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DESIGN AND IMPLEMENTATION OF AN IoT-Based SMART CLASSROOM MANAGEMENT SYSTEM USING STM32 AND LoRaWAN

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ABSTRACT

The Internet of Things (IoT) is increasingly recognized as a foundational pillar of digital transformation, with applications spanning industry, agriculture, and education. In education, the demand for smart classrooms that monitor and control the learning environment while optimizing energy use and operating costs has become imperative. This paper presents a smart classroom management solution based on LoRaWAN communications, leveraging its long-range connectivity, low cost, and low power consumption. The system employs an STM32 microcontroller as the central controller, integrating temperature–humidity sensors, occupancy sensors, and current–voltage sensors to acquire environmental data and electrical status. Collected data are transmitted to a server and visualized in a management application developed by the authors, enabling real-time monitoring and remote actuation (e.g., switching lighting and heating, ventilation, and air conditioning (HVAC) on/off). A hardware–software prototype was built and piloted in a simulated classroom. Preliminary results demonstrate stable operation, feasibility, scalability, and strong potential for practical deployment in smart educational environments.

Keywords: IoT, LoRaWAN, STM32, smart classroom.

1. INTRODUCTION

Nowadays, the Internet of Things (IoT) is one of the key technologies of the Fourth Industrial Revolution. Beyond its wide applications in industries and daily life, IoT plays an essential role in the development of smart schools. By integrating IoT devices and sensors, classrooms can be monitored and managed more efficiently, enabling energy-saving solutions and optimizing remote supervision. This study focuses on developing an IoT-based system for intelligent classroom management to create a more sustainable and effective educational environment.

The first definition of IoT was introduced by Kevin Ashton in the late 90s [3]. The IoT concept is used to describe a network of physical devices that connect and exchange data with each other or with other systems via the Internet. Since then, many new telecommunication technologies have been developed to support IoT platforms and systems. Therefore, the new transmission protocols have become one of the most interesting technology directions today, especially low-power and long-range wireless communication technologies.

New communication technologies not only ensure smooth communication in the IoT system but also extend the reach of device-to-device connections (nodes and gateways). At the same time, they help reduce energy consumption, thereby prolonging device uptime. Several wireless communication technologies have been developed specifically for IoT systems. We can mention several technologies such as Zigbee, Bluetooth[[1]], Wi-Fi, LoRa [[2]][[3]], NB-IoT [[4]], TI Sub-1 Ghz [[5]][[6]]… Depending on the requirements of the IoT system to be designed, we can choose one or more suitable communication technologies for our IoT platform.

LoRa is a radio modulation technology for low-power, wide area networks (LPWANs). This modulation method is proposed by Semtech to provide an effective wireless communication for IoT devices [[7]]. LoRa technology can provide long-range wireless communication: up to 5 kilometers in urban areas and up to 15 kilometers or more in rural areas (Line-of-sight). An important characteristic of the LoRa-based solutions is ultra-low-power requirements, which allows the battery-operated devices to have a lifetime of up to 10 years. The LoRaWAN is deployed in a star topology, making it ideal for applications that require long-range communication among many devices with low power requirements and that collect small amounts of data.

To develop an IoT system, a development kit (dev-kit) is often used to support engineers in the design process. It can reduce the time to build the actual circuit and allows users to test the functions of different devices easily. However, most of the available dev-kits that support LoRa are limited in terms of hardware resources and mainly exist as Arduino shields. To address this limitation, this work presents an IoT–LoRa custom board that integrates the STM32 microcontroller with the RFM95 LoRa transceiver and is complemented by a web-based management platform. The board provides efficient processing capability while maintaining low power consumption, and the integrated LoRa module enables long-range wireless communication. The accompanying website allows users to easily monitor, manage, and control IoT devices through a user-friendly interface. This system is particularly useful for schools in managing classrooms by monitoring environmental conditions (temperature and humidity), detecting student presence through occupancy sensing, and supervising electrical usage (current and voltage) to improve safety and energy efficiency.

To highlight the advantages of LoRaWAN in a smart classroom context, Table 1 compares it with common wireless technologies. While Wi-Fi and Zigbee are suitable for short-range applications, LoRaWAN provides superior penetration through concrete walls and covers the entire campus with minimal infrastructure.

Table 1. Comparison of wireless technologies for classroom management.

