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REAL-TIME MONITORING AND OPTIMIZATION OF ELECTRICAL LOAD IN A BUILDING

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Abstract

The growth of financial technology (FinTech) companies over the past decade highlights the significant evolution in digital innovation. Recently, FinTech ideas have begun to gain acceptance among traditional financial sector players, including financial institutions. Despite recent acquisitions of FinTech companies by banks, the majority of FinTech enterprises remain self-funded and open to partnerships with outside banks. FinTech companies have the potential to take over many crucial functions currently performed by traditional banks, particularly because many banks–apart from the well-known large ones–continue to offer outdated, expensive, and bureaucratic financial services. It is anticipated that FinTech companies will have a substitution effect, leading banks to abandon certain economic activities. In response to FinTech advancements, banks' incentives to take risks and improve their efficiency and profitability may have shifted. This underscores how FinTech developments will impact bank risk, efficiency, and profitability, presenting a viable alternative to traditional banks as a source of credit. This study aims to investigate these challenges from a global perspective.

INTRODUCTION

In our modern era, characterized by rapid technological advancements and burgeoning population growth, we confront two interrelated challenges of paramount significance: escalating energy costs and mounting environmental concerns. The ramifications of our energy consumption patterns reverberate globally, contributing significantly to pressing issues such as climate change and pollution. As energy demand continues to soar unabated, projections underscore a looming surge in the years ahead, exacerbating the strain on finite resources and compounding environmental degradation. Within Pakistan, a nation grappling with its own challenges, the staggering 40.29% surge in electricity bills from 2019 to 2024 paints a stark picture of economic strain, further compounded by heightened air pollution levels. It's a sobering reality underscored by Pakistan's classification as the second most polluted country globally in 2018, a designation that persists, casting a shadow over public health and environmental sustainability efforts. In the face of such daunting challenges, efficient energy management systems emerge as indispensable tools in our arsenal, offering a pathway toward sustainable development and resilience against the dual threats of economic instability and environmental degradation [1].

At the heart of this endeavor lies the concept of real-time monitoring, a dynamic process of observing and tracking various parameters or data points pertinent to energy consumption within buildings. This real-time insight empowers stakeholders with the ability to discern patterns, detect anomalies, and institute timely interventions aimed at optimizing energy usage. Among the critical facets of real-time monitoring is power consumption monitoring, a foundational pillar that provides a holistic view of energy usage patterns within a building. By tracking power consumption in real time, stakeholders gain invaluable insights into peak demand periods, enabling strategic decision-making to mitigate costs and enhance operational efficiency [2].

Complementing power consumption monitoring are ancillary processes such as voltage and current monitoring. These endeavors serve as vital safeguards against potential hazards such as overloading, voltage imbalances, or equipment malfunctions, thereby preserving equipment health and preventing costly damage. Moreover, the advent of demand response monitoring heralds a new era of dynamic energy management, wherein buildings can adjust their electrical load in response to fluctuating price signals or grid conditions. This proactive approach optimizes energy usage and fosters resilience in the face of evolving energy landscapes [3].

The pursuit of energy efficiency transcends mere monitoring; it necessitates a concerted effort toward optimization, a multifaceted endeavor aimed at maximizing efficiency and achieving desired outcomes through systematic planning and resource allocation. Optimization techniques, scheduling, also known as dynamic load allocation, offer a spectrum of tools to empower organizations in their quest for energy efficiency. Dynamic load allocation, in particular, emerges as a linchpin in this endeavor, enabling adaptive energy management based on occupancy, activity levels, and environmental conditions. By dynamically adjusting energy allocation in real time, organizations can optimize resource usage, enhance operational efficiency, and chart a course toward sustainability [4]

In the broader context of today's world, the imperative of real-time monitoring and optimization of electrical load in buildings assumes heightened significance. With societal expectations evolving and regulatory pressures mounting, organizations find themselves at a crossroads, compelled to embrace sustainable practices and chart a course toward a greener future. Real-time monitoring facilitates Cost savings and serves as a testament to organizational commitment toward environmental stewardship [5]. As we navigate the complexities of the 21st century, the convergence of technology and sustainability initiatives holds the promise of a more resilient, equitable, and sustainable future for future generations [6].

The rising energy costs and environmental concerns pose significant challenges for building operators and managers.

Conventional approaches to energy management often lack real-time monitoring capabilities and fail to adapt to dynamic operational conditions, resulting in suboptimal energy usage and increased costs.

There is a pressing need for innovative solutions that combine real-time monitoring and optimization techniques to optimize electrical load and promote energy efficiency in buildings.

Against the backdrop of increasing energy costs and environmental concerns, the project's background is rooted in the desire to create a smart and sustainable building ecosystem.

The primary goal is to leverage real-time data from various sensors, including environmental and electrical load sensors, to optimize energy consumption intelligently.

By analyzing data, comparing it to schedules and weather conditions, and providing actionable insights, the project aims to reduce costs while ensuring the comfort and productivity of building occupants.

The primary objective of the project "Real-Time Monitoring and Optimization of Electrical Load in a

Building" is to develop a comprehensive energy management system that integrates real-time monitoring and optimization techniques to optimize energy usage within buildings. Specific objectives include:

Develop a real-time energy monitoring and logging system for a building to track and record energy usage.

Utilize Dynamic load Allocation (Scheduling) to provide recommendations for optimizing electrical energy consumption in the building.

The scope of the project encompasses the development of a real-time energy management system focusing on buildings, including residential, commercial, and institutional facilities. The system integrates sensors, data analytics, and dynamic energy allocation techniques to optimize electrical load and promote energy efficiency. The research and development activities cover the design, implementation, and evaluation of the energy management system, with a focus on usability, effectiveness, and scalability.

LITERATURE REVIEW

In recent years, the growing demand for sustainability and energy efficiency has drawn much interest in real-time monitoring and optimization of electrical load in buildings. The possibility of cutting-edge technology and techniques to enhance building electrical load control has been investigated in several research. More precise analysis and optimization have been made possible by gathering delicate data on electrical load patterns made possible by advanced sensor technologies and IoT devices Click or tap here to enter text. . Demand response, peak shaving, and load-shedding are among the optimization techniques investigated to lower peak demand and energy consumption. Building electrical demand has also been predicted and optimized using machine learning and artificial intelligence methods. To accomplish real-time monitoring and optimization, research has also highlighted the need to combine BMS with sophisticated analytics and optimization tools. Moreover, it has been emphasized how occupant behavior and involvement contribute to electrical load optimization. The research indicates that real-time monitoring and optimization of building electrical demand need a multidimensional strategy that integrates cutting-edge technology, data analytics, and occupant involvement [7]. Effective building electrical load management is a major issue in modern society. Along with the energy demand, the need to reduce carbon emissions and optimize energy use has grown. Buildings use a large amount of energy worldwide, so achieving energy efficiency and sustainability depends critically on their electrical load management [8].

