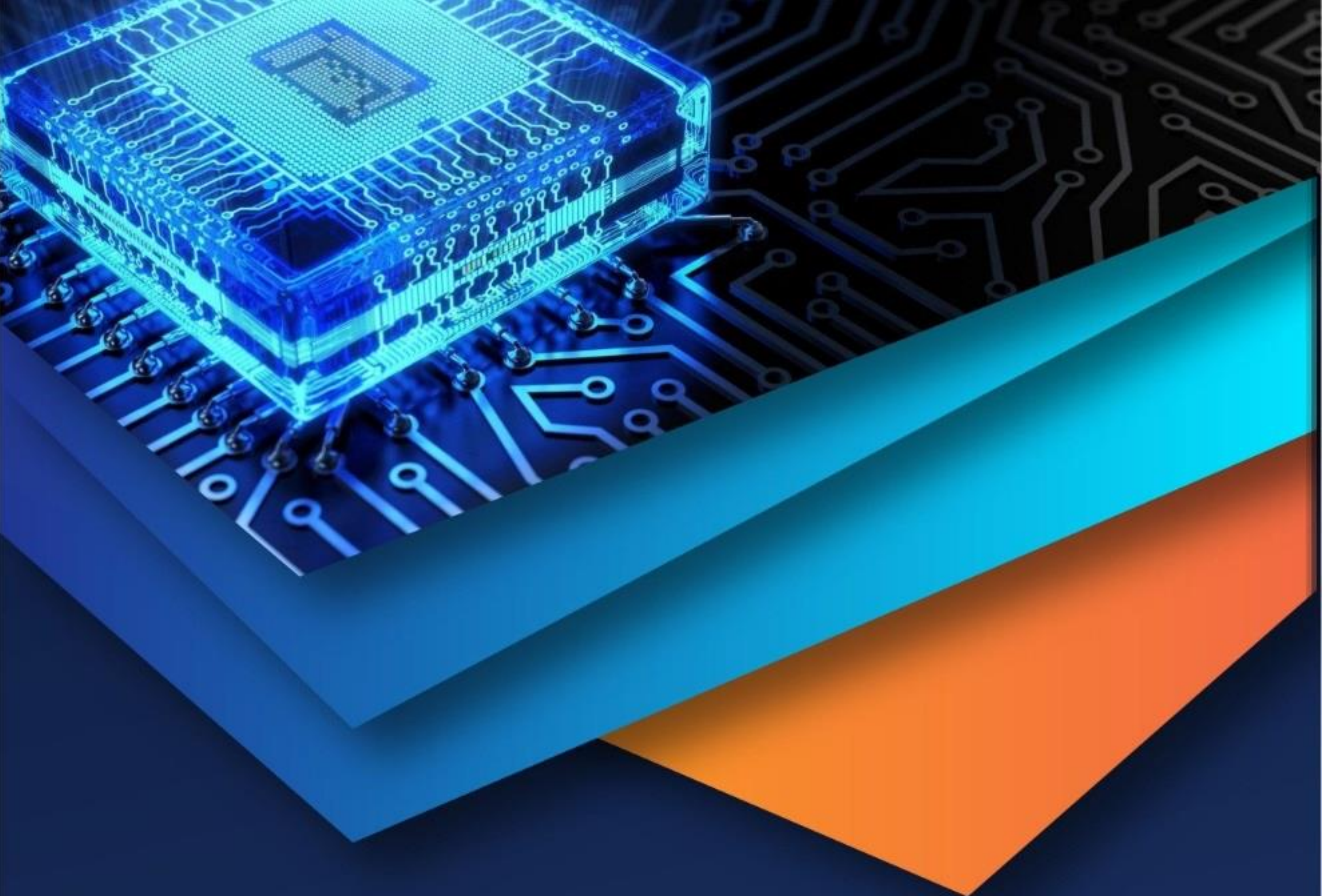

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