Feature	Wi-Fi	Zigbee	LoRaWAN (Proposed)
Range	Short (30-50m)	Short (70-100m)	Long-range (up to 15km)
Power Consumption	High	Low	Ultra-low
Indoor Penetration	Moderate	Low	High (Superior for multi-floor)
Scalability	Low	Moderate	High (Thousands of nodes)

The remainder of this paper is organized as follows: Section II presents an overview of the IoT–LoRa platform model, Section III focuses on the development of the IoT–LoRa custom board and the web-based dashboard for the system, and Section IV concludes the paper with future development directions. The model of a LoRaWAN-based IoT platform.

2. DESIGN AN IoT – LoRa CUSTOM BOARD

The general model of an IoT system based on LoRaWAN is illustrated in Fig. 1 [[7]]. In this model, the End Nodes (or End Devices) consist of a combination of sensors or actuators and a microcontroller. The End Nodes will collect the data from the environment and send it to the gateway through the LoRa connection. The gateway communicates with multiple End Nodes in the same area and forwards the collected data to the cloud via an Internet connection. Several studies have adopted similar LoRaWAN-based architectures for environmental monitoring, smart agriculture, and smart building applications. In these systems, low-power sensor nodes periodically measure physical parameters such as temperature, humidity, occupancy, or energy consumption and transmit the data to a network server or cloud platform for storage, visualization, and decision support. However, most existing works either focus on a single application domain or do not explicitly address the specific requirements of classroom management in schools, such as monitoring student presence together with environmental and electrical parameters. This motivates the design of our IoT–LoRa platform, which targets an integrated solution for smart classrooms.

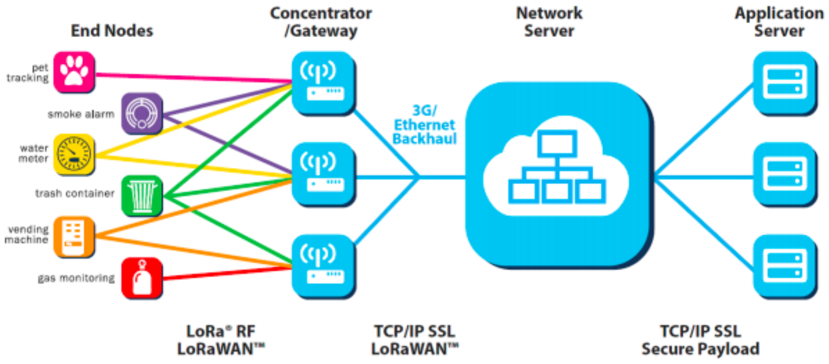


Fig. 1. The model of an IoT platform using LoRa technology [7].

In this paper, an IoT–LoRa custom board is designed for smart classroom systems, integrating sensors to collect environmental data and monitor energy consumption, while also supporting actuators to control classroom devices. The collected data is transmitted via LoRa connection to the gateway and then forwarded to the cloud. At the same time, a web-based management platform is developed to provide an intuitive interface that allows users not only to monitor classroom conditions and energy usage in real time but also to send control commands from the cloud to the IoT–LoRa custom board through the gateway. Together, the IoT–LoRa custom board and the web system form a complete IoT solution with practical applications in smart classroom models, with a particular focus on energy monitoring and management.

LoRaWAN Gateways [[8]] serve as the bridge between the End Nodes and the Cloud. End Nodes connect to the Gateway via LoRa to minimize power consumption, while the Gateway uses high-bandwidth networks such as Wi-Fi, Ethernet, or Cellular to connect to the Cloud. Equipped with a LoRa concentrator, the Gateway essentially acts as a router, enabling seamless two-way communication between the IoT–LoRa custom boards and the web platform.

2.1. Block diagram of the IoT – LoRa Custom Board

As mentioned in Section I, the IoT–LoRa custom board is designed based on the STM32 family of microcontrollers. Specifically, the system employs an STM32 microcontroller as the main processing unit (MCU), responsible for coordinating sensors, actuators, and the LoRa communication module.

The STM32 is a 32-bit high-performance microcontroller built on the ARM Cortex-M core, operating at clock speeds up to several hundred megahertz. It features large embedded memories and a wide range of peripheral interfaces, making it well-suited for IoT applications that demand both high processing capability and low power consumption.