In modern society, effective building electrical load management is a significant issue. As the need for energy rises and the threat of climate change intensifies, sustainable growth now depends critically on energy consumption optimization [9]. In particular, buildings are responsible for much of the world's energy use, and attaining energy efficiency depends critically on their electrical load management. One prospective answer to this problem is real-time monitoring and optimization of building electrical load. Real-time monitoring and management of electrical load is now feasible using sophisticated technology and sensors, which minimizes energy waste and maximizes energy use [10]. This article attempts to go deeper into this idea, concentrating on creating an electrical load monitoring and optimization system in real time for a university environment. A critical component of the energy crisis that the world is experiencing is buildings. They use a lot of energy, and their typically ineffective electrical load control wastes resources and raises carbon emissions [11]. Building electrical load management, as it is now done, relies on manual data collecting and a few optimization techniques. The underlying problem of buildings is that they do not need a dynamic, intelligent system to track and adjust their electrical demand in real time. Peak demand spikes, weakening of the grid, and lost chances for energy efficiency result from this [12]. To meet this problem, we must investigate cutting-edge methods and technology to maximize building electrical load management.

EXISTING TECHNOLOGIES AND RESEARCH

This project advances energy management efficiency by employing non-intrusive load monitoring (NILM), which analyses individual appliance energy consumption without needing intrusive equipment.

Utilizing advanced methods such as graph signal processing and spectral clustering, the system deciphers complex energy usage data into identifiable patterns. Techniques like spectral cluster mean (SC-M) and spectral cluster eigenvector (SC-EV) are employed for event detection, identifying significant disparities in appliance energy usage, which can revolutionize energy management strategies. Additionally, the integration of spectral clustering with graph signal processing is enhanced by refining pre- and post-processing procedures to increase accuracy and reduce computational complexity. The application extends to using inductive proximity sensors in industrial settings, crucial for automation control and enhancing industrial process security and productivity without physical contact. Future directions include refining sensor accuracy and integrating technologies such as artificial intelligence and the Internet of Things to develop more adaptable sensing systems and expand development opportunities. Furthermore, a prototype Smart Home Energy Management System (SHEMS) leverages NILM through fog-cloud computing to address Demand Side Management (DSM) issues within intelligent grid contexts, using a two-stage NILM methodology that includes deep learning and Artificial Neural Networks (ANNs) to identify and manage electrical loads efficiently [13].

In the quest to optimize energy management in buildings, our proposed method introduces a revolutionary approach through real-time monitoring and optimization of electrical loads. Unlike traditional methods that rely heavily on manual monitoring or scheduled load-shedding, this technique employs ESP32 controllers combined with voltage sensors. These devices facilitate the continuous monitoring and management of electrical loads. The integration of ESP32's robust processing capabilities with precise data from voltage sensors allows for real-time operational insights, displayed via an intuitive LCD interface for building managers. This innovation aims to significantly reduce energy costs, improve energy efficiency, and support sustainable energy practices within building infrastructures [14].

Electrical Load Management in Buildings is crucial for maximizing energy use efficiency, minimizing waste, and reducing peak demand costs. As building electrical systems become more complex, the challenge for facility operators and building managers to effectively manage these systems intensifies. The importance of electrical load management cannot be overstated, as it helps in reducing peak demand charges, avoiding penalties, extending the lifespan of electrical equipment, reducing maintenance costs, and supporting sustainable energy practices. Current electrical load management employs Energy Management Systems (EMS) and Building Management Systems (BMS), alongside traditional methods like manual monitoring and load scheduling based on occupancy and usage patterns. However, these methods often suffer from the need for human intervention, inaccurate load forecasting and scheduling, and lack real-time monitoring and control capabilities. Fortunately, advancements in technology present numerous opportunities for enhancement. Promising solutions include real-time monitoring with sensors and Non-Intrusive Load Monitoring (NILM), automated load scheduling with sophisticated algorithms and machine learning, integration with energy storage and renewable energy sources, and cloud-based platforms and IoT-enabled devices. By leveraging these technologies, buildings can achieve cost-effective energy usage, environmentally friendly practices, and lower energy bills [15].

In terms of Optimization Strategies for Electrical Load, a novel heuristic approach is introduced, formulated as a Mixed Integer Linear Programming (MILP) problem, to optimize energy consumption in HVAC systems of classroom environments. The strategy encompasses three phases: initialization, rescheduling, and energy minimization, effectively organizing classes and managing HVAC operations based on room occupancy and faculty schedules. Demonstrated through a simulation-based university case study, this method yields substantial energy savings while maintaining user satisfaction and shows superior processing efficiency compared to commercial solvers like IBM CPLEX and Gurobi, proving its scalability and applicability in extensive building energy management systems and university settings [16].

Another project focuses on reducing household energy consumption through the development of

Home Energy Management Systems (HEMS). It employs a Binary Bat Swarm Algorithm (BBSA) to optimize appliance scheduling, strategically reducing energy use during peak hours. This study includes hardware prototypes and a user-friendly graphical interface, which aid in practical implementation. Experimental validation against a Binary Particle Swarm Optimization (BPSO) controller demonstrates the BBSA's effectiveness in conserving energy and reducing electricity bills, contributing significantly to the advancement of efficient HEMS solutions for sustainable energy management in residential settings [17].

Furthermore, demand response programs are evaluated using a mixed-methods approach in Ghana's Greater Accra Region, where household energy consumption patterns are studied. The research identifies unique consumption behaviors through K-means clustering, enabling tailored demand response strategies. By analyzing consumer behavior and appliance usage, the study underscores the necessity for cultural awareness and specialized demand response systems to influence energy consumption effectively. The findings offer valuable insights for energy providers and policymakers to enhance demand response initiatives and optimize electricity usage, thereby establishing a foundation for similar studies in other regions and promoting sustainable energy management practices [18].

