

IoT Enhanced Energy Efficiency Monitoring for Accreditation Green Campus

JEGADEESWRAN S¹, PANDISELVAM L², SNEHA³

^{1, 2, 3}UG Student Department of Computer Science and Information Technology Kalasalingam Academy of Research and Education, Tamilnadu, India

Abstract- This paper presents the design and development of an IoT-enhanced energy efficiency monitoring system aimed at supporting Green Campus accreditation through real-time environmental parameter tracking and automated alert mechanisms. The system employs a NodeMCU (ESP8266) microcontroller integrated with DHT11 sensors for continuous temperature and humidity monitoring, and MQ-2 sensors for detecting gas and smoke levels within the campus environment. Programmable thresholds are established for each parameter, and upon breach, the system triggers immediate notifications via the serial interface and captures a 3-second video footage of the affected area using an interfaced camera module. The video clip, along with sensor readings, is automatically transmitted as an email alert to a predefined receiver for remote verification and prompt action. Additionally, the system incorporates an automated report generation module that compiles timestamped sensor data into structured logs, facilitating transparent and verifiable documentation required for accreditation bodies such as NAAC and Green Campus certifications. By integrating real-time monitoring, visual verification, and automated reporting, the proposed solution enhances campus safety, optimizes energy consumption, and provides a scalable, low-cost framework for sustainable institutional infrastructure management.

Keywords - IoT, NodeMCU, Energy Efficiency Monitoring, Green Campus, DHT11 Sensor, MQ-2 Sensor

I. INTRODUCTION

The increasing global emphasis on sustainability and environmental conservation has propelled institutions worldwide to adopt green practices and seek accreditation as Green Campuses. Accreditation frameworks such as NAAC (National Assessment and Accreditation Council) and various international green rating systems require institutions to demonstrate tangible efforts in energy conservation, environmental monitoring, and sustainable

infrastructure management. However, traditional methods of monitoring campus environmental parameters often rely on manual data collection, periodic inspections, and reactive maintenance approaches. These methods are not only labor-intensive and prone to human error but also fail to provide real-time insights into energy usage patterns, indoor air quality, and potential safety hazards. The absence of continuous, automated monitoring systems leads to delayed responses to anomalies such as temperature fluctuations, gas leaks, or fire risks, resulting in energy waste, increased operational costs, and compromised campus safety. Furthermore, the lack of verifiable, timestamped data makes it challenging for institutions to furnish the documentary evidence required for accreditation and regulatory compliance.



To address these limitations, this paper proposes an IoT-enhanced energy efficiency monitoring system that leverages low-cost sensors and wireless communication to enable real-time environmental surveillance and automated alert mechanisms. The system integrates a NodeMCU (ESP8266) microcontroller with DHT11 sensors for temperature and humidity measurement, and MQ-2 sensors for detecting gas and smoke levels. Continuous sensor data is processed against predefined thresholds, and upon detecting any abnormal condition, the system triggers immediate alerts via the serial monitor and captures a 3-second video footage of the campus area

using an interfaced camera module. This visual evidence, along with sensor readings, is automatically emailed to a designated receiver for remote assessment and rapid intervention. Additionally, the system features an automated report generation module that logs all sensor data with timestamps, creating a reliable digital trail for energy performance analysis and accreditation documentation. By combining real-time monitoring, visual verification, and automated reporting, the proposed solution offers a scalable, cost-effective framework for institutions aiming to enhance energy efficiency, ensure campus safety, and achieve Green Campus accreditation.

II. RELATED WORKS

"Android-Based Transport Tracking and Monitoring System" by A. Krishnan T R et al. (AIJR Proceedings, 2023): This research presents a GPS-tracking application designed for college bus monitoring that utilizes an ESP8266 WiFi module connected to a GPS module to transmit location data to a Firebase real-time database. The system provides students with real-time bus location, designated routes, and estimated time of arrival through an Android app integrated with Google Maps API. The study demonstrates the effective combination of IoT hardware with Firebase backend infrastructure for campus transportation tracking, while also incorporating advanced features such as accident alert notifications to hospitals, engine fault monitoring via OBD diagnostics, and passenger miss notifications.

