



An IoT-Based Smart Room System for Energy-Efficient Lighting, Temperature Regulation, and Security Monitoring

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Abstract

Smart Room systems exemplify a significant application of Internet of Things (IoT) technology designed to enhance energy efficiency, user comfort, and indoor security in residential settings. The rising use of electrical gadgets in indoor environments frequently results in superfluous energy usage during periods of vacancy, inadequate temperature control, and restricted security surveillance. Consequently, an automated and intelligent room control system is essential to efficiently resolve these challenges. This study delineates the design and execution of a microcontroller-driven Smart Room system that amalgamates motion, light, and temperature sensing for autonomous room management. The suggested system utilizes a PIR sensor to detect human presence for occupancy-based control and basic security monitoring through presence detection, an LDR sensor to assess ambient light conditions for automated lighting management, and a DHT22 sensor to evaluate room temperature for automatic fan operation. The ESP32 microcontroller serves as the primary controller for processing sensor input and executing control logic in real time. The system functions independently without ongoing user involvement, but a web-based interface facilitates real-time observation of sensor data and device status. Experimental testing was performed to assess system functionality, responsiveness, and reliability across several environmental circumstances. The findings indicate that the system effectively executes automated management of lighting, ventilation, and security functions utilizing real-time environmental data. Sensor detection and actuator responses remained reliable and consistent during the testing process. The Smart Room system offers a pragmatic IoT-based solution for augmenting energy efficiency, expanding indoor comfort, and bolstering room security via automated environmental regulation.

Keywords: Smart Room System, Internet of Things, ESP32, Energy Efficiency, Security Monitoring

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1. Introduction

Current technological developments have brought changes in various aspects of life, including in the management of room conditions. A room is an enclosed space used to carry out activities, requiring the regulation of conditions such as human movement, lighting, temperature, and humidity so that activities within it can take place comfortably and efficiently. The manual control of electronic devices in rooms has resulted in inefficient use of electrical energy, necessitating a system that can operate automatically [1]. According to research [2], the development of Internet of Things (IoT) technology has brought about significant changes in room automation systems, such as in homes or offices. This technology allows various electronic devices to be connected to each other and controlled automatically or manually via the internet, enabling electronic devices to connect to each other, collect data from various sensors, and perform automatic control to improve comfort, electrical energy efficiency, and room security [3]. IoT is a concept developed to support the automation process, and solutions that have emerged alongside technological developments have made daily activities easier.

Many homes experience energy waste due to the uncontrolled use of electronic devices, such as lights, fans, or other electronics that remain on even when the room is empty. This condition shows that manual control of electronic devices is still common, which can potentially cause electricity waste and high costs [4]. In addition, home security is a serious concern when the house is left unattended for a long time. The risk of intruders or theft causes anxiety for homeowners, requiring a reliable automatic detection mechanism [5]. Based on these conditions, a system is needed that not only automatically regulates electronic devices but is also capable of real-time remote control, namely a smart room system. Smart room systems are a form of IoT application in everyday life. This system is designed to provide comfort, energy efficiency, and ease in controlling electronic devices in a room. The smart room system functions as an electricity consumption regulator and as a monitoring tool in a room with the aim of saving electricity and ensuring room security [6].

Various studies have discussed the use of IoT for energy efficiency by integrating PIR, LDR, and DHT22 sensors as the basis for controlling room devices [7], [8]. This study discusses the design and development of a system for monitoring room temperature using an ESP8266 microcontroller and a DHT11 sensor. The system is connected to the Blynk application for data transmission [9]. Research conducted by [10] aimed to create a switch that could automatically turn lights on and off in a room without having to press a switch button. This device is equipped with an LDR sensor and a PIR sensor, both providing digital outputs, while monitoring is controlled by an Arduino Uno. The system uses a relay to control a 5V light output. This lighting automation system will send notifications to Android devices using a Telegram bot. Research conducted by [11] proves that the DHT22 and PIR sensors are capable of providing stable and real-time monitoring of temperature and humidity. In this smart home system, an Arduino microcontroller module is used, enabling it to connect to the internet via WLAN. Control of electronic devices and other electrical appliances is managed through a Smart Home application on Android. Control is applied to home lights, fans, TVs, and door locks. The Android application used is Basic for Android (B4A) as the Smart Home controller. Indicators of changes in lights, fans, TVs, and door locks in response to loads detected by current sensors were studied in [12]. This study fills that gap by combining PIR, LDR, DHT22, and buzzer sensors as simultaneous warnings to make homes efficient, comfortable, and safe.