Another advantage of the STM32 platform lies in its software development flexibility, as it is compatible with multiple programming environments, such as Arduino IDE, STM32CubeIDE, and PlatformIO. This compatibility allows developers to easily program, test, and reuse libraries in the process of building IoT–LoRa systems.

The block diagram of this IoT–LoRa custom board is shown in the **Error! Reference source not found.**.

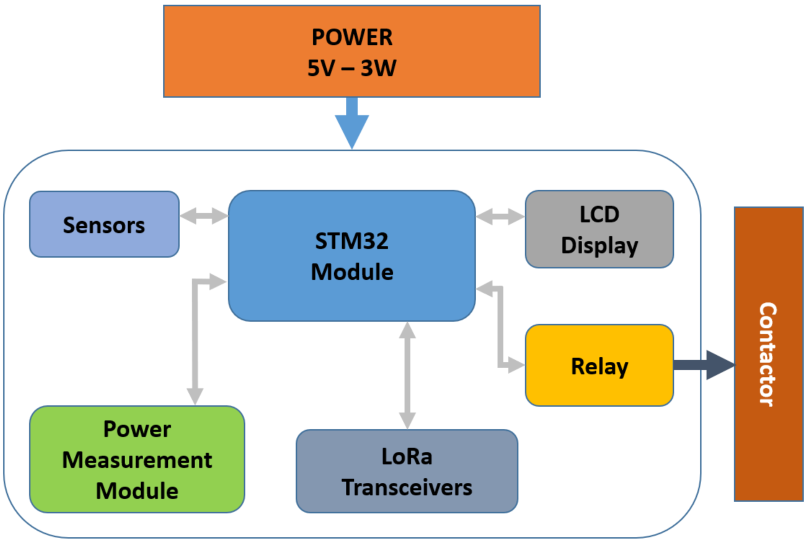


Fig. 2. The block diagram of the IoT–LoRa custom board.

To form a complete IoT solution, the STM32 microcontroller is integrated with several peripheral modules. The RFM95W LoRa module provides long-range wireless communication with low power consumption. The sensor module includes temperature, humidity, and human presence sensors that provide essential data for monitoring classroom conditions. Temperature and humidity values help optimize air conditioning operation, while the presence sensor ensures that energy-consuming devices are activated only when the classroom is occupied. A power measurement module monitors voltage, current, and power consumption in real time, enabling analysis and optimization of electricity usage. The LCD provides locally essential system status and sensor information. Additionally, a relay combined with a contactor is used to control high-power loads such as lighting or air conditioning units, ensuring both safety and reliability. The power supply module uses a 5V 3W adapter to provide stable energy for the entire system, distributing regulated voltages to the STM32, LoRa, sensors, and LCD.

Sensor and power measurement data, together with actuator states, are transmitted to the web-based platform via the LoRaWAN connection and gateway. Through this platform, users can monitor environmental and energy conditions in real time and remotely control classroom devices via an intuitive web interface, ensuring efficient and intelligent classroom management.

2.2. IoT – LoRa Custom Board Schematic and PCB Design

Based on the proposed block diagram, the schematic of the IoT–LoRa custom board is designed as shown below. Fig. 3 illustrates the connection between the STM32 microcontroller and the RFM95 LoRa transceiver. The RFM95 uses the SPI interface and connects to the STM32 via MISO, MOSI, SCK, and NSS (CS).

In addition to the LoRa transceiver, the IoT–LoRa custom board integrates several peripheral modules:

- An OLED display (I2C) for local visualization of system status,
- A DHT22 temperature and humidity sensor,
- An RD-04 presence sensor,
- A PZEM-004T power measurement module,
- An RGB LED and a relay combined with a contactor for load control,
- A power supply module using a 5V/3W adapter to provide stable energy for the entire system.

Together, these modules enable the board to collect environmental and energy data, perform real-time monitoring, and directly control classroom equipment. Unlike conventional development kits that mainly focus on basic sensing and control, this IoT–LoRa custom board includes an integrated power measurement module tailored for classroom energy management. Furthermore, all collected data and control states are transmitted via LoRaWAN to a gateway and then to a web-based platform, where users can remotely monitor and manage devices via an intuitive dashboard.