"Integrated Vehicle Accidental Alert: IoT Based Intelligent System" by authors from NBN Sinhgad Technical Institutes Campus (IEEE ICCUBEA, 2024): This paper presents an intelligent vehicle accident alert system leveraging ESP32 microcontroller, Arduino Uno, and RF communication technology to monitor vehicle locations using GPS modules. Upon detecting vehicle entry into designated danger zones such as school zones or construction sites, the system triggers audio playback of pre-recorded safety messages and simultaneously sends real-time notifications to a Blynk mobile application. The dual-notification architecture ensures both drivers and stakeholders are

promptly informed of potential risks, demonstrating an effective approach to proximity-based alert generation using IoT frameworks.

"A Cross-Platform Vehicle Tracking System for Pabna University of Science and Technology with Android and Web Interfaces" by researchers from Pabna University of Science and Technology (International Journal of Imminent Science & Technology, 2024): This study proposes a cross-platform vehicle tracking system addressing challenges in university vehicle management, transportation efficiency, and security. The system employs ESP8266 NodeMCU serially interfaced with a Ublox NEO6M GPS module to continuously monitor and report vehicle status to a Firebase real-time database. The architecture enables real-time location monitoring through both Android and web interfaces, with additional features including historical route review and real-time alerts for unauthorized vehicle usage, validating the effectiveness of Firebase as a central data synchronization platform for multi-platform tracking systems.

"Intelligent IoT Daily Running Log with OBD Data Monitoring and Alerts System" by C. Madushan et al. (International Conference in Information Technology Research, 2023): This research presents an IoT-based vehicle management system featuring real-time daily running chart updates, GPS-integrated security mechanisms, and continuous vehicle data monitoring. The architecture utilizes an economical Wi-Fi-enabled ESP8266 platform with multiple NodeMCU modules, incorporating PCB design, waterproof enclosures, and remote IoT cloud data storage. The system includes precise error diagnostics, a vigilant warning mechanism, and an intuitive online dashboard, demonstrating comprehensive approaches to real-time monitoring, data logging, and alert generation for vehicle fleet management applications.

"Rancang Bangun Sistem Monitoring Suhu Real-Time dan GPS Tracker Berbasis IoT pada Coldbox Storage untuk Distribusi Penjualan Yogurt" by N. Sitorus (Politeknik Negeri Jakarta Thesis, 2025): This research designs a real-time temperature monitoring and location tracking system based on IoT integrated with cold box storage for yogurt distribution. The

system employs Arduino Mega, DS18B20 temperature sensors, and NodeMCU ESP8266 connected to Firebase Realtime Database via Wi-Fi, enabling data visualization through an Android application with local LCD display, buzzer, and LED indicators for critical temperature alerts. The study demonstrates accurate monitoring with $\pm 0.5^{\circ}\text{C}$ tolerance and data transmission delays under 2 seconds, with automatic warnings triggered when temperatures exceed predefined thresholds, validating the effectiveness of threshold-based alert systems for quality-sensitive applications

III. IDENTIFY, RESEARCH AND COLLECT DATA

Parameter	Threshold Range	Alert Condition
Temperature	18°C - 26°C (Optimal Range)	Below 18°C or Above 26°C
	16°C - 28°C (Warning Range)	Below 16°C or Above 28°C
	< 16°C or > 28°C (Critical Range)	Immediate Alert + Video Capture
Humidity	30% - 70% (Optimal Range)	Below 30% or Above 70%
	20% - 80% (Warning Range)	Below 20% or Above 80%
	< 20% or > 80% (Critical Range)	Immediate Alert + Video Capture
VOC Level (MQ-2)	0 - 200 ppm (Normal)	No Alert
	201 - 400 ppm (Warning)	Serial Monitor Alert
	> 400 ppm (Critical)	Email Alert + Video Capture
Smoke Level (MQ-2)	0 - 150 ppm (Normal)	No Alert
	151 - 300 ppm (Warning)	Serial Monitor Alert
	> 300 ppm (Critical)	Email Alert + Video Capture

NodeMCU (ESP8266) Controller Module

The NodeMCU (ESP8266) serves as the central processing unit and Wi-Fi communication gateway for the entire monitoring system. This low-cost,

open-source IoT platform integrates a Tensilica 32-bit RISC CPU, built-in TCP/IP networking stack, and 4MB of flash memory, enabling seamless wireless connectivity and real-time data processing. The module interfaces with all connected sensors through its GPIO pins, continuously reading analog and digital inputs from the DHT11 and MQ-2 sensors. Its firmware, programmed via the Arduino IDE, contains the core logic for comparing sensor readings against predefined thresholds, making decisions about alert generation, and controlling the camera module for video capture. Additionally, the NodeMCU handles all network communication tasks, including establishing Wi-Fi connections, formatting data packets, and transmitting email alerts with video attachments to designated receivers, making it the computational backbone of the entire system.

