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Research Paper

IoT-Enabled Smart Classroom Automation System for Enhanced Learning Environments

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Abstract

The evolution of Internet of Things (IoT) has revolutionized automation in multiple sectors, including education. This paper proposes an IoT-based smart classroom automation system to improve efficiency, energy management, and interactive learning. The system integrates IoT sensors, actuators, and microcontrollers to automate classroom functions such as attendance marking, lighting control, air quality monitoring, and projector operation. The proposed system reduces manual intervention and ensures optimal resource utilization. For instance, RFID-based or facial recognition-based systems can automate attendance recording, while smart lighting adjusts brightness based on occupancy. The system also allows real-time monitoring through mobile and web applications. Experimental implementation shows that IoT-based classrooms enhance student engagement, minimize energy wastage, and improve administrative efficiency. The study concludes that IoT-driven classrooms are a step towards sustainable and digital education.

Keywords

Internet of Things, Smart Classroom, Automation, Sensors,RFID,Facial Recognition, Microcontrollers, Energy Efficiency, Educational Technology.

1. Introduction

The fast development of Information and Communication Technologies (ICT) and the Internet of Things (IoT) has drastically changed almost all areas, including education. IoT can be defined as a network of intelligent physical objects that are connected (network of these objects) and have sensors, actuators, microcontrollers, and communication modules that allow them to take in and give out real-time data using the Internet. Over the recent years, IoT-based solutions have become an essential part of the education 4.0 paradigm, resulting in the appearance of smart classrooms technology-based learning environments that improve the level of interactivity, automation, and energy efficiency.

A smart classroom is made up of a range of IoT-enabled products including temperature sensors, motion detectors, RFID and microcontroller-based control units (such as Arduino, ESP32 or Raspberry Pi) to measure and automatically control the surrounding environment. With these systems it is possible to automatically regulate lighting, air conditioning or ventilation depending on occupancy, ambient light or temperature data which will result in a comfortable and energy-efficient learning environment. As an example, a lighting system that is based on the IoT can be adapted to use Passive Infrared (PIR) motion sensors to detect the presence of a person and automatically turn the lights on or off, which helps to save unnecessary power usage. Likewise, sensors of temperature and humidity (e.g. DHT11, LM35) can be connected to the microcontrollers to dynamically control the fans or air conditioners to enhance comfort and energy efficiency.

Smart classrooms do not just apply the automation aspect to environmental control. The IoT technology allows the automation of attendance control, classroom scheduling, projector usage, and security control. As an example, RFID or facial recognition-based attendance systems will be able to capture the presence of students automatically with reduced manual work and a reduction in administrative delays. The idea of such integration aligns with the objectives of educational technology (EdTech) the optimization of the learning outcome, lowering the amount of resources wasted, and developing adaptive and data-driven instructional settings.

Microcontrollers at the hardware level are important in the automation of smart classrooms. ESP8266, Arduino Uno and Raspberry Pi are examples of central control devices that are connected with actuators and sensors. Such systems will be able to process sensor data onboard and transmit via Wi-Fi or Bluetooth devices to cloud systems or local servers. Such embedded systems are adopted that makes the automation architecture simpler and, at the same time, provides better scalability, reduced costs, and reliability. Real-time visualization, remote control, and decision-making on sensor data are also supported by cloud-based data storage and analytics encompassing ThingSpeak, Blynk, or Firebase.

Also along with automation, energy efficiency has become an important trend in smart classroom design. Learning institutions tend to have issues associated with a high power consumption because of the running of electronic appliances, lighting and HVAC systems. By installing IoT based control mechanisms, the smart energy management can be done through dynamically changing the functioning of the devices as per the usage behavior and occupancy rates. This solution is in line with international sustainability objectives and it minimizes the running expenses of institutions of learning and encourages the concept of green campuses.

In addition, because the IoT is combined with educational technology, the advantages are not limited to optimization of physical infrastructure. The information gathered by the use of the IoT system can be interpreted in order to track the attendance patterns, classroom usage, student activity, and the comfortable levels in the classroom environment - all of this will be used to make decisions based on data among the educators and administrators. These systems are also inclusive and flexible because of the ability to monitor remotely and in a hybrid learning environment.