To optimize energy use in scheduled buildings, a practical approach is adopted, beginning with an understanding of current energy usage and identifying potential areas for improvement. This foundational analysis paves the way for the application of advanced scheduling techniques aimed at enhancing the distribution and consumption of energy. Additionally, an emphasis is placed on engaging occupants directly in the energy-saving process through real-time feedback and encouraging proactive energy-saving actions. The combination of these technical and behavioral strategies is designed to significantly reduce overall energy consumption and promote sustainability within the building environment [19].

Building Management Systems (BMS) play a critical role in this ecosystem. These computerized systems are tasked with monitoring and managing the mechanical and electrical components of buildings, such as security, lighting, and HVAC systems. The primary goals of traditional BMS include maximizing energy efficiency, reducing energy costs, and improving occupant comfort and security. However, conventional BMSs are often limited by their inability to integrate with advanced optimization tools, lack of real-time monitoring capabilities, and restricted data analytics capacity. These limitations hinder their effectiveness in achieving optimal energy management [20]

Recent advancements in building management technology have addressed these issues by enabling BMS to integrate with sophisticated analytics and optimization tools, including energy management software and machine learning (ML) algorithms. This enhanced integration facilitates real-time energy usage monitoring, enables predictive maintenance, and supports automated fault detection. Advanced analytics provide building managers with detailed insights into energy consumption patterns, allowing for informed decision-making and optimization of energy efficiency [21].

The effectiveness of integrating BMS with advanced analytics is demonstrated through various case studies. For instance, a commercial building in New York City implemented an integrated BMS and energy management system, resulting in a 25% reduction in energy use and an annual savings of $100,000 in energy costs. Another example is a university campus that employed machine learning algorithms in conjunction with its BMS, achieving annual energy cost savings of $50,000 and reducing energy consumption by 15%. These examples underscore how the synergy between BMS and sophisticated analytics can significantly enhance building energy efficiency and reduce operational costs [22].

In addition to technological interventions, occupant behavior and engagement are critical components of effective energy management in scheduled buildings [23]. Optimizing electrical load is essential for lowering peak energy demand. Load management strategies such as load shedding and peak shaving are employed to manage electrical loads during peak hours. Load shedding involves temporarily turning off non-essential loads, while peak shaving reduces energy usage during peak periods [24].

Energy use in scheduled buildings is often predetermined; therefore, techniques like demand response and energy storage are less applicable. Instead, energy managers focus on optimizing the use and distribution of energy within the established parameters. This includes scheduling energy-intensive activities during off-peak hours and maximizing energy usage efficiency during peak periods. The foundation of these optimization techniques lies in the use of advanced scheduling algorithms and energy management systems. These systems are crucial for ensuring that energy consumption and peak demand are minimized within the scheduled framework [25].

Overall, the strategic integration of advanced technologies and occupant engagement in energy management not only helps in reducing energy consumption and costs but also contributes to the environmental sustainability of building operations. By optimizing energy distribution and usage, scheduled buildings can achieve reduced energy bills and environmental impacts without compromising their operational effectiveness [26].

Methodolgy

ESP32 microcontroller, functioning as the central processing unit orchestrating the diverse functionalities and ensuring seamless integration of the system's operations. To maintain operational integrity and reliability, a meticulously designed voltage regulation process is implemented, leveraging a combination of a voltage regulator and IC 7805 to translate the standard 220V AC mains power into a stable 3.3V supply compatible with the ESP32's requirements. This foundational element provides the necessary power infrastructure for the system to function effectively and efficiently. A smart meter is made at the very start that generates display on LCD and shows the voltages, current, Power and unit consumption. The sensory landscape within the system is expansive and strategically deployed, comprising multiple sensors meticulously positioned throughout the building environment. These include the ZMPT101B voltage sensor, ACS712 current sensor, DHT22 temperature and humidity sensor, and a raindrop sensor, collectively forming a robust data collection network essential for monitoring and analyzing critical environmental parameters. Each sensor fulfills a specific role, contributing valuable data insights crucial for informed decision-making and real-time optimization of electrical load management within the building. Integral to the system's functionality is the management and optimization of electrical loads, a task facilitated by the incorporation of three distinct loads with varying power requirements. Through the implementation of a sophisticated scheduling, these loads are dynamically managed and allocated based on predefined time slots categorized as free, busy, and free. This dynamic load management strategy ensures optimal energy utilization while catering to the building's operational requirements and constraints, thereby fostering efficiency and sustainability. In tandem with load management, the system boasts a comprehensive user interface, designed to provide stakeholders with intuitive access to real-time data and actionable insights. LCD displays, including two 16x2 and a 16x4 variants, offer visual representations of key parameters such as power consumption, units consumed, temperature, voltage, current, humidity, rainfall status and load consumptions in different rooms. Complementing these displays is the Blynk app, a versatile platform enabling remote monitoring and control, further enhancing user engagement and facilitating informed decision-making. Moreover, the system's optimization mechanisms extend beyond mere load management, encompassing strategic notification protocols to minimize disruptions and maximize energy efficiency. Notifications are intelligently managed to alert users exclusively during designated free time slots, mitigating unnecessary interruptions and empowering stakeholders to respond proactively to emerging trends or anomalies.

In summation, this comprehensive exposition of the system's design and architecture provides stakeholders and readers alike with an exhaustive understanding of its underlying framework, integration, and optimization strategies. Through meticulous attention to detail and innovative design principles, the system emerges as a formidable tool for real-time energy management within the building environment, poised to enhance efficiency, sustainability, and operational resilience as shown if Fig 1.