Based on several previous studies, this system uses the ESP32 microcontroller as the system control center because it has Wi-Fi connectivity that allows the creation of a local web server. Through this web server, users can monitor sensor conditions and control devices manually or automatically from a browser on a laptop or smartphone. In addition, several sensors are used, such as a PIR sensor to detect movement. The PIR sensor and buzzer are useful when the user activates security mode. When security mode is on, the PIR sensor will detect human movement through infrared reflection and activate the buzzer as a security alarm. The LDR (Light Dependent Resistor) sensor is used to measure light. This sensor's performance is such that the lamp will turn on if the room is dark. The DHT22 sensor reads room temperature and humidity. This sensor activates the fan automatically when the temperature exceeds 30°C. Based on data from these sensors, the web controls actuators such as lights, fans, and buzzers according to the detected conditions. Users can easily switch the operating mode from automatic to manual while monitoring the status of the room's conditions in real-time.

2. Methodology

This research employs a systematic approach to design, implement, and evaluate an IoT-enabled Smart Room system. Figure 1 illustrates the overall research methodology.

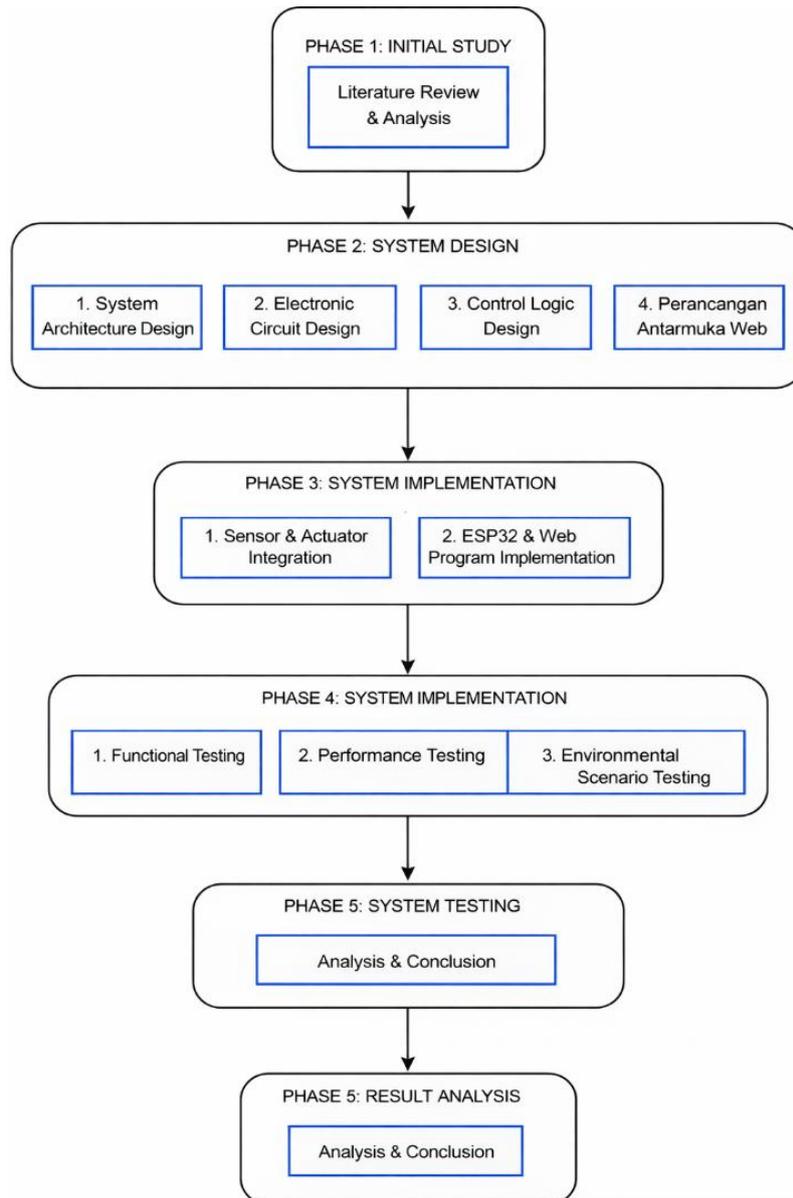


Figure 1. Methodology Design

2.1 Needs Analysis

A needs analysis was conducted to ensure that the Smart Room system functions in accordance with its development objectives, namely providing real-time monitoring of room conditions as well as manual and automatic device control through a web-based interface. This analysis also identified the hardware and software components required to support system operation.

Based on observations of small room environments, the system must be capable of responding in real time to variations in motion, ambient light, and temperature, as commonly implemented in microcontroller-based room automation systems [13]. A web-based dashboard is necessary for user interaction, with an ESP32 microcontroller functioning as the primary processor and Wi-Fi communication unit. A relay module regulates electrical loads, while constant data collecting from PIR, LDR, and DHT22 sensors is vital for ensuring precise and dependable automatic control. By fulfilling these criteria, the system is anticipated to be responsive, user-oriented, and proficient in enhancing energy efficiency within the monitored setting.

2.2 System Design

The system design phase is structured into three primary components: system architecture design, data flow design between sensors and actuators, and web interface design. The system architecture is designed in a layered structure to distinctly organize the interactions among sensors, the microcontroller, and actuators.