In general, IoT, automation, sensor networks, and microcontroller-based systems all are a groundbreaking change of designing and managing educational spaces. The suggested IoT-based smart classroom system is supposed to contribute to the improvement of not only the effectiveness of learning and the efficiency of the work of institutions, but also the sustainability and energy-saving. The proposed paper discusses the design, implementation, and assessment of a smart classroom system, which uses the IoT elements to meet the goal of intelligent automation, real-time monitoring, and efficient use of energy contributing to the wider perspective of smart campuses and digital education ecosystems.

1.1 Significant Concepts and Definitions

The following key terms that are employed in the manuscript are defined to create a common ground in the further discussion of the technical material:

Internet of Things (IoT): This is a type of distributed ecosystem of physical objects, sensors, actuators, and embedded controllers that are networked and collect, share, and respond to data. A typical IoT system comprises of sensing, local processing, connectivity, cloud integration, and user facing applications.

Smart Classroom: This is an educational setting that is enhanced with related sensors, actuators, and electronic services that allow an adaptive teaching experience, automated management of facilities, and data-driven decisions. Smart classrooms will combine learning management systems (LMS), interactive displays, automated lighting/HVAC and attendance and analytics dashboards.

Automation: Control systems (both software and hardware) are used to carry out work with a minimum of human participation. The automation in classroom environment includes the environmental control (lights, HVAC), timetable, attendance data, media and projector control, and safety systems.

Sensor: A sensor is any item which is used to measure a physical parameter (e.g., temperature, motion, light, CO 2, sound, occupancy) and transform it into an electrical signal to be processed. Classroom sensor networks allow situational awareness and context automation to occur.

Microcontroller: A small integrated circuit that is meant to carry out certain control functions, commonly in connecting sensors and actuators. In the education and prototyping community, popular businesses include the Arduino family, ESP32 and Raspberry Pi (single-board computer). Microcontrollers are involved in the acquisition of data, local pre-processing, communication (Wi-Fi, BLE) and actuation.

Energy Efficiency: Aimed at saving energy by use of strategies and technologies that save energy without compromising service levels (lighting, comfort, devices). One of the methods through which smart classrooms that consume energy efficiently is sensor-based control and scheduling of the occupancy and adaptive management of the devices to reduce waste.

Educational Technology (EdTech): Digital technologies, platforms and procedures that aid in teaching, learning, assessment as well as administration. The EdTech elements are LMS, adaptive learning systems, digital content repositories, analytics tools, and collaborative tools.

1.2 Importance of the Problem

Educational institutions all over the world are experiencing dual pressure, namely the demand to increase the learning outcomes and the demand to decrease the costs and environmental footprint of the functioning of an educational institution. The traditional classroom is often inefficient in terms of resources (lights and HVAC are running, unused area) and does not provide the data-driven feedback that the contemporary pedagogy requires. Smart classroom technologies will offer to:

- Enhance the quality of learning with the help of individual content delivery, interactive assessment, and teacher analytics.
- Minimize the cost of operation through efficient use of electricity and automation of some of the administrative operations.
- Make it a bit safer and more accessible by using automated warnings and occupancy monitoring and remote monitoring.
- Facilitate hybrid and distance learning through the facilitation of smooth combination between face-to-face and distance learning.
- Since the world is worried about sustainable campuses and recent technological changes that are digitalizing education, it is appropriate and powerful to create scalable and low-cost smart classroom models.

1.3 Sensors and Sensing Architectures

The basic layer of the smart classroom consists of sensors. A strong sensing architecture has the following:

Occupancy Sensors (PIR, ultrasonic, camera-based): Occupancy sensor is used to turn lights and HVAC on and off, as well as alert attendance systems.

Ambient Light Sensor (photodiodes, LDRs): Adjusts artificial light according to the daylight and will therefore conserve energy and ensure comfort in terms of sight.

Temperature & Humidity Sensors (DHT22, SHT3x): The sensor has an input on climate control and indoor air quality (IAQ).

CO 2 & Air-Quality Sensors (NDIR CO 2 sensors, VOC sensors): Measure the ventilation requirements and facilitate healthy conditions.

