EduVision: Journal of Innovations in Pedagogy and Educational Advancements
Volume 2, Issue 6, June 2026
brightmindpublishing.com
ISSN (E): 3061-6972

DESIGN AND EVALUATION OF AN IoT-BASED SMART HOME SYSTEM FOR RESOURCE-EFFICIENT BUILDING MANAGEMENT

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Abstract

The rapid development of Internet of Things (IoT) technologies has created new opportunities for intelligent residential building management and energy optimization. Smart home systems integrate environmental monitoring, wireless communication, and automated control mechanisms to improve user comfort, operational efficiency, and resource utilization. This study presents the design and evaluation of an IoT-based smart home system for resource-efficient building management. The proposed architecture incorporates environmental sensors, an ESP32-based controller, wireless communication technologies, and user interfaces for real-time monitoring and control. The system continuously collects data related to temperature, humidity, illumination, occupancy, and air quality, enabling automated operation of lighting, ventilation, and climate-control devices. A web-based dashboard and mobile application provide remote access and monitoring capabilities. The results demonstrate that the developed smart home system effectively supports environmental monitoring and automated control of residential devices. Comparative analysis indicates that intelligent automation and occupancy-based control strategies can significantly reduce unnecessary energy consumption while maintaining comfortable living conditions. The proposed architecture offers a scalable and cost-

EduVision: Journal of Innovations in Pedagogy and Educational Advancements
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brightmindpublishing.com
ISSN (E): 3061-6972

effective solution for modern residential buildings and contributes to improved energy efficiency and sustainable resource management.

Keywords: Smart home, Internet of Things, IoT, energy management, home automation, environmental monitoring, ESP32, energy efficiency, intelligent control.

Introduction

The rapid advancement of Internet of Things (IoT) technologies has significantly transformed the management of residential buildings by enabling intelligent monitoring, automation, and optimization of household operations. Smart home systems integrate sensors, communication networks, and embedded control devices to create a connected environment capable of improving comfort, security, energy efficiency, and resource utilization. As the demand for sustainable and energy-efficient living environments continues to increase, IoT-based home automation has become an important area of research and development.

Residential buildings account for a considerable share of global energy consumption. Traditional home management approaches often rely on manual control of lighting, heating, ventilation, air conditioning, and household appliances, which may result in inefficient energy usage and increased operational costs[1]. The integration of IoT technologies provides opportunities for real-time monitoring of environmental conditions and intelligent control of household systems, allowing more efficient utilization of energy resources while maintaining occupant comfort.

Recent developments in wireless communication technologies, cloud computing, and low-cost embedded platforms have accelerated the adoption of smart home solutions. Devices such as ESP32 microcontrollers, environmental sensors, and mobile applications enable continuous data collection, remote access, and automated decision-making [2-4}. These technologies support the implementation of intelligent building management systems capable of adapting to user preferences and changing environmental conditions.

Despite the growing popularity of commercial smart home platforms, many existing solutions are characterized by high implementation costs, limited flexibility, and dependence on proprietary ecosystems. Therefore, the development of cost-effective and scalable IoT-based architectures remains an important research challenge [5].

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Resource-efficient building management requires not only automation capabilities but also mechanisms for monitoring environmental parameters, optimizing energy consumption, and supporting remote supervision.

The objective of this study is to design and evaluate an IoT-based smart home system for resource-efficient building management. The proposed system integrates environmental monitoring, wireless communication, automated control algorithms, and remote user interfaces into a unified architecture. The developed solution aims to improve energy efficiency, enhance user comfort, and provide a flexible platform for intelligent residential building management.

2. MATERIALS AND METHODS

2.1. Smart Home System Architecture

The proposed smart home system was designed according to the Internet of Things (IoT) paradigm and consists of sensing, communication, processing, and control layers. The architecture integrates environmental sensors, embedded controllers, wireless communication technologies, and user interfaces into a unified management framework [6]. The system enables continuous monitoring of indoor environmental conditions and automated control of household devices to improve comfort and energy efficiency.

The architecture supports real-time data acquisition, remote access, and intelligent decision-making. Sensor data are collected from different areas of the residential building and transmitted to the central controller, where information is processed and used for automated control actions.