The first layer is the sensor layer, which includes a PIR sensor for motion detection, an LDR sensor for ambient light measurement, and a DHT22 sensor for temperature and humidity sensing. The second layer is the processing layer, where the ESP32 functions as the main controller that receives sensor data and controls the relay module to activate or deactivate devices such as lights, fans, and buzzers, in accordance with microcontroller-based room automation concepts commonly applied in recent studies. The final layer is the application layer, which provides a dashboard developed using HTML, CSS, and JavaScript. This dashboard can be accessed via a local Wi-Fi connection for real-time monitoring and manual device control.

All sensors periodically transmit their values to the ESP32, which then displays them in real time on the dashboard as information cards, including temperature, humidity, light (LDR), and motion (PIR). Each card features color indicators, such Normal, Bright, or Detected, to facilitate users' rapid interpretation of room circumstances. The ESP32 analyzes sensor data with conditional logic to execute suitable automatic actions, such as illuminating lights in low ambient light conditions or starting the fan as temperatures rise [14].

In addition, the ESP32 processes user commands from the dashboard control menu, allowing the system to switch between AUTO and Manual modes without interrupting the monitoring process. The web interface is engineered to be efficient, informative, and user-centric. The dashboard features a concise menu structure, encompassing system connection status, sensor data representation, and device controls like Security, Lamp, and Fan. The control buttons are color-coded with distinct ON/OFF indicators, facilitating straightforward device operation without the need for supplementary software. This interface design adheres to established UI/UX standards employed in IoT-based room automation platforms to guarantee user comfort and interaction simplicity [15].

2.3 Device Design

The device design stage begins with configuring the ESP32 module as the main control unit responsible for reading sensor data and controlling actuators. At this stage, the ESP32 is programmed to periodically acquire data from the PIR, LDR, and DHT22 sensors, then process the information to determine whether the lights, fan, or buzzer should be activated automatically.

In addition, the ESP32 hosts an HTTP-based web server that allows users to access the dashboard, monitor sensor data, and control devices via a Wi-Fi network, as implemented in various IoT-based automation systems [16]. The operational workflow of the ESP32-based Smart Room system is illustrated in Figure 2, which depicts the sequence of sensor data acquisition, decision-making processes, and actuator control.