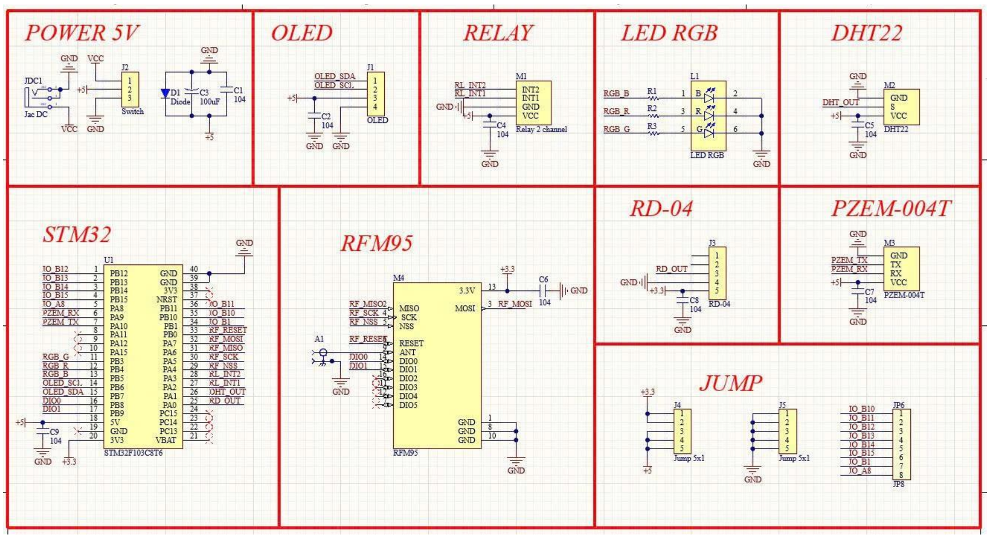


Fig. 3. IoT – LoRa Custom Board Schematic Design.

After completing the schematic design, PCB design is an essential step to ensure an optimized layout for board manufacturing. A well-designed PCB not only helps reduce the overall size of the IoT–LoRa custom board but also effectively addresses heat dissipation and minimizes crosstalk noise. The PCB layout of the board is illustrated in Fig. 4, while its 3D model is shown in Fig. 5.

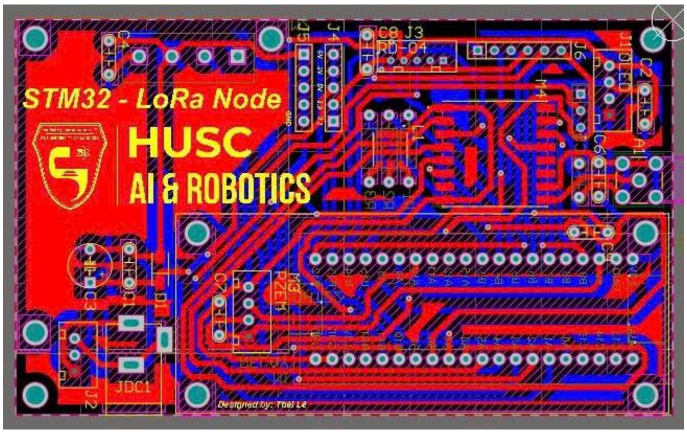


Fig. 4. PCB Layout of the IoT – LoRa Custom Board.

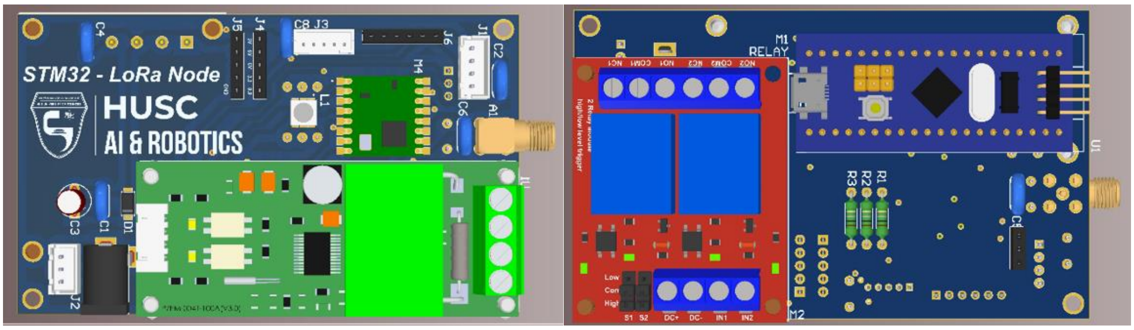


Fig. 5. The 3D simulation model of the IoT – LoRa Custom Board.