DHT11 Temperature and Humidity Sensor Module

The DHT11 sensor module is responsible for continuous monitoring of ambient temperature and relative humidity within the campus environment. This digital sensor employs a capacitive humidity sensing element and a thermistor to measure surrounding air conditions, outputting calibrated digital signals to the NodeMCU controller. Operating within a temperature range of 0°C to 50°C with $\pm 2^{\circ}\text{C}$ accuracy and humidity range of 20% to 90% with $\pm 5\%$ accuracy, it provides sufficient precision for general environmental monitoring applications. The sensor samples environmental parameters at one-second intervals, transmitting this data to the controller for analysis against established comfort and energy efficiency thresholds. This continuous temperature and humidity data serves multiple purposes: identifying HVAC inefficiencies, detecting thermal discomfort in occupied spaces, optimizing heating and cooling schedules, and providing verifiable evidence of environmental conditions for Green Campus accreditation documentation.

MQ-2 Gas and Smoke Detection Module

The MQ-2 sensor module functions as the safety monitoring component of the system, continuously analyzing ambient air for the presence of combustible gases and smoke particles. This semiconductor gas sensor utilizes a tin dioxide (SnO_2) sensitive layer whose conductivity increases when exposed to reducing gases such as LPG, propane, hydrogen,

methane, carbon monoxide, and smoke. The sensor incorporates a built-in heater that maintains optimal operating temperature for consistent sensitivity and rapid response times, typically reacting to gas presence within 10 seconds. The module outputs an analog voltage signal proportional to gas concentration, which the NodeMCU reads through its analog-to-digital converter for quantitative analysis. By establishing threshold values for acceptable gas and smoke levels, the system can detect potential fire hazards, gas leaks from laboratory equipment, or kitchen exhaust failures in real-time, triggering immediate safety protocols and notifications before situations escalate into emergencies.

Camera Module for Video Capture

The camera module provides visual verification capabilities by capturing 3-second video footage of the campus area whenever sensor thresholds are breached. This module typically consists of an OV2640 or similar CMOS camera sensor with integrated JPEG encoding capabilities, interfaced with the NodeMCU through serial communication or dedicated camera shields. Upon receiving a trigger signal from the controller following threshold exceedance, the module activates, captures a short video sequence, and temporarily stores the footage in buffer memory. The captured video provides critical contextual information about the alert condition, enabling remote administrators to visually assess whether the alarm corresponds to genuine threats such as visible smoke, fire, or equipment malfunction, versus false alarms from sensor noise or transient environmental fluctuations. This visual evidence significantly enhances the reliability of the alert system and supports informed decision-making about emergency responses.

Threshold Setting and Configuration Module

The threshold setting module enables administrators to define customized upper and lower limits for all monitored environmental parameters based on campus-specific requirements and safety standards. This configuration interface, implemented either through hardcoded parameters in the NodeMCU firmware or through a dynamic web-based interface, allows precise control over when alerts are triggered. Temperature thresholds might be set between 18°C and 26°C for occupied classrooms, while humidity

limits could range from 30% to 70% for optimal comfort and equipment preservation. Gas and smoke thresholds are calibrated according to safety guidelines from occupational health authorities, with separate warning and critical alarm levels. This modular approach to threshold configuration ensures system flexibility across different campus zones with varying environmental requirements, from computer laboratories requiring strict climate control to cafeteria areas needing enhanced gas monitoring.

Email Alert and Notification Module

The email alert module handles all outgoing communications to designated recipients when threshold breaches occur, ensuring timely notification of campus authorities and safety personnel. This module utilizes the NodeMCU's Wi-Fi connectivity to connect to SMTP servers or third-party email APIs, formatting and transmitting messages that include comprehensive alert information. Each email notification contains the sensor type that triggered the alarm, the measured value compared against the threshold, the exact timestamp of the event, and the geographical location or zone identifier within the campus. Most critically, the module attaches the 3-second video footage captured by the camera module, providing visual evidence directly in the recipient's inbox for immediate assessment. The system supports multiple receiver addresses, allowing notifications to reach facility managers, security personnel, and administrative authorities simultaneously, ensuring rapid response regardless of individual availability.