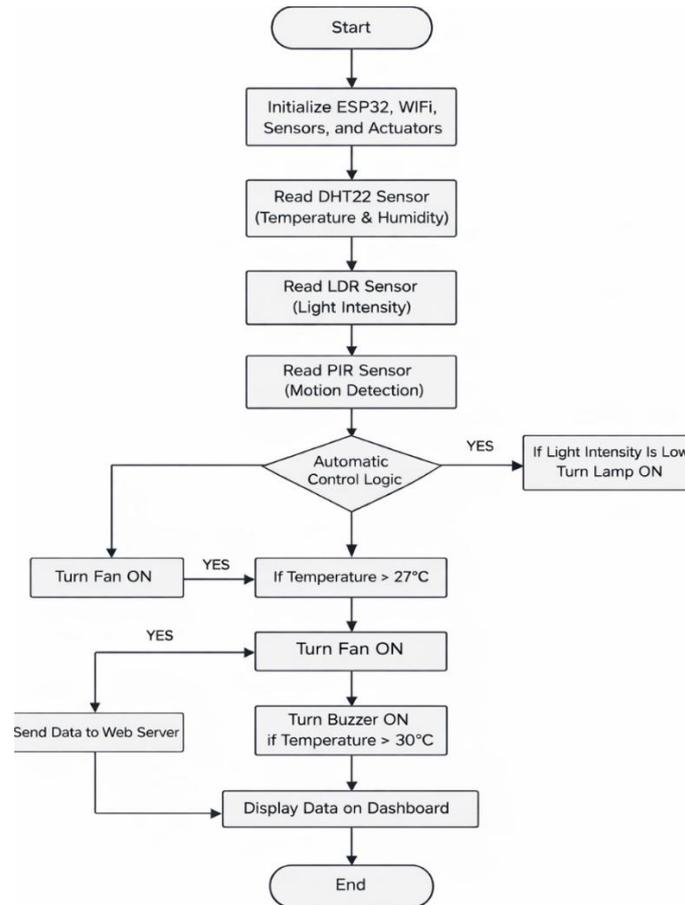


Figure 2. Flowchart of the ESP32-Based Smart Room System

The flowchart illustrates the operational workflow of an ESP32-based automation system designed to monitor and control environmental parameters, including temperature, humidity, light intensity, and human movement. The system is also capable of transmitting sensor data to a web server for real-time monitoring through a dashboard.

1. System Initialization

The process begins with initializing the ESP32, Wi-Fi connection, sensors (DHT22, LDR, and PIR), and actuators (fan, buzzer, and light), ensuring that all components are ready for operation.

2. DHT22 Sensor Reading (Temperature and Humidity)

The DHT22 sensor measures ambient temperature and humidity, which are used as references for controlling the fan and buzzer.

3. LDR Sensor Reading (Light Intensity)

The LDR sensor detects ambient light conditions to determine whether the environment is bright or dark.

4. PIR Sensor Reading (Motion Detection)

The PIR sensor detects human movement, which is used to trigger system actions and initiate data transmission.

5. Automatic Control Logic

Sensor data are processed to generate automatic control decisions. If ambient light levels are low, the lighting system is activated. When the temperature exceeds the predefined threshold, the cooling fan is turned on, and a buzzer is activated when the temperature reaches a critical level as a warning.

6. Data Transmission to the Web Server
Sensor data are periodically transmitted to the web server via a Wi-Fi connection, enabling real-time monitoring.
7. Dashboard Display
The transmitted data are displayed on the dashboard, including temperature, humidity, light intensity, and device status.
8. Continuous Operation
After completing one cycle, the system returns to the sensor reading stage and continues operating in a continuous loop.