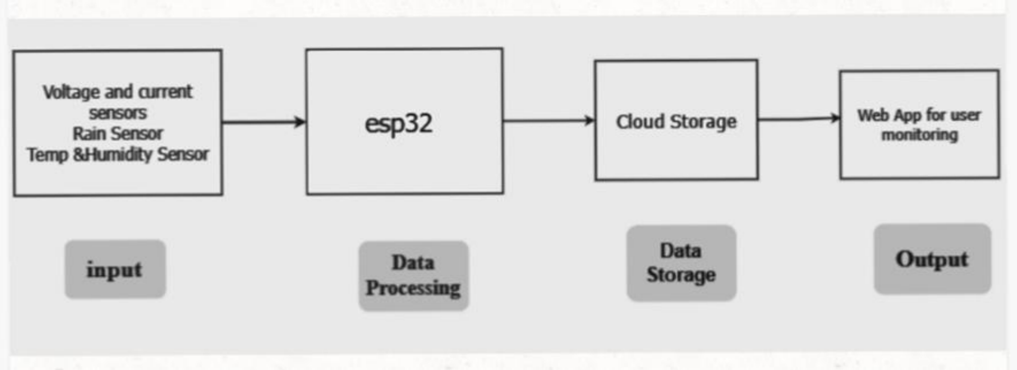


Fig 1. Block Diagram

Sensors stand as the vigilant sentinels, tasked with the meticulous collection of crucial data points essential for understanding the nuanced dynamics of the building environment. From the voltage sensor, meticulously monitoring the electrical network's stability, to the current sensor, diligently tracking the flow of energy through circuits and equipment, each sensor plays a vital role in painting a comprehensive picture of the building's energy landscape. Meanwhile, the temperature and humidity sensor, akin to a digital meteorologist, provides valuable insights into the ambient climate conditions, ensuring comfort and efficiency within the building's confines. Furthermore, the raindrop sensor, attuned to the subtle rhythms of nature, stands ready to detect even the faintest whisper of precipitation, aiding in weather monitoring and resource management. This trove of sensor data converges at the doorstep of the ESP32 microcontroller, the veritable master orchestrating the symphony of data processing and analysis. With its computational prowess, the ESP32 deftly aggregates, interprets, and synthesizes the influx of sensor data, transforming raw measurements into actionable insights. Yet, the journey does not end here; instead, it embarks upon a celestial voyage to the ethereal realms of cloud storage. Here, amidst the digital heavens, data finds sanctuary, nestled within the secure confines of cloud servers, awaiting the discerning gaze of stakeholders seeking enlightenment. Finally, the user monitoring interface emerges as the terrestrial interface, the bridge between the esoteric realm of data and the tangible world of human interaction. Through intuitive visualizations, immersive dashboards, and timely notifications, stakeholders are empowered to navigate the labyrinthine corridors of data, uncovering hidden truths, and charting a course towards optimized energy usage, enhanced efficiency, and sustainable building practices. In this symbiotic dance of sensors, microcontrollers, cloud storage, and user interfaces, the narrative of real-time monitoring and optimization of electrical load within the building unfolds, a testament to the ingenuity of human innovation and the boundless potential of technological advancement. The flow chart shows the complete process as shown in Fig 2.

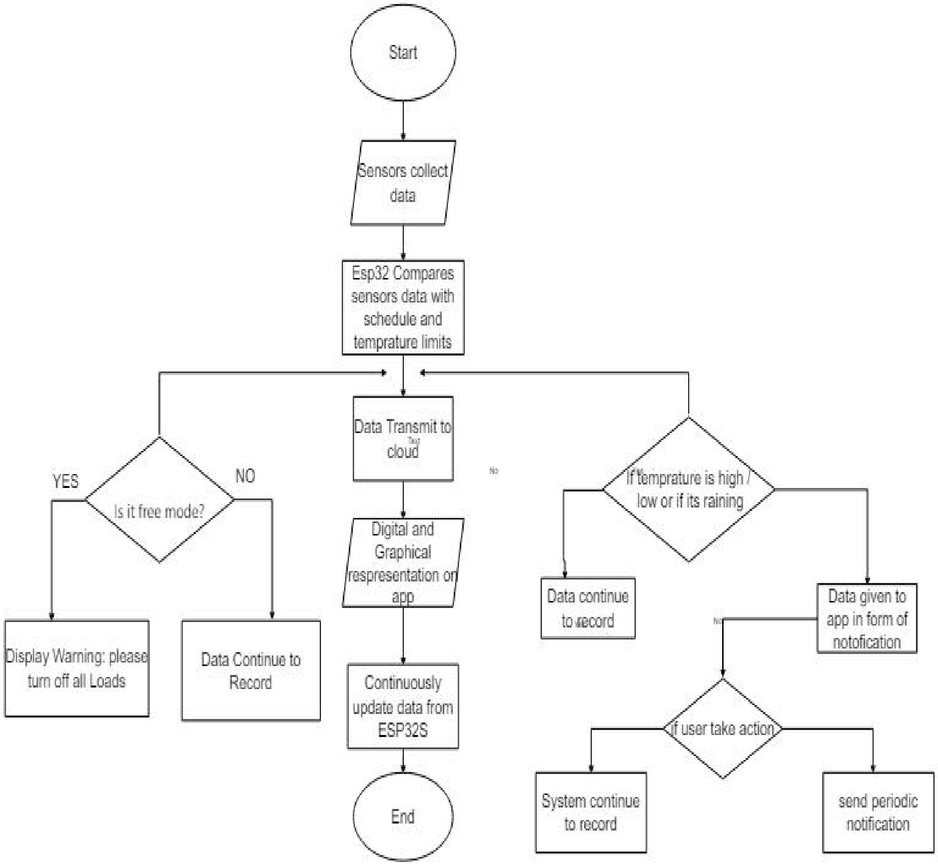


Fig2. Flow Chart

The process of real-time monitoring and optimization of electrical load within a building unfolds through a systematic series of steps, as outlined in the flowchart. It all begins with sensors strategically placed throughout the building, tasked with collecting crucial data on voltage, current, temperature, and humidity. This data is then transmitted to the ESP32 microcontroller, where it undergoes processing and analysis. Subsequently, the processed data finds its way to cloud storage, ensuring both its preservation and accessibility for further analysis and decision-making. Yet, the system doesn't merely operate in a passive mode; rather, it incorporates proactive measures to address potential anomalies or deviations from the norm. For instance, if the temperature veers outside the acceptable range, a notification mechanism is triggered, alerting stakeholders to act. The user's response to such notifications dictates the course of action, with options to either acknowledge and continue data recording or investigate further if necessary. Similarly, in instances of high voltage levels, a similar notification mechanism comes into play when load consumption is in free mode or free time, urging users to take action to mitigate risks. Throughout this process, the emphasis remains on continuous data recording and analysis, ensuring a comprehensive understanding of energy usage patterns. Once recorded, the data is seamlessly integrated into the Blynk app's cloud storage, where it is presented in a visually comprehensible graph format, facilitating easy interpretation and decision-making. Ultimately, this process represents a holistic approach to energy management, leveraging technology, data analytics, and proactive intervention to optimize resource usage, enhance operational efficiency, and pave the way towards a more sustainable future.

Hardware:

In this project, we're using the ACS712 current sensor to measure electrical currents accurately, as shown in Fig 3. We connect it to our ESP32 microcontroller pin no. 34 to sensor data din, calibrate it for precision, and read current values using the sensor's analog output. With this data, we implement alert mechanisms based on predefined thresholds for timely notifications or actions.