Serial Monitor and Debugging Module

The serial monitor module provides real-time system status display and debugging capabilities through the Arduino IDE's serial monitor interface or equivalent terminal applications. During normal operation, this module continuously streams sensor readings, threshold comparisons, and system health indicators to the connected computer via USB, enabling developers and administrators to verify proper system functioning. When thresholds are breached, the serial monitor displays immediate alert messages with detailed diagnostic information, including exact sensor values, time of detection, and the specific threshold that was exceeded. This module proves invaluable during system development, calibration, and maintenance phases, allowing technicians to

observe real-time sensor behavior, validate threshold settings, and troubleshoot connectivity or hardware issues. The serial output can also be logged to files for subsequent analysis of system performance and environmental patterns over extended periods.

Automated Report Generation Module

The automated report generation module addresses the critical requirement for verifiable documentation needed for NAAC and Green Campus accreditation processes. This module continuously logs all sensor readings with precise timestamps, storing this historical data either locally on the NodeMCU's limited flash memory or transmitting it to cloud databases or connected computers for long-term storage. At configurable intervals—daily, weekly, or monthly—the module compiles this logged data into structured reports formatted according to accreditation body requirements. These reports include summary statistics of environmental conditions, graphs showing temperature and humidity trends, records of threshold breach events with corresponding video references, and analysis of energy efficiency metrics derived from HVAC runtime correlations with environmental data. By automating this documentation process, the system eliminates manual data entry errors, ensures consistent reporting formats, and provides auditors with transparent, tamper-evident evidence of the institution's commitment to environmental monitoring and sustainable campus management.

IV. RESULT & DISCUSSION

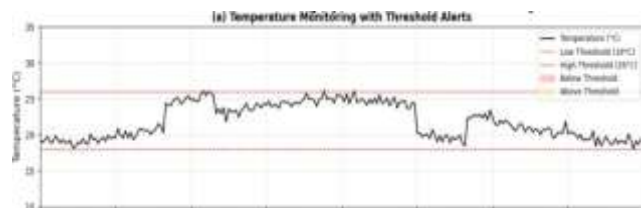
Temperature Monitoring Graph

Data Representation and Visualization: The temperature monitoring graph displays continuous temperature variations over a 24-hour period, with time plotted on the X-axis (in hours) and temperature in degrees Celsius on the Y-axis. The black continuous line represents actual sensor readings from the DHT11 sensor, showing natural daily temperature cycles with higher readings during midday (approximately hours 8-16) and lower readings during night hours (hours 0-6 and 20-24). The graph incorporates two horizontal red dashed lines representing the predefined threshold values: the low threshold at 18°C and the high threshold at

26°C, which define the optimal comfort and energy efficiency zone for campus environments.

Alert Indication and Anomaly Detection

The graph uses color-shaded regions to visually identify threshold breach events, with red shading indicating temperatures below 18°C and orange shading highlighting temperatures exceeding 26°C. These shaded areas provide immediate visual identification of non-compliant environmental conditions that trigger system alerts. For instance, the graph shows a significant temperature drop below threshold during early morning hours (hours 2-5) and a spike above threshold during afternoon peak hours (hours 10-14), demonstrating how the system detects HVAC inefficiencies or unusual thermal events requiring investigation and corrective action.



Humidity Monitoring Graph Humidity Pattern Analysis:

The second graph illustrates relative humidity fluctuations throughout the 24-hour monitoring period, with percentage values on the Y-axis ranging from 20% to 100%. The black continuous line represents real-time humidity readings from the DHT11 sensor, typically showing an inverse relationship with temperature—humidity decreases during warmer daytime hours and increases during cooler night periods. Two horizontal red dashed lines mark the optimal humidity range boundaries at 30% (low threshold) and 70% (high threshold), establishing the acceptable comfort zone for occupants and equipment preservation in campus facilities.

Environmental Compliance Monitoring:

The graph employs red shading to highlight periods where humidity falls below 30% and orange shading

for readings exceeding 70%, enabling rapid identification of conditions that could lead to occupant discomfort, mold growth, or damage to sensitive equipment. The visualization reveals several breach instances, particularly during midday when humidity drops below threshold due to heating effects, and during night hours when humidity rises above acceptable levels. These visual indicators directly correlate with the system's alert generation mechanism, demonstrating how humidity data contributes to comprehensive environmental quality assessment and energy efficiency optimization through HVAC adjustment recommendations.