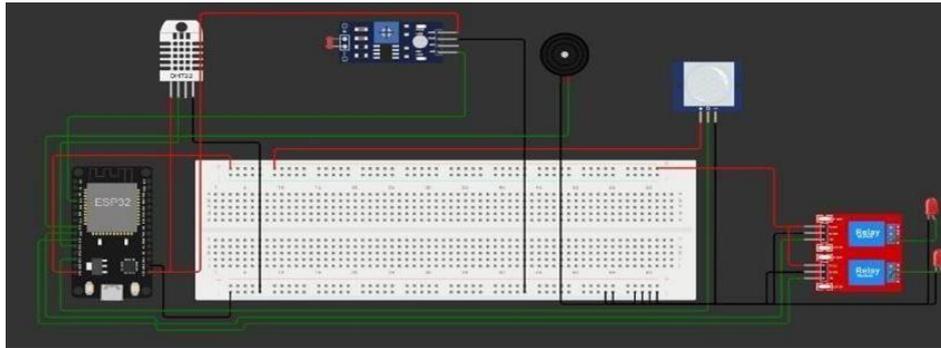


Figure 3. Electronic Circuit of the ESP32-Based Smart Room System

The Figure 3 illustrates the electronic circuit of the Smart Room system, employing an ESP32 as the central control unit. The DHT22 sensor quantifies temperature and humidity, the LDR sensor assesses ambient light intensity, and the PIR sensor detects human movement. The ESP32 processes sensor data and presents it on the dashboard in real time.

The system includes a relay module for the automatic regulation of lighting and cooling devices in response to sensor inputs, along with a buzzer for aural notifications. All components are coupled via a breadboard and powered by the ESP32, creating a responsive and efficient environmental monitoring system for the room.

2.4 System Testing

System testing was conducted to evaluate the performance, stability, and usability of the developed web-based Smart Room system. The testing process was divided into three main categories: functional testing, reliability testing, and usability testing, as commonly recommended for evaluating IoT-based automation systems [17].

1. Functional Testing

Functional testing was performed to verify that all essential system functionalities operated as expected. This evaluation encompassed:

- a. the manual control capabilities of the web dashboard for lights, fans, and buzzers;
- b. real-time data collection from PIR, LDR, and DHT22 sensors;
- c. the accuracy of sensor data presented on the web interface; and
- d. the responsiveness of devices to automated control logic triggered by environmental factors.

Black-box testing was applied to evaluate functional compliance without examining the internal program structure.

2. Reliability Testing

Reliability testing was conducted to assess system consistency during uninterrupted operation. Several parameters were evaluated, including:

- a. the stability of the Wi-Fi connection between the ESP32 and the web dashboard during extended usage;
- b. continuous sensor data acquisition without interruption; and
- c. actuator responsiveness to repeated changes in environmental conditions.

The results confirmed that the system could operate reliably in typical room monitoring scenarios.

3. Usability Testing

Usability testing was carried out to assess how easily users could understand and operate the web dashboard. The evaluation focused on navigation clarity, display readability, and interaction comfort, following usability assessment practices commonly applied in IoT-based room automation research.

2.5 Energy Savings Evaluation

System performance was further evaluated by observing the consistency of device responses to sensor data. During testing, the PIR, LDR, and DHT22 sensors provided stable and continuous information on room conditions, which was displayed on the web dashboard with minimal delay. Actuators, including lights, fans, and buzzers, responded to both automatic and manual commands with an average latency of approximately 1–3 seconds, consistent with the ESP32 sensor reading interval. This indicates that communication between the sensors, microcontroller, and web interface operated efficiently.

Observations showed that electrical devices functioned more efficiently compared to manual control. Lighting was activated only under low ambient light conditions, the fan operated when the temperature increased, and the buzzer was triggered exclusively upon motion detection in security mode. Although no quantitative measurements of electricity consumption were conducted, this condition-based operation helps prevent devices from operating continuously. Therefore, the developed Smart Room system demonstrates functional improvements in energy efficiency through sensor-based automatic control.