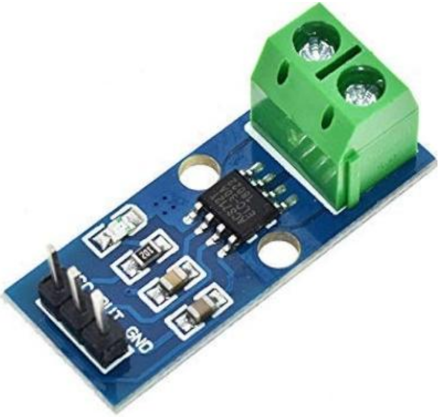


Fig 3. ACS 712

Integrating the DHT22 temperature and humidity sensor into our project allows for accurate monitoring of environmental conditions. Connected to the ESP32 microcontroller pin no 19, it provides real-time temperature and humidity data. This data is essential for various functions like environmental control and triggering actions based on specific thresholds, enhancing project functionality. As soon it detects an abnormality it sends signal to Esp32 and it generate notification for temperature and hence tells user how to control the Air Conditioner or heater as shown in Fig 4. Also generating an output on out LCD about the temperature and humidity.

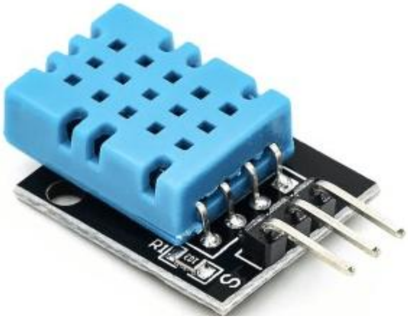


Fig 4. DHT22

In our project, we utilize the raindrop sensor to detect precipitation. Connected to the ESP32 microcontroller pin no 4, it provides real-time data on rainfall intensity. This information is crucial for weather monitoring. By integrating the raindrop sensor, we enhance our project's capability to respond to changing weather conditions and ensure efficient resource management as shown in Fig 5.

Fig 5. YL-83

In our project, we incorporate the ZMPT101b voltage sensor as shown in Fig 6 to measure voltage levels accurately. Connected to the ESP32 microcontroller pin no 35, it provides real-time voltage data. This information is essential for applications such as power monitoring, overload protection, and voltage regulation. By integrating the ZMPT101b sensor, we enhance our project's capability to monitor and manage electrical systems effectively.

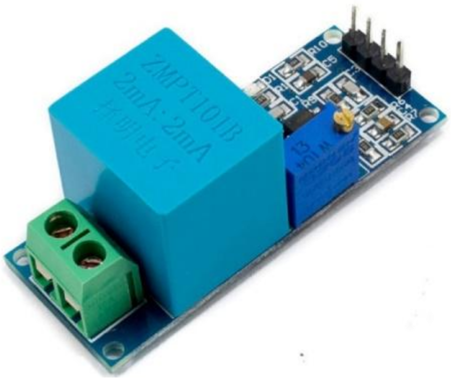


Fig 6. ZMPT101b

Three LCD displays are utilized for displaying various environmental and system parameters as shown in Fig 7. The first LCD (1602 or 1604 model) shows real-time temperature, humidity readings, and rainfall status detected by a raindrop sensor. This information is gathered using sensors like DHT22 for temperature and humidity, along with a raindrop sensor to detect rainfall. The ESP32 microcontroller processes sensor data and updates the first LCD to reflect current environmental conditions, including whether it is raining. The second LCD provides power-related metrics such as voltage, current, and calculated power consumption (in kWh or units). Sensors for voltage and current are integrated with the ESP32 to capture and process electrical data, which is then displayed on the second LCD. Lastly, the third LCD acts as a mode indicator, displaying the operational state of the system (free or busy) based on predefined conditions or tasks managed by the ESP32 microcontroller. This project involves integrating sensors with the ESP32 microcontroller and developing code to manage sensor data and update the LCD displays, accordingly, providing comprehensive environmental monitoring and system status feedback.

Fig 7. LCDs

A 220V AC to 12V DC power supply module is utilized to convert standard household alternating current (AC) electricity into a lower-voltage direct current (DC) output as shown in Fig 8. This conversion process involves several stages. Firstly, the 220V AC input is passed through a step-down transformer to reduce the voltage to around 12V AC. Next, the AC output is rectified using a diode bridge to convert it into pulsating DC voltage. To smooth out this pulsating DC voltage and reduce ripple, a filter capacitor is employed. Optionally, a voltage regulator circuit may be used to ensure a stable and precise 12V DC output regardless of variations in input voltage or load conditions. The final output is a regulated 12V DC supply that can safely power various electronic components within the project, providing a reliable and consistent power source for efficient operation.

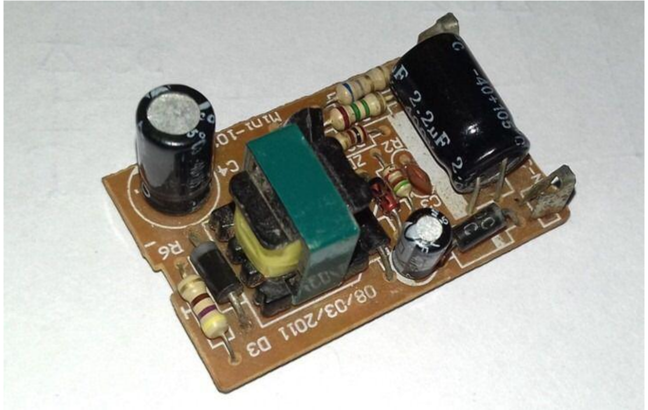


Fig 8. Power Supply Module

An IC 7805 is employed to regulate voltage by converting a higher input voltage (such as 12V) to a stable 5V output as shown in Fig 9. The IC 7805 is a linear voltage regulator integrated circuit that provides a constant output voltage of 5V regardless of variations in the input voltage or load conditions. This component is crucial for supplying a reliable and consistent 5V power source. The working principle of the IC 7805 involves using internal circuitry to maintain a fixed output voltage. When a higher input voltage 12V is applied to the input pin of the IC 7805, the internal circuitry of the regulator adjusts the voltage to ensure a steady 5V output at the output pin. The excess voltage (in this case, 7V) is dissipated as heat through the regulator, so proper heat sinking may be required depending on the amount of current being drawn and the temperature conditions. To integrate the IC 7805 into the project, connect the input pin of the regulator to the 12V power source, the ground pin to the common ground, and the output pin to the components requiring a 5V supply.