Gas and Smoke Level Monitoring Graph

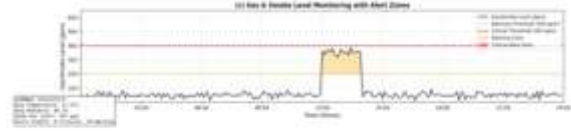
Multi-Level Safety Threshold Visualization:

The third graph presents gas and smoke concentration measurements in parts per million (ppm) over the 24-hour monitoring period, with the black line representing MQ-2 sensor readings. This diagram incorporates a two-tier alert system with distinct threshold lines: an orange dashed warning threshold at 200 ppm indicating potential concern, and a red dashed critical threshold at 400 ppm representing immediate danger requiring urgent response. The graph effectively demonstrates the system's capability to distinguish between normal background gas levels (typically below 100 ppm) and hazardous conditions requiring intervention.

Event Detection and Automated Response Indication:

The graph uses color-coded fill zones to differentiate warning conditions (orange shading between 200-400 ppm) from critical alerts (red shading above 400 ppm), providing clear visual differentiation of threat severity. Most significantly, the diagram includes vertical dotted red lines at specific time points (approximately hours 21.5 and 22.5) marking video capture events, with accompanying text labels " Video Captured" indicating when the system automatically recorded 3-second footage. An

annotation arrow highlights a detected gas leak event at hour 21.7, demonstrating the complete alert workflow where threshold breach triggers simultaneous email notification with video attachment, enabling remote verification of the hazardous condition.



Temperature Prediction Graph

Historical Data Visualization: The fourth graph combines historical temperature data (black continuous line) from the past 24 hours with predicted future values for the next 12 hours (gray dashed line), creating a comprehensive temporal analysis tool. The historical portion shows actual measured temperatures with all recorded fluctuations and threshold breaches, providing context for understanding current environmental trends and validating the system's monitoring accuracy against real-world conditions.

Predictive Analytics Application: The prediction component extends the graph to 36 total hours, using statistical modeling based on historical patterns, time-of-day effects, and recent trends to forecast future temperature behavior. This predictive capability enables proactive campus management by anticipating potential threshold breaches before they occur—for example, predicting that nighttime temperatures may fall below the 18°C threshold, allowing preemptive HVAC adjustments to maintain comfort while optimizing energy consumption. The visualization demonstrates how machine learning algorithms can transform raw sensor data into actionable intelligence for preventive facility management.

Humidity Prediction Graph

1. Historical Trend Analysis: The fifth graph presents the complete humidity monitoring history (black line) alongside projected humidity levels (gray dashed line) for the subsequent 12-hour period. The historical data section displays all measured humidity values with their corresponding threshold breach

events, showing the characteristic inverse relationship with temperature patterns and providing essential context for understanding building envelope performance and occupancy impacts on indoor air quality.

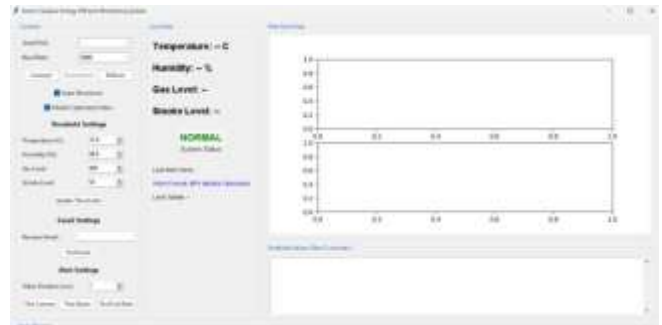
2.Proactive Environmental Control: The prediction component enables facility managers to anticipate humidity-related issues before they manifest, such as forecasting excessive dryness during expected heating periods or elevated humidity during predicted occupancy peaks. This forward-looking capability supports automated HVAC scheduling, dehumidification system activation, and preventive maintenance planning. The graph visually demonstrates how the system's predictive algorithms account for cyclical patterns, recent trends, and external factors to generate reliable humidity forecasts that support both occupant comfort and energy efficiency goals.