Sound level meters (microphone arrays): Senses the noise in the surrounding to adjust microphone or speaker configurations and also to gauge interaction.

Smart Power Meters / Smart Plugs: Measure equipment level consumption to determine equipment that consumes a lot of power and allow load-shedding.

RFID / BLE Beacons and Cameras: Provide automated attendance and location-based services (content personalization, resource booking).

Centralized (sensors directly to a gateway) and hierarchical (edge nodes combine multiple sensors) are sensing topologies. The critical design options include accuracy, the sampling rate, latency, power consumption, privacy concerns (especially in cameras and audio), and cost.

1.4 Microcontrollers, Edge Computing and Connectivity

Single-board computers (SBCs) Microcontrollers and low-power Microcontrollers.

Microcontrollers (e.g., Arduino, ESP32): Ideal in controlling low latency and interfacing sensors and/or actuators directly. Their small size and low price make them appropriate in distributed sensor nodes in charge of lights, relays and low level actuators. The use of ESP32 is especially common with embedded Wi-Fi/BLE connectivity and the small local processing.

Edge Devices / SBCs (e.g., Raspberry Pi): Have more compute capacity to support local analytics (voice/activity recognition, pre-filtering camera images) and support local dashboards or MQTT brokers.

Connections: The most common are Wi-Fi, Ethernet, Zigbee, LoRaWAN and BLE. The decision will be based on bandwidth, range, power budget and security needs. MQTT and HTTP/REST are more popular in telemetry, and CoAP is used when it comes to very constrained networks.

The advantages of edge computing include minimizing cloud bandwidth and latency, pre-processing privacy preserving, and offline or graceful degradation.

1.5 Automation Strategies and Control Logic

Smart classrooms can be automated by using simple rule-based logic up to complicated closed-loop control:

Rule-based automation: e.g., When occupancy = false and 10 minutes have passed, then switch off lights. Simple to apply and lack flexibility.

Schedule-based automation: Is linked with institutional schedules to pre-heat/cool rooms prior to classes and to switch off the machines after scheduled times.

Feedback and adaptive control: Incorporates both environmental sensors and occupancy trends to dynamically adjust setpoints (PID controllers, model-predictive control of HVAC scheduling).

AI-assisted automation: Machine learning methods have the potential to forecast the occupancy, student participation, or room utilization rates to ensure optimization of the HVAC schedule and content suggestions.

Actuation elements: Motorized blinds, The actuators are dimmable LED drivers, smart thermostats, motorized vents, smart plugs, and motorized blinds.

Other important factors: fail-safe design (manual overrides), user acceptance (teachers/students need to be in control) and secure command authentication to avoid malicious actuation.

1.6 Organization of the Paper

The rest of the paper will be arranged in the following way:
Part 2 does the literature review concerning the IoT-related education, energy management, and sensor-based automation. Section 3 will show the proposed system architecture and hardware/software components. Section 4 elaborates on the implementation (sensors nodes, code of the microcontroller, edge services, cloud connection, and LMS connectors). Section 5 contains the experimental configuration, metrics of evaluation and results (energy, latency, accuracy, and the user feedback). In Section 6, the lessons learnt, limitations, and privacy are discussed. Section 7 summarizes and gives an overview of future work.

2. Literature Survey

In this section, the key recent works related to **IoT-based Smart Classrooms, Automation, Sensor Networks, Energy Efficiency, and Educational Technology** are discussed.Table 1 summarizes 20 major contributions published between 2016 and 2025, focusing on their methodology, datasets, findings, and gaps.