Implement a data logging system within the microcontroller to record and store these measurements over time, allowing for analysis and optimization of load performance. This data-driven approach enables the identification of inefficient loads, adjustment of operational schedules, and implementation of load optimization strategies to enhance energy efficiency and overall system performance. Develop a user interface for visualizing monitored data and enabling user interaction to manually control load settings or activate optimization strategies based on specific requirements.

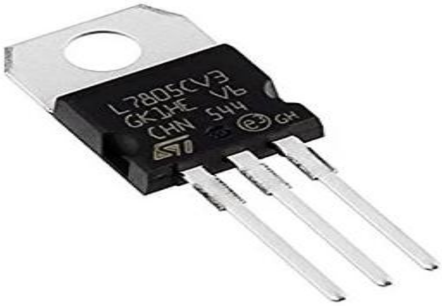


Fig 9. IC 7805

Adding ESP32 In projects offers various features dealing with different sensors, load, Wi-Fi usage, and sensors as shown in Fig 10.

Firstly Esp32's dual-core processor and low working power requirement make it a great device for cost-saving, portable and efficient projects. It handles different sensors and ensures accurate and fast data processing. Secondly, it has built in Wi-Fi and Bluetooth modules, that allow seamless data transmission from cloud storage to actual platforms supporting the feature of real- time monitoring. Thirdly, having built-in encryption features and HMAC features ensure safe communication between sensors, microcontrollers and web applications. Fourthly, Esp32's connectivity features also enable the implementation of an alert mechanism based on projects.

Here all sensors, 3 load data, Buttons acts as input for Esp32, where 3 LCD and web app acts as output for the Esp32.

Fig10. ESP32 Micro-Controller

The Blynk app is integrated with IoT capabilities to enable remote monitoring and control of various parameters using Wi-Fi connectivity as shown in Fig 11.

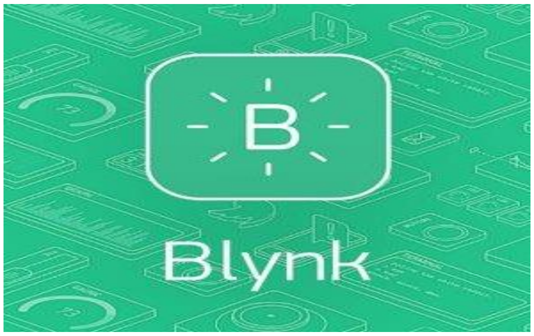


Fig 11. Blynk

The app's interface provides real-time updates on temperature, humidity, voltage, and current measurements from sensors connected to the system. Users can set temperature thresholds to trigger notifications for heater control based on predefined limits (e.g., turning off the heater if the temperature exceeds 40°C and turning it on if it drops below 20°C). Additionally, the app integrates a raindrop sensor to detect rainfall, sending notifications when rain is detected. Users can also toggle between "BM" and "FM" within the app, with notifications indicating the current system mode. The graphical interface on the Blynk app displays load consumption patterns over time, allowing users to visualize and compare active and idle periods. This comprehensive integration of IoT functionalities with the Blynk app enhances convenience, providing remote access, and monitoring the project's operational parameters from anywhere with internet connectivity as shown in Fig 12 &13.