2.2. Hardware Components and Sensor Network

The hardware infrastructure includes a set of environmental sensors, an ESP32 microcontroller, communication modules, and actuator interfaces. The selected sensors are responsible for monitoring key parameters affecting indoor comfort and energy consumption.

Temperature and humidity are measured using DHT22 sensors, while illumination levels are monitored using BH1750 light sensors. Motion sensors are employed to detect occupant presence and support automated lighting control. Additional sensors may be integrated for monitoring air quality and other environmental parameters [7].

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The ESP32 microcontroller serves as the central control unit due to its integrated Wi-Fi functionality, low power consumption, and sufficient processing capabilities. Sensor nodes collect environmental measurements and transmit them through a wireless communication network for further processing and analysis.

2.3. Data Processing and Communication Platform

The developed system utilizes Wi-Fi communication technology to establish connectivity between sensors, controllers, and user interfaces. Environmental data are transmitted in real time and stored for monitoring and analysis purposes.

A web-based monitoring platform and mobile application provide remote access to system functions. Users can monitor environmental conditions, view historical measurements, receive notifications, and manually control connected devices when necessary [8]. The platform also supports data visualization through graphical charts and status indicators.

2.4. Control and Energy Optimization Algorithm

The smart home control strategy is based on automated decision-making using predefined environmental thresholds and occupancy conditions. Sensor measurements are continuously compared with reference values to determine whether control actions are required.

Lighting systems are automatically activated or deactivated according to illumination levels and occupancy information [9]. Ventilation and climate-control devices operate based on temperature and humidity measurements. The algorithm is designed to reduce unnecessary energy consumption while maintaining comfortable living conditions.

To evaluate system effectiveness, the proposed architecture was assessed in terms of monitoring functionality, automation capabilities, remote accessibility, and potential contribution to energy-efficient residential building management.

3. RESULTS AND DISCUSSION

3.1. Developed Smart Home Architecture

Based on the selected hardware and software components, an IoT-based smart home architecture was developed to support automated monitoring and control of residential environments. The proposed architecture integrates environmental

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brightmindpublishing.com
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sensors, wireless communication modules, a central controller, and user interfaces into a unified management system.

The developed system enables continuous acquisition of environmental data, including temperature, humidity, illumination, and occupancy information. Sensor measurements are transmitted to the ESP32 controller, where data processing and decision-making procedures are performed. The processed information is then delivered to the monitoring platform through a Wi-Fi communication network.

The architecture supports both automatic and user-controlled operation modes. In automatic mode, household devices are managed according to predefined control rules and environmental conditions. In manual mode, users can remotely access the system through a web interface or mobile application and control connected devices in real time.

Figure 1 illustrates the developed IoT-based smart home architecture designed for resource-efficient building management. The system integrates environmental monitoring devices, wireless communication technologies, intelligent control mechanisms, and user interfaces into a unified automation framework.

The sensor module continuously collects information about indoor environmental conditions, including temperature, humidity, illumination, occupancy, and air quality. These measurements are transmitted to the ESP32-based central controller through the local communication network. The controller performs data acquisition, processing, decision-making, and device control functions.

The processed information is exchanged with the user interface through Wi-Fi communication. The web dashboard and mobile application enable real-time monitoring of environmental parameters, remote control of connected devices, and notification management. This functionality allows users to supervise home operations regardless of their physical location.