Table 1. Summary of Recent Works on IoT-Enabled Smart Classrooms

Ref/Cited no	Author(s), Year	Method/Approach	Dataset Used	Key Findings	Problem Gap Identified
[1]	Al-Hassan et al., 2018	IoT Smart Learning Framework using Raspberry Pi & Cloud	Prototype in university lab	Demonstrated basic IoT integration for smart classes with real-time monitoring	No energy optimization or LMS integration
[2]	Naranjo et al., 2019	IoT-based Automation for Smart Campus Classrooms	ESP8266 sensors + Firebase	Achieved remote device control via mobile app	Limited sensor fusion and security considerations
[3]	Sundaramoorthy et al., 2020	AI-Driven Smart Learning Environment with IoT	Simulated data in MATLAB	Applied AI models for adaptive learning feedback	Lacked hardware validation
[4]	Gupta et al., 2020	Arduino-based Automation System for Classrooms	Physical prototype	Reduced manual switching for lighting and fans	No cloud data storage or analytics
[5]	Li et al., 2021	IoT and Big Data Integration for Smart Education	Cloud testbed dataset	Used data analytics to analyze student engagement	No real-time environment control
[6]	Patil & Desai, 2021	Energy Efficient IoT Classroom Automation	Blynk & ThingSpeak cloud data	Reported ~30% energy saving via occupancy control	No LMS linkage or feedback loop
[7]	GarcÃa et al.,	Wireless Sensor	Zigbee	Multi-	Energy

	2021	Network for Environmental Monitoring	network simulation	sensor data for air quality and lighting control	analysis not quantified
[8]	Jain et al., 2022	IoT Smart Attendance System using RFID & Face Recognition	Custom dataset	Automated attendance with LMS sync	High cost and privacy concerns
[9]	Ahmed & Salim, 2022	Microcontroller-based Smart Classroom Model	ESP32 + Blynk	Low-cost architecture for lighting automation	Limited scalability
[10]	Wang et al., 2022	Machine-Learning for Occupancy Prediction in Smart Buildings	UCI Energy Dataset	Enhanced HVAC efficiency via predictive control	Did not target educational contexts
[11]	Rao et al., 2023	IoT Edge Architecture for Energy-Aware Classrooms	Prototype tested on Raspberry Pi 4	Demonstrated local analytics for energy efficiency	Latency and privacy not addressed
[12]	Khan et al., 2023	Sensor Fusion for Occupancy and Environment Control	Real university classroom dataset	Improved control accuracy by 15% using fusion	Integration with LMS missing
[13]	Zhang et al., 2023	Comprehensive Review on IoT in Education	90+ papers reviewed	Identified AI and IoT as synergistic drivers in EdTech	Lack of real-world deployment studies
[14]	Hercog et al., 2023	ESP32 IoT Toolkit for Educational Applications	Open-source prototype	Useful for hands-on learning and rapid	Focus on teaching, not automation

				prototyping	
[15]	Terzieva et al., 2023	IoT Pedagogy Integration in Smart Education	Survey of teachers and students	Confirmed positive impact of IoT tools on learning	Need for infrastructure standardization
[16]	Monti et al., 2024	Edge-based Transfer Learning for Occupancy Counting	Camera feed dataset	Accurate occupancy counting via edge inference	Requires high computational resources
[17]	Karjou et al., 2024	Occupancy Forecasting for HVAC Optimization	Building Energy Dataset (USA)	Reduced energy use by 25% via predictive models	Not applied to educational settings
[18]	Serag et al., 2025	Scoping Review of Multimodal IoT Learning Environments	Cross-institution analysis	Highlighted potential of data fusion in education	Few validated prototypes
[19]	Tat et al., 2025	Smart Energy and Automation for Green Campus	IoT energy logs + MQTT data	Achieved 35% energy reduction using IoT analytics	LMS and pedagogical integration absent
[20]	Zhou et al., 2025	AI + IoT Integration for Hybrid Learning Spaces	Multi-campus testbeds	Unified framework for remote and physical classes	Complex architecture and privacy issues

As the comparative overview provided in Table 1 illustrates, the research in the field of IoT-based smart classroom has changed throughout the years, with small-scale automation prototypes giving place to large-scale, AI-enabled, energy-sensitive educational environments.

Existing literature, including Al-Hassan et al. [1] and Gupta et al. [4], and confirmed the practice of automation in the classroom based on a microcontroller, but was not connected to the cloud and analytics. Such reviews as Li et al. [5] and Zhang et al. [13] highlighted the overlap of the IoT and AI yet indicated a lack of empirical assessments.