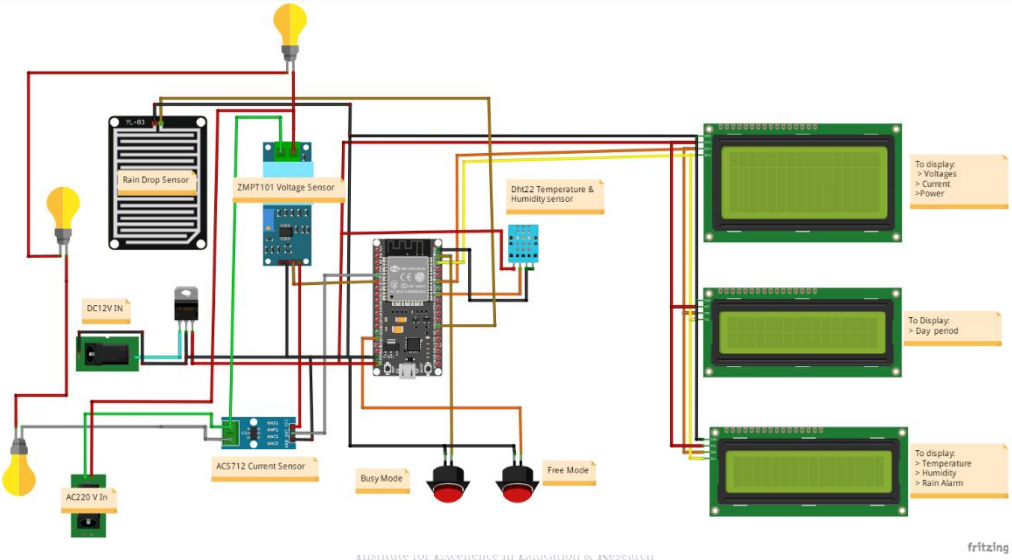


Fig12. Circuit Diagram

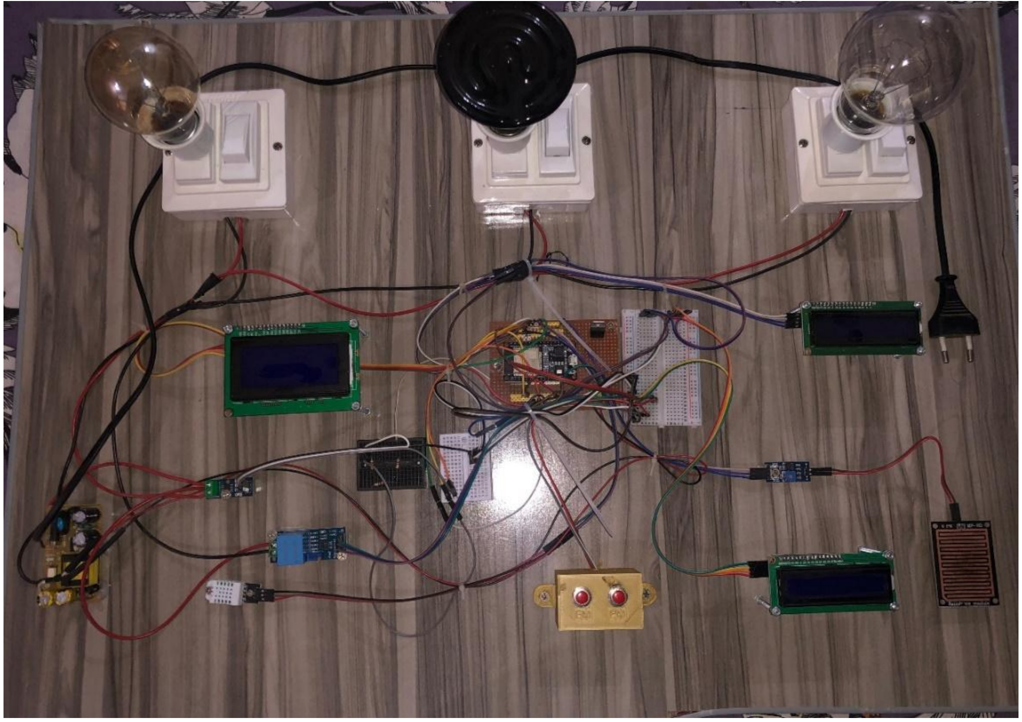


Fig 13. Prototype

Resutls

Esp32 works as the brain of the hardware, all the sensors are connected to it and the loads connected to it as well. The temperature sensors keep track of temperature and humidity, and rain sensor of the rain. Before implementing our optimization technique of free and busy mode, the loads were only monitored. A smart meter is also created, by which the user or anyone in the building can easily see the units, power, voltages, and current in real time on the LCD .In Application of a university environment few of the loads against the usage were remained turn on, and values were recorded, the unit consumption were noted, then after adding 3 days schedule in the code the hardware was run again with keeping track of busy and free mode. And unit consumption were noted both on the LCD as well as recorded and monitored on the App in form of graphs as shown in Fig 14.

Fig14. App monitoring output

The monitoring output is displayed in app, this provides a clear and concise overview of the real time temperature, humidity, voltage, current, power and unit consumption in kWh. This data allows the user to track and analyses the important parameters, providing efficient energy management and response to any anomalies as shown in Fig 15 & 16

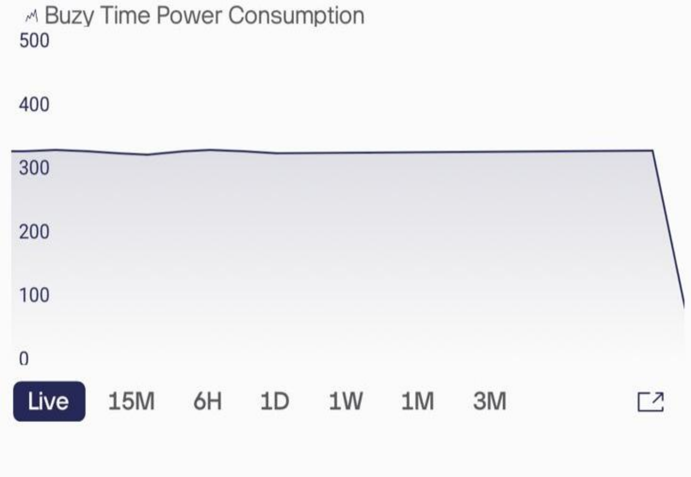


Fig15. Busy time output

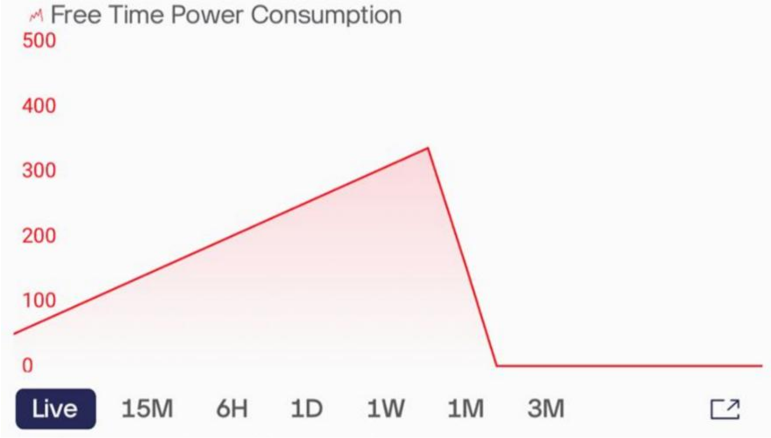


Fig16. Free time output

These graphs show the energy consumption during busy and free time throughout the day. The x-axis shows time in months, days or years, while the y-axis displays our loads consumption. The graph tracks data per minute, illustrating how load consumption varies between busy and free periods. This data that is without optimization helps us understand the patterns of energy usage in different time frames.

4.1 Comparisons in Power Consumption:

The graph reveals distinct patterns of energy consumption during busy and free times, as shown in Fig 17. Here where optimization is not applied, in a building where students often leave the load on after class or by mistake, some loads were left on. By following this scenario, the load consumption was quite high, the unit consumption was 14.4 kw/h and the unit rate was 461.232/-

Fig. 17: Comparison output

4.2 With optimization load utilization and Comparisons in Power Consumption:

By following Fig. 18 the optimization technique, it can be seen that consumption was only done when needed else loads were turned off. By following the optimization technique load consumed less as compared to before, and the load consumption was reduced to 9.6kw/h, and the unit consumption was reduced to 307.488/-. There was a reduction of about 33.33% after using optimization, and the bill reduction was 153.744/- rupees.