The total board size is 100×60 mm, making it easy to integrate this IoT–LoRa custom board into larger systems via an expansion connector if needed. The fully assembled PCB is shown in Fig. 6. In addition, a 5 dBi omnidirectional antenna is employed to improve system sensitivity.

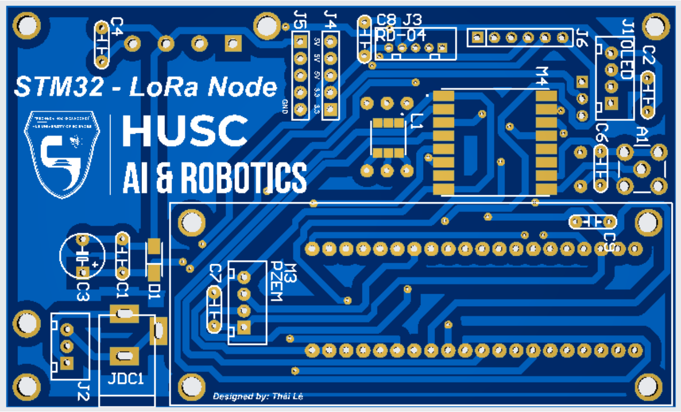


Fig. 6. The manufactured PCB.

3. DEVELOPMENT OF THE WEB-BASED DASHBOARD AND API CONNECTION

3.1 Objectives

This section presents the design and implementation of a web-based dashboard that bridges LoRaWAN end-devices and end users in a clear, low-friction way. The solution focuses on three capabilities: live monitoring of decoded sensor values, safe issuance of downlink commands with visible feedback, and optional history for trends and reports. Beyond functionality, the system must keep connections encrypted, remain simple to deploy on a local server or in the cloud, and provide a consistent user experience across common browsers.

Concretely, the dashboard aims to show key fields such as temperature, humidity, and door state together with basic radio information (timestamp and signal strength) nearly in real time; to let operators send on/off and configuration commands from the browser with clear confirmation; and to store data when long-term charts or summaries are required. These goals inform the architecture and the API connection discussed next.

3.2 Architecture & API Connection

The overall architecture follows a simple chain—Device → The Things Network (TTN) → Backend → Browser—so that each role is well defined. In the data path, devices publish sensor readings to TTN; the backend receives these readings and streams them to the browser so charts and tables refresh without page reloads. In the control path, the browser sends a request to the backend, which forwards the command to TTN for delivery to the target device. Keeping protocol details inside the backend avoids duplicating logic in the browser and makes validation and logging consistent.

The API connection to TTN uses MQTT over TLS (port 8883) at the application level. Authentication relies on an application username of the form {app-id}@{tenant} together with an API key created in the TTN Console. Only the minimum required permissions are granted—reading application traffic and sending downlink traffic—and the key is handled as a secret via environment variables or a vault [[9]][[10]].

To ingest device data, the backend subscribes to the following topic pattern:

v3/{app-id}@{tenant}/devices/+/up

Each uplink message is a JSON object that includes the device identifier, receive time, application port (f_port), and payload. When the Payload Formatter is enabled, decoded application fields appear under decoded_payload (e.g., "temperature": 24.8) and can be forwarded directly to the dashboard. This arrangement keeps the browser lightweight and allows near-instant visual updates over a WebSocket connection.

To deliver commands, the backend publishes to the topic:

v3/{app-id}@{tenant}/devices/{device-id}/down/push

The publish body is a small JSON document with a downlinks array, for example:

{"downlinks": [{"f_port":15,"frm_payload":"AQID","priority":"NORMAL"}]}

Here, frm_payload is the Base64 form of the bytes to send (for example, hex 01 02 03 becomes AQID). Before publishing, the backend verifies the device identifier, checks that f_port falls within 1–233, and validates payload length and format. Because this interface operates at QoS 0, the backend also performs light de-duplication and automatically resubscribes after transient disconnects.