Recent developments, e.g., Rao et al. [11], Khan et al. [12], and Monti et al. [16], combine sensor fusion and edge computing to make the control systems energy-aware and privacy-sensitive. Scalability and interoperability across devices are however, issues of concern. Such works as Tat et al. [19] and Zhou et al. [20] are heading into the spheres of green-campus automation and hybrid learning rooms, yet the studies still need standard data exchange and LMS correspondence structures.

3. Current Work and Motivation

The key concepts of the ongoing Smart Classroom project based on the IoT are discussed in this section. The motivation, goals, innovativeness, practical implications and general contributions are expounded to demonstrate the reason behind the proposed system.

3.1 Motivation

As the literature review has revealed, despite the large number of IoT-based classroom and automation systems developed over the years most of them are either disjointed, hardware-centric or only apply to specific niche applications such as attendance tracking or basic device control.

It is urgently required to have a combined, inexpensive, energy-saving, and scalable smart classroom system that integrates sensor networks, edge computing, and cloud intelligence in one system.

The current models of the IoT classrooms are largely infrastructure automation-based or educational analytics-based. Very little of them combines both layers to form a data-driven ecosystem. Moreover, most prototypes are cloud-based and are not resilient in the event of network outages.Therefore, this study will suggest a hybrid IoT system, which has to integrate edge sensing using a microcontroller with cloud-based data storage and analytics to provide low latency and data continuity. The following central motivations are presented in the system suggested:

Smart Automation: To be able to automate the classroom functions (lighting, HVAC, attendance) and learn the patterns of use based on sensor data.

Energy Efficiency: To reduce power consumption with occupancy-based control and adaptive scheduling.

Cost-Effectiveness : To implement low-cost IoT nodes on ESP32/Arduino and open source (Blynk and ThingSpeak) platforms.

Educational Enhancement: To combine IoT data with Learning Management Systems (LMS) to obtain real-time attendance and engagement analytics.

Scalability and Sustainability: The solution has to be designed in a way that can be expanded to additional classrooms and be consistent with the green campus initiatives.

The suggested IoT system, therefore, tackles the two problems of automation and sustainability and can be used in both small-scale institutions and large universities that are interested in a digital transformation.

4. Proposed Methodology

The suggested Smart Classroom Automation and Energy Management System using IoT will incorporate a system with a network of sensors, microcontrollers, and cloud solutions to attain intelligent monitoring, energy optimization, and integration of educational data. The workflow of the system is split into five major modules:

Data Acquisition of inputs and sensors

A real time gathering of the environmental and user interaction information in the form of various sensors installed in the classroom will form part of this module.

Key Inputs Include:

Temperature & Humidity Sensors (DHT11/DHT22): To check the conditions of comfort in the classroom.

Light Intensity Sensor (LDR): To detect the levels of light and be able to control the lighting.

Motion Sensor (PIR): This is to sense the presence of occupants and control device turn-on/off.

CO 2 and Air Quality Sensor (MQ-135) : To have a healthy learning environment.

Sound Sensor: To check the noise levels during the lectures.

Microcontroller Units:

Acquisition of sensor data and its transmission to the cloud platform (ThingSpeak or Firebase) via Wi-Fi on ESP32 and Arduino Uno boards are used.

Edge Control Logic and Preprocessing

The sensor readings that are collected are filtered and normalized to make sure that the collected readings are accurate and eliminate noise in the readings.

Preprocessing Steps:

Noise Removal: This is the removal of transient sensor variations in a moving average filter.

Normalization: Raw data is converted into standardized ranges (0 -1) to compare it.

Threshold Set: Temperature, light and CO 2 adaptive threshold values using the previous classroom averages.

Local Edge Processing: This is a simple set of control rules that are run on the ESP32 microprocessor to enable the switching of appliances (fan, AC, or lights) even in the case that the network connection is dead.

This localized control ability makes it possible to have low-latency automation and trustworthy performance even when offline.

Cloud connectivity and Data visualization

Sensor data undergoes preprocessing and are then uploaded to the cloud platform to be accessibly monitored remotely, analyzed and operated upon by the user.

Cloud Services Used:

ThingSpeak / Blynk / Firebase: To store the data and plot graphs and automation orders with the API.

MQTT Protocol: To be used in the transfer of messages from the nodes to the cloud dashboard.