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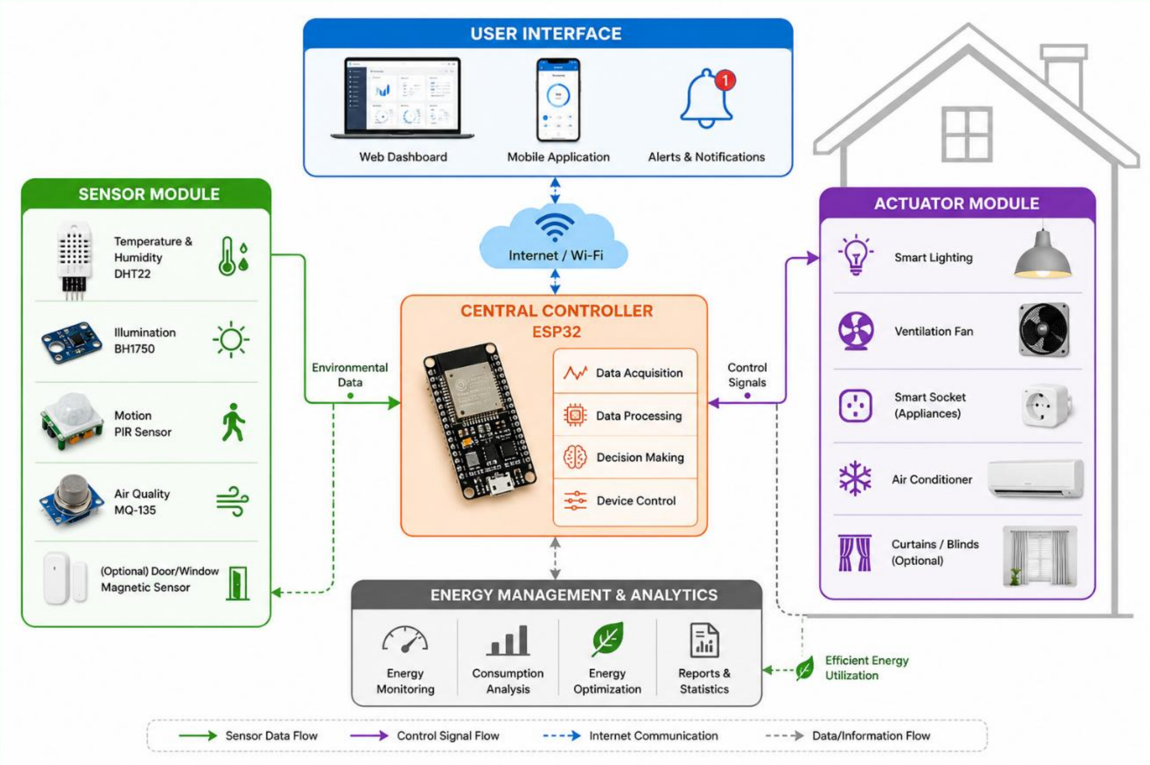

Fig.1. Developed IoT-based smart home architecture for resource-efficient building management.

The actuator module includes smart lighting systems, ventilation equipment, smart sockets, air-conditioning units, and optional automated curtain control mechanisms. Based on sensor measurements and predefined control rules, the system automatically adjusts the operation of household devices to maintain comfortable living conditions. An additional energy management and analytics layer supports monitoring of energy consumption, data analysis, optimization of resource utilization, and generation of statistical reports. The integration of environmental monitoring, automated control, and energy management functions contributes to improved energy efficiency, enhanced user comfort, and more sustainable residential building operation.

3.2. Monitoring and Control Functions

The developed system provides continuous monitoring of key environmental parameters that influence indoor comfort and energy consumption.

The monitoring platform successfully collected and displayed real-time measurements from all connected sensors. Environmental data were visualized

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through graphical interfaces, enabling users to track indoor conditions and respond to abnormal situations when necessary.

The implemented automation functions demonstrated stable operation during system testing. Lighting control responded to occupancy and illumination conditions, while climate-control devices were activated according to temperature and humidity measurements. These capabilities contributed to improved comfort and reduced unnecessary device operation.

Table 1. Environmental parameters monitored by the smart home system

Parameter	Sensor	Control Function
Temperature	DHT22	Climate Control
Humidity	DHT22	Ventilation Control
Illumination	BH1750	Lighting Control
Occupancy	PIR Motion Sensor	Automated Device Control
Air Quality	MQ-135	Ventilation Management

3.3. Energy Efficiency Assessment

An evaluation of the proposed system demonstrated its potential contribution to energy-efficient building management. Automated control of lighting and climate systems reduced unnecessary energy consumption by ensuring that devices operate only when required.

The results indicate that the proposed smart home system provides significant functional advantages compared with traditional residential management approaches. The integration of monitoring, automation, and remote-control capabilities creates opportunities for improving energy efficiency and supporting sustainable residential building operation.

The developed architecture also demonstrates scalability and flexibility, allowing additional sensors, controllers, and intelligent services to be integrated according to user requirements. Therefore, the proposed solution represents a practical and cost-effective approach to resource-efficient smart home management.