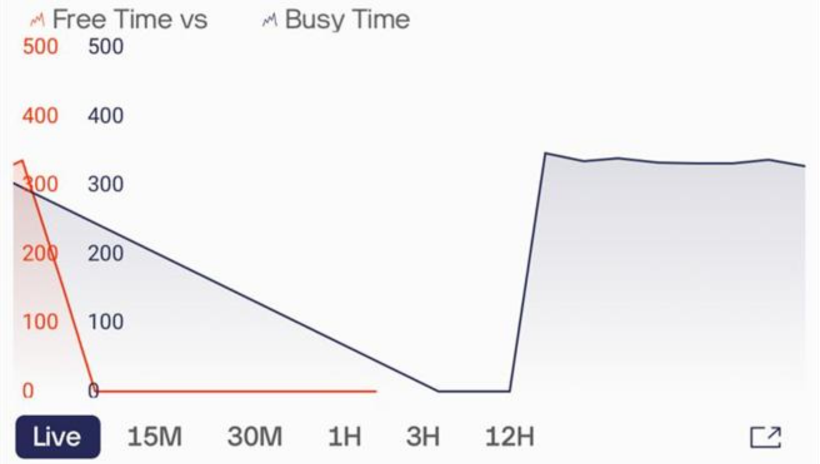
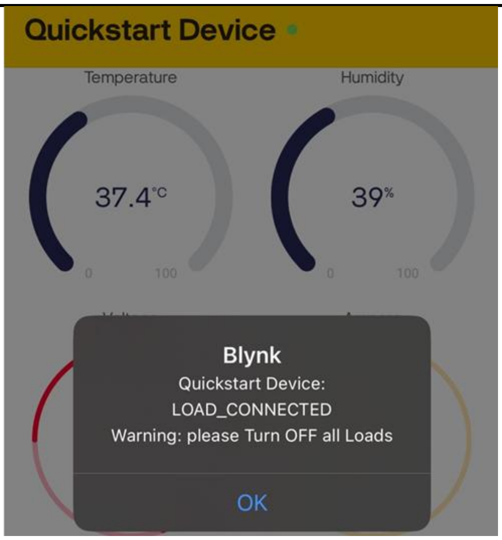


Fig. 18: Comparison output

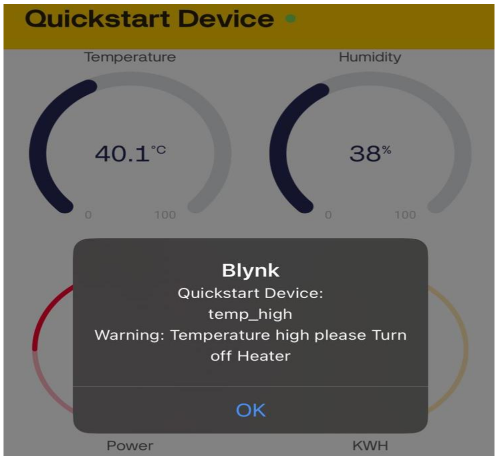
4.3 Notifications Generated in Optimization

The notification was generated as soon as the load consumption was detected against the working hours or scheduled hours. The notification period is about 120 seconds, and users must act within it. Then the action is also recorded in the forms of graphs as shown in Fig 19,20,21 &22.



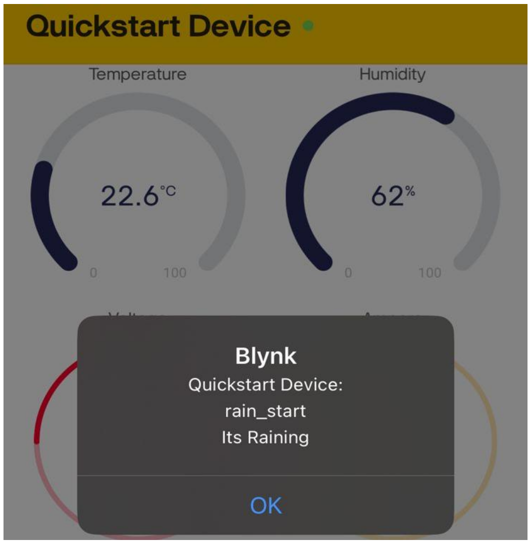
Blynk
Quickstart Device:
LOAD_CONNECTED
Warning: please Turn OFF all Loads
OK

Fig. 19: Load consumption on free time



Blynk
Quickstart Device:
temp_high
Warning: Temperature high please Turn off Heater
OK

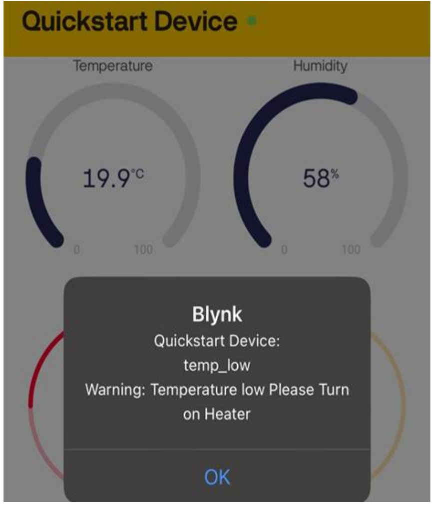
Fig. 20: Temperature above threshold



Blynk
Quickstart Device:
rain_start
Its Raining
OK

Fig. 21: Temperature below threshold

These notifications are generated whenever a temperature is detected above the threshold values. A value of 16 was set for low temperatures and 30 for high temperatures. A heater or a soldering iron was placed close to the sensor, and it detected the high temperature and sent a notification to Blynk. And later, a notification is generated to "turn on" the heater, and when a cold bottle was placed near it "turn off" heater notification was generated.



Blynk
Quickstart Device:
temp_low
Warning: Temperature low Please Turn on Heater

Fig. 22: Rain sensor (YL-83) output

A rain sensor is also integrated in the prototype which helps one notice weather conditions and make decisions on the base of it. When moisture is detected, it generates a notification of 120 sec, that it is raining.

Conclusion

The implementation of an intelligent energy management system in smart campuses has the potential to significantly reduce energy consumption and costs. The proposed system, which integrates IoT devices, sensors, and microcontrollers, enables seamless two-way communication between energy optimization techniques and IoT devices. The cloud-based platform provides a user-friendly dashboard for monitoring energy consumption, interactive charts, and features that can be applied within a smart campus context.

The system's ability to dynamically adjust energy allocation based on occupancy, through "busy mode" and "free mode," ensures efficient utilization of energy while providing flexibility to meet varying operational needs. The integration of rain and temperature sensors enables the system to control air conditioners and heaters in response to weather conditions, further reducing energy consumption. The user-defined threshold value allows for temperature settings that are tailored to specific weather needs, promoting energy efficiency and cost reduction.

The benefits of this system are multifaceted. Firstly, it contributes to a more sustainable and environmentally friendly campus by reducing energy consumption and promoting energy efficiency. Secondly, it helps to reduce energy costs, which can be redirected towards other important university initiatives. Finally, the system's proactive management and optimization of energy usage enable universities to achieve their energy-saving goals and reduce their carbon footprint.

In conclusion, the proposed intelligent energy management system has the potential to revolutionize the way universities approach energy consumption and management. By leveraging IoT technology, sensors, and microcontrollers, universities can create a more sustainable, efficient, and cost-effective energy management system that benefits both the environment and the institution.

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