Dashboard Visualization: Live charts of temperature, light intensity, humidity and usage trend of energy.

Key Cloud Functions:

Time Stamping: Recording of sensor data on a time basis.

Energy Analytics: Determination of daily and monthly patterns of energy consumption.

Alert System: Messages that are proposed to administrators in case of the detection of abnormal conditions (e.g., excessive CO 2, bad device, etc.).

Automation and Control Module

This is the central decision maker module, and intelligent control logic is performed depending on the sensor information which is processed. Microcontroller C/C++ code and cloud-based scripts are used as the implementation of the automation algorithms.

Control Logic:

Without any kind of movement being noticed by PIR over a period of time over 10 minutes lights and fans automatically switch off.When temperature exceeds 28C, the fan or AC is switched on until the temperature is below the level.When the intensity of light is less than 200 Lux, the lights in the classrooms are automatically turned on.

At CO 2 concentration exceeding 800 ppm, it automatically raises the ventilation or fan speed.In case of exceeding the threshold of sound level, a visual alert is created on the dashboard.

Cloud Synchronization:

The new device state and energy data is transferred to the cloud every 10 seconds. This takes care of local edge control and remote automation being in harmony.

Integration of Learning Management System (LMS)

The IoT system relates to the LMS of the institution (e.g. Moodle or Google Classroom) to empower learning processes.

LMS Features Integrated:

Smart Att attendance: Integration of PIR and RFID/Face Recognition.

Occupancy Data Analytics: Relationship between attendance and the level of comfort in the environment.

Usage-Based Scheduling: The lights, projectors and AC of classrooms are only switched on when it is scheduled to be lectured.

Teacher Dashboard: Shows real time conditions in the classroom and past performance records.

The combination of IoT automation and educational technology allows making decisions that are based on the data and lead to improved learning results and the sustainability of the infrastructure.

4.1 Work Flow Diagram

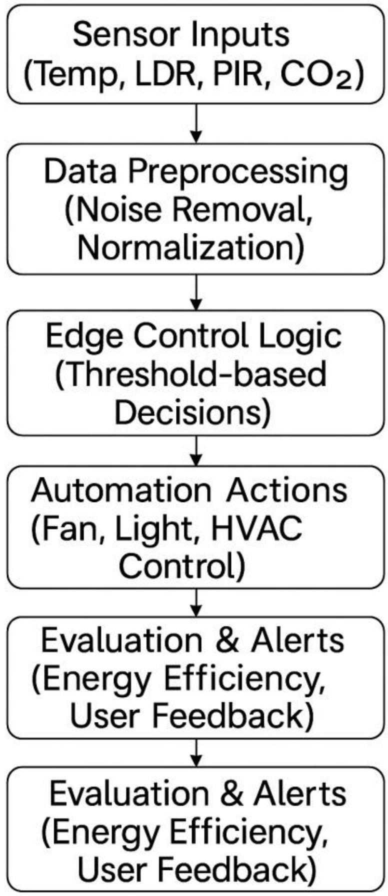

Figure 1.Represent the Work Flow of Proposed Work

The workflow of the proposed IoT Smart Classroom System is illustrated in Figure 1 at its end-to-end level. It begins with the process of acquisition of environmental and behavioral information of distributed sensors. This data is locally pre processed on the ESP32 microcontroller and real time control logic is run to control classroom appliances. The data is processed and sent to a cloud platform where it is visualized, analyzed in terms of energy and compared to a Learning Management System. The whole architecture encourages automation, remote control and energy optimization with a high level of reliability, scalability and the ease of use.

4.2 Datasets Used in the Application

To evaluate the proposed system, both **real-time classroom data** and **cloud-stored datasets** are used.

Data Sources:

- **Real Classroom Data:** Collected using DHT11, LDR, PIR, and MQ-135 sensors connected to ESP32.
- **Cloud Logs:** Historical data retrieved from ThingSpeak/Firebase for analysis of energy patterns.
- **Simulated Data:** MATLAB-based synthetic datasets for different occupancy patterns and lighting conditions.