3. Results and Discussion

3.1 System Design Results

The Smart Room system that has been developed was successfully designed by combining several main components, namely temperature and humidity sensors, light sensors, motion sensors, fans, lights, buzzers, and an ESP32 microcontroller as the control center. All of these components are assembled into a single system that can be monitored and controlled via a web page. The web page displays real-time room conditions, such as temperature, humidity, light levels, and movement. The data is presented with distinct symbols, facilitating user comprehension of room conditions at a glance.

In addition to monitoring, the web page also provides device settings through two modes, namely manual and automatic. In manual mode, users can turn lights and fans on or off directly via buttons on the web page. Meanwhile, in automatic mode, the device operates according to the environmental conditions detected by the sensors, such as turning on the lights when it is dark or turning on the fan when the temperature rises. All changes that occur to the device or sensors are recorded automatically, allowing users to view the system's activity history. The operational features of the Smart Room system, including device status visualization and automatic control logic, are presented in the web-based dashboard shown in Figures 4 and 5.



Figure 4. Device status display and mode setting

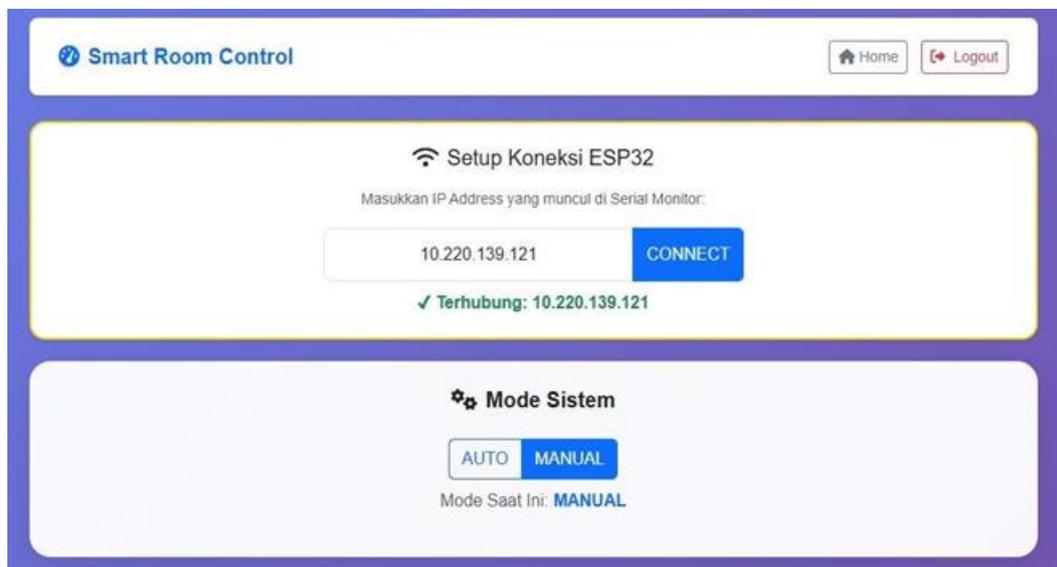


Figure 5. Automatic logic display and activity logging

3.2 Functional and Performance Test Results

Functional testing was performed to verify that all functionalities of the Smart Room system operated as intended. Testing encompassed sensor functionality, manual device configurations, automatic adjustments according to environmental conditions, and activity documentation on the web interface. The test results demonstrate that all fundamental system functions functioned well and reacted as expected. The temperature, humidity, illumination, and motion measurements remained consistent during the testing procedure.

In automatic mode, the system is able to activate devices according to the conditions detected by the sensors. Lights turn on when the room is dark, fans run when the temperature rises, and buzzers sound when motion sensors detect activity. From several tests, most of the automatic responses worked correctly. Minor errors that occurred were usually due to rapid changes in light or unstable room conditions, but did not interfere with the main use of the system. The functional testing results of the Smart Room system are summarized in Table 1, which presents the evaluation of both manual and automatic system operations, including sensor readings, device control, and activity logging.