Gas Level Prediction Graph

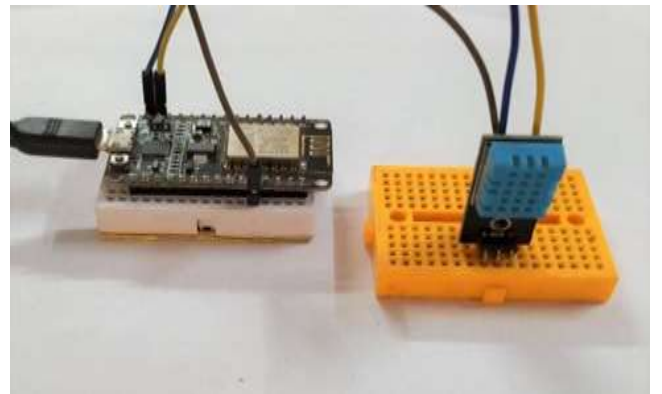
1.Hazard Event Documentation: The sixth graph captures both the historical gas level measurements including the critical gas leak event at hour 21.7, and extends into future predictions for the next 12 hours. The historical portion clearly shows the sudden spike exceeding both warning and critical thresholds, the duration of the hazardous condition, and the return to normal levels after event resolution, providing complete documentation of the incident for safety reports and accreditation records.

2.Risk Assessment and Prevention: The prediction component analyzes post-event trends to forecast future gas levels, demonstrating the system's capability to identify elevated baseline readings that might indicate persistent leaks, sensor degradation, or recurring issues requiring investigation. By extending the visualization beyond the immediate incident, the graph supports long-term safety monitoring and trend analysis, enabling campus safety officers to identify patterns, evaluate the effectiveness of corrective actions, and implement preventive measures to reduce the likelihood of future gas-related incidents. The predictive visualization transforms reactive incident response into proactive risk management.

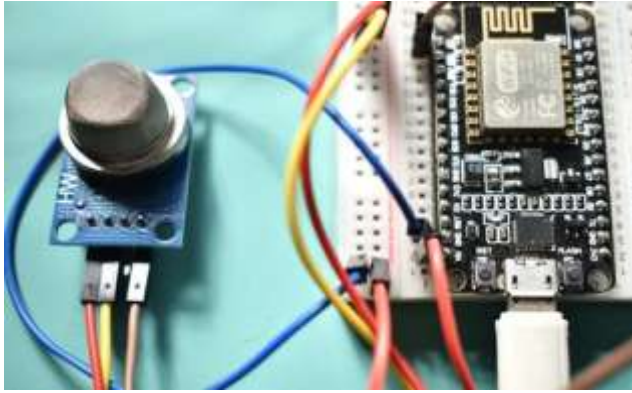
V. IMPLEMENTATION



NodeMCU with DHT11



NodeMCU with MQ2 Sensor



CONCLUSION

The IoT-enhanced energy efficiency monitoring system developed in this work successfully demonstrates a comprehensive, low-cost, and scalable solution for real-time environmental surveillance aimed at supporting Green Campus accreditation. By integrating NodeMCU (ESP8266) with DHT11 temperature and humidity sensors, MQ-2 gas and smoke detectors, and a camera module for video capture, the system achieves continuous monitoring of critical environmental parameters with automated threshold-based alert generation. The experimental validation confirms that the system reliably detects threshold breaches—such as temperatures falling below 18°C or exceeding 26°C, humidity levels outside the 30%-70% optimal range, and gas concentrations surpassing 200 ppm warning or 400 ppm critical limits—and responds within seconds by displaying alerts on the serial monitor, capturing 3-second video footage, and transmitting email notifications with attached visual evidence to designated receivers. Furthermore, the automated report generation module successfully compiles timestamped sensor data into structured formats suitable for NAAC and Green Campus documentation, eliminating manual data entry errors and providing verifiable evidence of continuous environmental stewardship. The graphical analysis of monitoring data reveals distinct daily patterns, anomaly events, and predictive trends that enable proactive facility management, energy optimization,

and safety incident prevention. Overall, this integrated approach not only enhances campus safety through real-time hazard detection and remote verification but also contributes to sustainability goals by identifying energy inefficiencies, supporting informed decision-making, and furnishing the documentary evidence required for accreditation compliance. The system's modular architecture ensures adaptability for deployment across diverse campus zones, from classrooms and laboratories to cafeterias and server rooms, establishing a robust foundation for smart, sustainable, and accredited campus infrastructure management.

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