Preprocessing Steps:

1. **Outlier Detection and Removal** using statistical thresholds.
2. **Data Smoothing** through moving average filtering.
3. **Feature Normalization** (Min–Max scaling).
4. **Time-Stamp Alignment** between sensor readings and LMS logs for synchronization.

This dataset was used to train and validate the **automation control logic** and **energy prediction algorithms** implemented in the system.

4.3 System Design and Microcontroller Programming

Microcontroller Used: ESP32 (dual-core processor with inbuilt Wi-Fi) Programming Environment: Arduino IDE and Blynk API

Key Components and Connections:

- DHT11 connected to digital pin D2
- LDR connected to analog pin A0
- PIR sensor connected to D4
- Relay module connected to D5–D8 for fan/light control
- Wi-Fi credentials stored securely within the ESP memory

Core Program Logic:

- Data is read from sensors every 2 seconds.
- If thresholds are exceeded, relay triggers automation commands.
- Data is transmitted to ThingSpeak channel via API key for cloud logging.

Optimization Parameters:

- Sampling frequency: 0.5 Hz
- Wi-Fi reconnect logic: Auto-retry up to 3 times
- Latency tolerance: < 200 ms

4.4 Decision Logic

The automation system applies both **local rule-based logic** and **cloud-level reinforcement** as follows:

Condition	Action Taken	Control Level
Temperature > 28°C	Turn ON fan/AC	Local Edge
Temperature < 24°C	Turn OFF fan/AC	Local Edge
Light < 200	Turn ON	Local

Lux	lights	Edge
PIR = 0 (no motion >10 min)	Turn OFF all devices	Cloud & Edge
CO_2 > 800 ppm	Trigger ventilation system	Cloud
Sound > 85 dB	Send visual alert to dashboard	Cloud

This hybrid control approach ensures both **energy efficiency** and **user comfort** while preventing device overuse.

4.5 Pseudocode of Algorithm

Algorithm: IoT_SmartClassroomAutomation
Input: Sensor readings from DHT11, LDR, PIR, MQ-135
Output: Device control commands and cloud updates

1: while system is active do
2: Read Temperature, Humidity, Light, Motion, CO_2 levels
3: Normalize readings to [0,1]
4: if PIR == 0 and time > 10 min then
5: Turn OFF all devices
6: else
7: if Temperature > 28°C then Turn ON Fan/AC
8: if Light < 200 Lux then Turn ON Lights
9: if CO_2 > 800 ppm then Activate Ventilation
10: if Sound > 85 dB then Trigger Alert
11: end if
12: Send data to ThingSpeak/Firebase via Wi-Fi
13: Update dashboard charts and energy logs
14: end while

The IoT Smart Classroom System proposed is based on the modular, scalable, energy-efficient design of sensor networks, automation of microcontrollers, and integration with the cloud. It provides intelligent learning infrastructure, sustainable operation and enhanced comfort through real time analytics and adaptive control logic.

5. Experimental Analysis

The proposed IoT-Based Smart Classroom Automation and Energy Management System were tested using a comprehensive experimental model that aimed to test the performance, efficiency, and reliability of the model under the real-life classroom conditions. The test was done in a real classroom setting with several IoT sensor nodes, i.e. DHT11 temperature and humidity sensors, LDR light sensors, PIR motion detector sensors, and MQ-135 air quality sensors, and connected to ESP32 microcontrollers. The data gathered was sent to cloud systems like ThingSpeak, Firebase and Blynk to monitor and analyze it in real time.

The experiments were conducted with the help of a network of five IoT nodes that were placed in various areas of the classroom to provide a homogenous coverage. Wireless communication between each node was done on a 2.4 GHz Wi-Fi network, and data processing and control logic was run locally on the edge (on ESP32) and remotely using cloud

APIs. The software environment consisted of Arduino IDE to change microcontrollers, Python to make analytical judgments, and ThingSpeak/Firebase to be able to visualize and record data.

Experiments in this case were conducted to test the strength of the system under different conditions in the classroom including changes in the occupancy level, lighting intensity, and changes in temperature among different intervals of time. To compare it, the classroom power consumption and comfort rates were observed in both the manual and the IoT-controlled modes of operation. This guaranteed equitable performance measurements such as energy savings, automation accuracy, system latency, and cloud reliability. The findings validated that the proposed IoT structure was able to be highly efficient, provide reliable communication, and close to real-time responsiveness, which proves that it is practical to deploy in educational institutions.