3.3 Implementation & Evaluation

Implementation follows directly from the architecture but adds a few practical details that matter in day-to-day use. The system is deployed using the AU915 frequency plan (915-928 MHz, FSB 1) to comply with regional regulations. To achieve a balance between long-range connectivity and low latency, the LoRaWAN parameters are configured with a Spreading Factor of SF7, a Bandwidth of 125 kHz, and a Coding Rate of 4/5. On the server side, a small Node.js service maintains a secure MQTT connection to TTN, parses each uplink message once, and converts it into a compact event containing the device ID, receive time, decoded fields, and basic radio metrics. These events are streamed to the browser over WebSocket so the page can update without reloading. For control, the server exposes a /downlink endpoint: the dashboard sends a device identifier, port, and hex payload; the server converts the payload to Base64, publishes the command to TTN, and returns a clear "accepted/error" status. Short network drops are handled by automatic reconnection and light de-duplication, so users do not see repeated points or broken charts [[11]].

The Building Overview page (

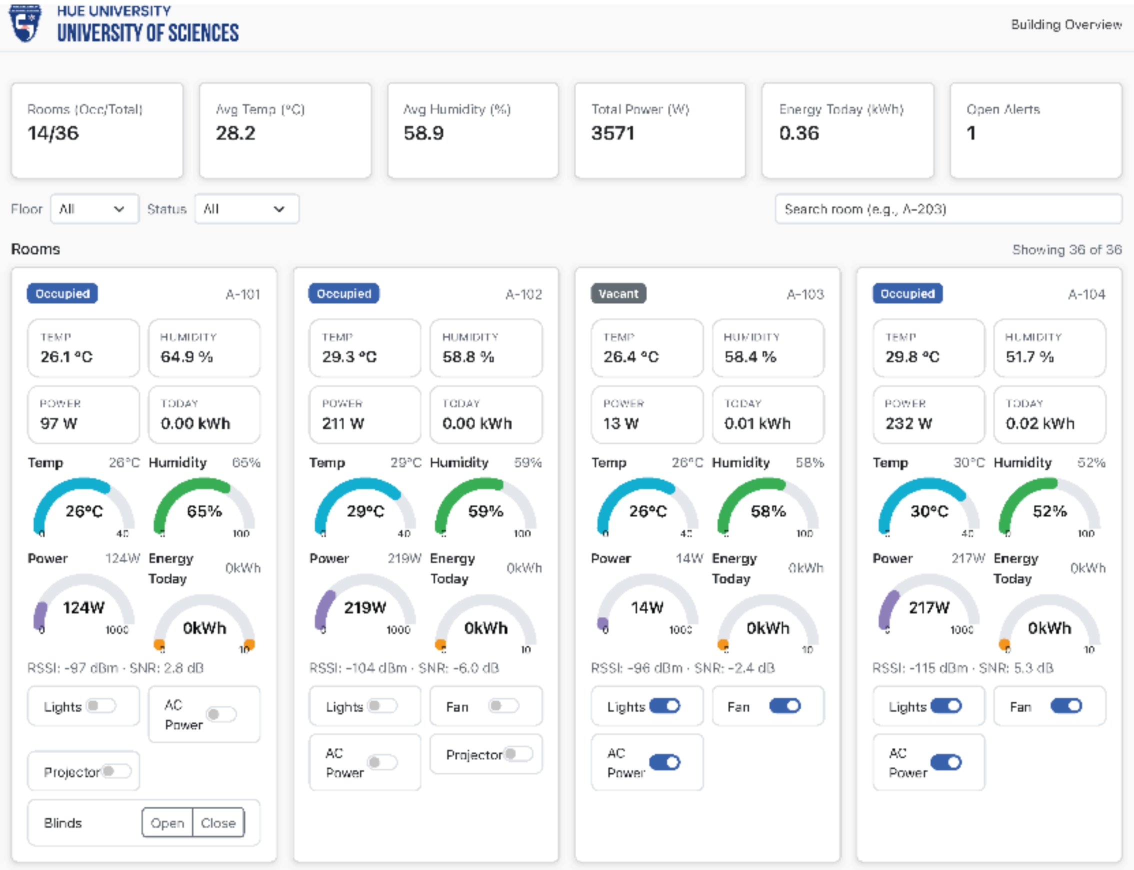
Fig. 7) presents a concise summary at the top—occupied rooms over total, average temperature and humidity, total power, energy today, and open alerts—so users can grasp building status at a glance. Filters for floor and room status, together with a search box, narrow the view quickly. Each room card then shows key readings (temperature, humidity, instantaneous power, and today's energy) with simple gauges that move smoothly as new data arrive. Radio quality is visible through RSSI/SNR, which helps explain outliers (e.g., a flat line or delayed updates). Occupancy is indicated with clear badges ("Occupied"/"Vacant"), and the lower part of each card holds the main controls (lights, fan, AC power, projector, blinds). When a user toggles a control, the dashboard sends a single command to the server; once TTN accepts the request, the card shows immediate feedback, which keeps the interaction predictable.