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Table 2. Functional comparison of conventional and IoT-based home management

Feature	Conventional Home	Proposed Smart Home
Real-Time Monitoring	No	Yes
Remote Access	No	Yes
Automated Control	Limited	Yes
Energy Optimization	Limited	Yes
Occupancy-Based Operation	No	Yes

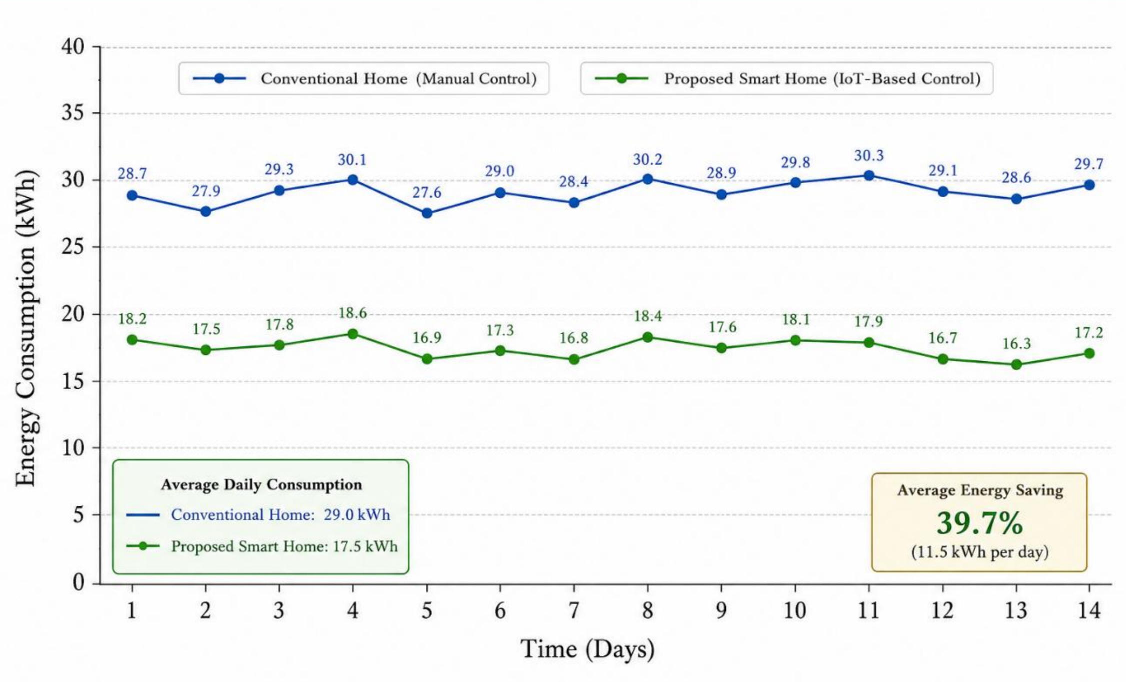

Fig. 2. Daily Energy Consumption Comparison Between a Conventional Home and the Proposed IoT-Based Smart Home System

Figure 2 illustrates the effect of the proposed IoT-based smart home system on residential energy consumption. Compared with conventional home operation, the developed system demonstrates consistently lower daily energy usage due to automated control of lighting, ventilation, and household appliances. The results indicate that intelligent monitoring and occupancy-based device management contribute to improved energy efficiency and reduced resource consumption.

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4. CONCLUSION

The study presented the design and evaluation of an IoT-based smart home system for resource-efficient building management. The developed architecture integrates environmental sensors, wireless communication technologies, intelligent control algorithms, and user interfaces into a unified automation platform capable of monitoring and managing residential environments in real time [10].

The proposed system enables continuous monitoring of temperature, humidity, illumination, occupancy, and air quality parameters. Through the use of an ESP32-based controller and automated decision-making mechanisms, the system supports efficient control of lighting, ventilation, climate-control equipment, and household appliances.

The results demonstrated that the integration of monitoring and automation functions can significantly improve residential energy efficiency. Comparative analysis showed that the proposed smart home solution reduces unnecessary energy consumption through occupancy-based operation and intelligent environmental control strategies. The obtained results indicate potential energy savings of approximately 39.7% compared with conventional home management approaches.

The developed architecture is scalable, cost-effective, and adaptable to various residential applications [11]. Future research may focus on the integration of artificial intelligence, predictive analytics, and advanced energy optimization techniques to further enhance the performance and sustainability of smart home systems.

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