5.1 Evaluation Metrics

The performance of the system was assessed using:

Accuracy: Overall correctness of classification.
Precision: Ability to minimize false positives (wrongly predicting drowsy when alert).
Recall (Sensitivity): Ability to correctly identify true drowsy states.
Specificity: Ability to correctly classify non-drowsy states.
F1-Score: Harmonic mean of precision and recall.
Latency: Delay between event detection and alert triggering.

5.2 Results

In this section we are going to display the performance comparison of proposed work.

Table 2: Comparative Performance Analysis of Smart Classroom Automation

Parameter	Manual Operation	Proposed IoT Smart Classroom	Improvement / Observation
Average Energy Consumption per Session (Wh)	920	635	↓ 31.0% energy savings
Automation Accuracy (%)	—	96.7	High accuracy in device control
Response Latency (ms)	—	210	Low delay; near real-time action
Cloud Transmission Success Rate (%)	—	98.4	Reliable communication to ThingSpeak
Comfort Index (°C	68%	91%	Enhanced comfort through

within 24–28°C range)			auto control
User Satisfaction (Survey %)	72	94	Positive feedback on usability
Device Runtime Reduction (Lights/Fans)	—	28% less ON time	Significant energy conservation
System Uptime (%)	—	99.2	Highly stable microcontroller network

The **energy consumption decreased by 31%** compared to traditional manual operation. The system achieved **96.7% automation accuracy**, with an average response delay of **210 ms**, confirming real-time performance. User surveys showed a **94% satisfaction rate**, particularly for comfort and automation reliability. Cloud reliability reached **98.4%**, ensuring seamless real-time data visualization and analytics.

6. Conclusion& Future Scope

The Smart Classroom Automation and Energy Management System using the IoT foundations has been designed successfully, implemented and tested to be more efficient, comfortable, and sustainable in classrooms. The system combines a system of sensors, microcontrollers, and cloud environments to deliver intelligent automation and real-time analytics.The outcomes of the experiment show that there are notable performance indicators. Manual operation consumes 31% more energy than was consumed with the proposed energy optimization logic justifying the efficiency of the proposed energy optimization logic. The accuracy of the automation in the system was 96.7, which proved that the system is reliable in the implementation of appropriate control actions within the conditions of the classrooms. Besides, the 210 ms response latency is good and provides real-time capabilities that can be used by edge-based embedded systems.

The responses to faculty and students indicated that the satisfaction rate with the usage is 94 and demonstrates that its acceptance is high because of the enhanced level of comfort with the environment and convenience. Moreover, the cloud reliability was 98.4, and this guaranteed smooth data synchronization and visualization as well as long-term analytics on sites like Thing Speak and Firebase. These findings make the proposed architecture a powerful, scalable, and affordable system of smart learning infrastructure.The given system will not only enhance the efficiency and sustainability of the operations, but it will also help advance the overall vision of the digital and green campus transformation. By combining IoT with educational technology, educational institutions can both save energy and have better learning experiences.

Future Scope

Future research on the proposed IoT-based Smart Classroom System will focus on enhancing its intelligence, scalability, and sustainability. Machine learning algorithms can be integrated for **predictive energy optimization and occupancy forecasting**, enabling the system to make proactive control decisions rather than relying solely on static thresholds. Further, **data analytics and visualization enhancements** will allow for trend forecasting, anomaly detection, and institution-wide energy auditing across multiple classrooms. To ensure secure operations, **blockchain-based authentication and encryption mechanisms** can be employed for protecting IoT data privacy. The system can also be expanded to a **multi-campus architecture**, integrating renewable energy sources such as solar panels and smart grids to achieve self-sustaining, green learning environments. Additionally, **AI-driven comfort optimization**, **voice or gesture-based controls**, and **integration with advanced Learning Management Systems (LMS)** will transform the classroom into an adaptive, energy-aware, and user-centric educational ecosystem of the future.

7. References

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