The Room Detail page (

Fig. *8*) is designed for focused troubleshooting and verification. It highlights the latest values in large tiles (temperature, humidity, power, energy today, RSSI, SNR) and groups the gauges in one panel to make short-term trends easy to read. The control panel on the right mirrors the equipment available in that room and keeps the same interaction model as the overview: a single click issues a command; the page then confirms the outcome without navigating away. When the device is temporarily offline, the page displays the last update time and disables controls until connectivity returns. This consistency between the two views helps users move from a building-wide scan to a room-level action with minimal cognitive load.

To evaluate the system, we focused on four aspects that matter in practice: how quickly a new reading becomes visible on the page, how fast a command is accepted by TTN, how the interface behaves during short connectivity issues, and whether the overview remains smooth when many rooms are shown at once. Experimental results show that the average end-to-end latency is 450 ms with a standard deviation of 120 ms. This latency is subdivided into LoRa airtime (~45 ms at SF7), gateway processing time, and MQTT/WebSocket transmission, confirming that the system meets the requirements for prompt monitoring and control. During brief drops, automatic reconnection and de-duplication keep charts clean and avoid confusing jumps. With the current deployment scale (

Fig. 7), the overview remains responsive, while the detail page provides a clear, low-friction path to verify a room and act on it. Overall, the results indicate that the chosen design is fast enough for routine monitoring and reliable enough for everyday control tasks.



Rooms (Occ/Total) 14/36
Avg Temp (°C) 28.2
Avg Humidity (%) 58.9
Total Power (W) 3571
Energy Today (kWh) 0.36
Open Alerts 1

Floor All
Status All
Search room (e.g., A-203)

Showing 36 of 36

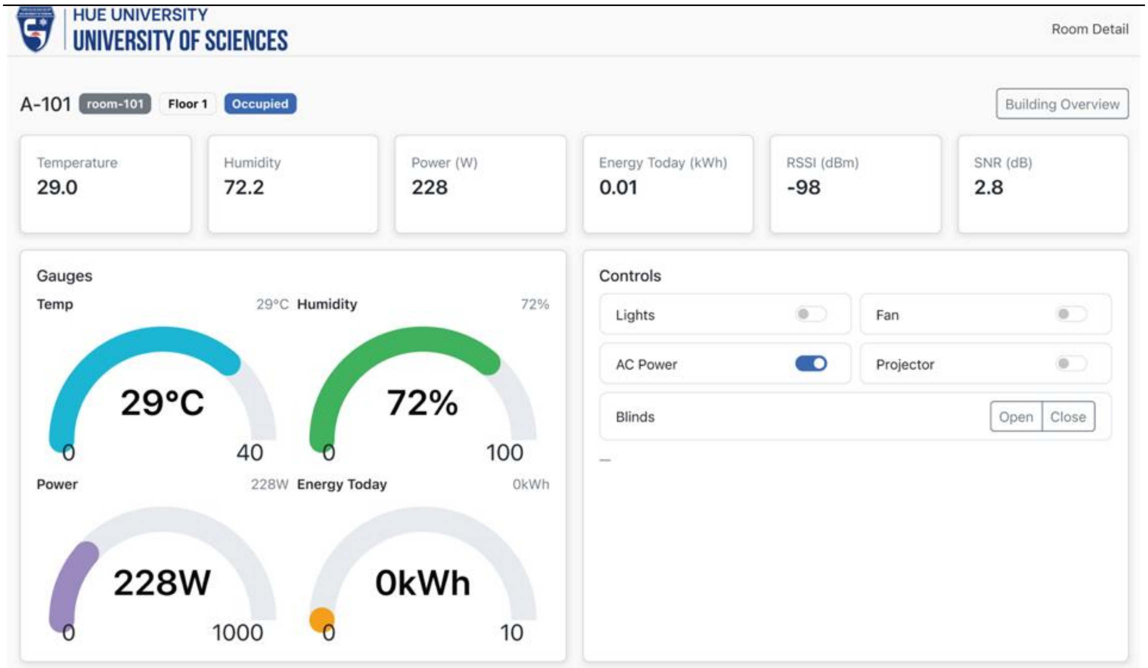
A-101 Occupied
TEMP 26.1 °C
HUMIDITY 64.9 %
POWER 97 W
TODAY 0.00 kWh
Temp 26°C
Humidity 65%
Power 124W
Energy Today 0kWh
RSSI: -97 dBm · SNR: 2.8 dB

A-102 Occupied
TEMP 29.3 °C
HUMIDITY 58.8 %
POWER 211 W
TODAY 0.00 kWh
Temp 29°C
Humidity 59%
Power 219W
Energy Today 0kWh
RSSI: -104 dBm · SNR: -6.0 dB

A-103 Vacant
TEMP 26.4 °C
HUMIDITY 58.4 %
POWER 13 W
TODAY 0.01 kWh
Temp 26°C
Humidity 58%
Power 14W
Energy Today 0kWh
RSSI: -96 dBm · SNR: -2.4 dB

A-104 Occupied
TEMP 29.8 °C
HUMIDITY 51.7 %
POWER 232 W
TODAY 0.02 kWh
Temp 30°C
Humidity 52%
Power 217W
Energy Today 0kWh
RSSI: -115 dBm · SNR: 5.3 dB

Fig. 7. Building Overview dashboard.



A-101 room-101 Floor 1 Occupied

Temperature: 29.0
Humidity: 72.2
Power (W): 228
Energy Today (kWh): 0.01
RSSI (dBm): -98
SNR (dB): 2.8

Lights ○
Fan ○
AC Power ●
Projector ○

Fig. 8. Room detail view.

4. CONCLUSION

This work presented an end-to-end smart classroom management solution that combines a custom STM32-based LoRa node with an intuitive web dashboard for real-time monitoring and remote actuation. The hardware integrates long-range LoRa communication, environmental sensing (temperature, humidity, occupancy), and a dedicated power-measurement path, enabling both condition awareness and energy-centric control in a single, compact board. Together with the cloud-connected dashboard, the system closes the loop from sensing to user action, supporting practical building-level operations. The prototype demonstrates stable operation with near real-time updates and predictable command handling, indicating that the approach is feasible and scalable for deployment across multiple rooms. These results—together with the low-power, long-range characteristics inherent to LoRaWAN—underscore the suitability of the proposed design for smart educational environments focused on safety, comfort, and energy efficiency.

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THIẾT KẾ VÀ CHẾ TẠO HỆ THỐNG QUẢN LÝ LỚP HỌC THÔNG MINH DỰA TRÊN IOT SỬ DỤNG STM32 VÀ LoRaWAN

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TÓM TẮT

Internet vạn vật (IoT) đóng vai trò then chốt trong chuyển đổi số, đặc biệt là trong việc phát triển các lớp học thông minh nhằm tối ưu hóa môi trường học tập và tiết kiệm năng lượng. Bài báo này trình bày giải pháp quản lý lớp học thông minh dựa trên công nghệ truyền thông LoRaWAN, tận dụng ưu thế về khoảng cách kết nối xa, chi phí thấp và tiêu thụ năng lượng thấp. Hệ thống sử dụng vi điều khiển STM32 làm trung tâm, tích hợp các cảm biến đo nhiệt độ - độ ẩm, sự hiện diện và thông số điện năng để thu thập dữ liệu môi trường và trạng thái thiết bị. Dữ liệu được truyền về máy chủ và hiển thị trên ứng dụng quản lý do nhóm tác giả phát triển, cho phép giám sát thời gian thực và điều khiển từ xa các thiết bị điện (chiếu sáng, điều hòa). Kết quả thử nghiệm trên mô hình thực tế cho thấy hệ thống vận hành ổn định, có tính khả thi và khả năng mở rộng cao, hứa hẹn tiềm năng ứng dụng lớn trong các môi trường giáo dục hiện đại.

Từ khóa: IoT, LoRaWAN, STM32, lớp học thông minh.