Table 1. System Functional Testing

No	Features tested	Test Scenario	Results	Status
1	Manual Light Control	Turning lights on and off via a web page	Quick response	Successful
2	Manual Fan Control	Turning fans on and off via a web page	Quick response	Successful
3	Sensor Readings Temperature & Humidity	Comparing results with other measuring devices	Accurate and stable	Successful
4	Light Sensor Readings	Light/dark detection	Suitable for room conditions	Successful
5	Motion Sensor Readings	Human activity detection	Well detected	Successful
6	Sensor Readings Light Auto Mode	Lights turn on when it is dark	Successful	Successful
7	Fan Auto Mode	Fan turns on when the temperature rises	Successful	Successful
8	Buzzer Auto Mode	Buzzer activates when there is movement	Successful	Successful
9	Activity Logging	Log records changes in device status	Correctly recorded	Successful
10	Dashboard Access	Opening the web page via WIFI	Stable and responsive	Successful

Performance testing was conducted to determine how quickly the device responds to commands, the extent to which sensor data is updated accurately, and how robust the system is when used over a certain period of time. The results show that the device responds to commands quickly enough that users can feel the changes in status immediately. Sensor data is also updated continuously without any significant delays, indicating that communication between the device and the web page is running smoothly.

In durability testing, the system was left to operate for a sufficiently long period of time. During the testing process, the device continued to run normally without any interruptions. The connection between the web page and the device remained stable, with no network disconnections. These conditions prove that the system design is robust and ready to be used to monitor room conditions. Table 2 presents the results of performance testing, highlighting system response times, data update rates, and overall stability during continuous operation.

Table 2. System Performance Testing

No	Parameters	Results	Description
1	Light Command Response Time	± 200–300 ms	Fast response
2	Fan Command Response Time	± 200–300 ms	Fast response
3	Sensor Data Update Time	< 500 ms	Real-time
4	Web Dashboard Stability	Stable for 24 hours	No interruptions
5	ESP32 Process Load	Low	Safe to use
6	Memory Usage	Fairly low	Does not burden the device

3.3 Energy Saving Evaluation

An energy-saving assessment was performed to evaluate the efficacy of the Smart Room system in minimizing electricity use through automatic adjustments based on sensor data and device usage duration. Testing was performed with devices integrated into the system, specifically one LED bulb and one tiny fan, which function via ESP32 in both manual and

automatic modes. Measurements were taken under two conditions: before the automatic system was used and after the system was activated.

1. Initial conditions

In the initial conditions, the lights and fan were controlled entirely by the user manually. As a result, the devices were often left on even when the room was not in use. From observation, the lights can remain on for 30-60 minutes after no one is around. This happens because users forget to turn off the devices or are unaware that they are still on. Based on measurements, this condition causes electricity waste, especially when the room is dark or when the temperature is hot but there is no activity around.

2. Condition with the Smart Room system

Once automatic mode is activated, the lights only turn on when the room is dark based on the light sensor, while the fan only turns on when the temperature exceeds a certain limit. The motion sensor additionally guarantees that the device remains inactive in the absence of action. This approach enables the device to activate more efficiently, eliminating instances of unintended activation by the user. Observations over several days indicated a substantial reduction in energy consumption relative to the initial conditions.

The comparison between device operating duration before and after the implementation of the Smart Room automation is presented in Table 3.

Table 3. Smart Room System Energy Consumption Testing

No	Parameters	Before Automation	After Automation	Change
1	Lighting time per day	± 6 hours	± 3-4 hours	Decrease by 35-40%
2	Fan operating time per day	± 5 hours	± 2-3 hours	Decrease by 40-50%
3	Device turns on without user	30-60 minute	0 minute	Eliminated by 100%
4	System activity automatic	-	± 95% as per conditions	Effective
5	Estimated energy savings	-	30-40%	Efficient

The results indicate that the Smart Room system can markedly decrease energy use. This is due to the devices' independence from manual operation. Illumination activates just in the absence of light, and fans function exclusively when temperatures increase, thereby enhancing energy efficiency. This modification is additionally facilitated by motion sensors that guarantee the devices remain inactive in the absence of activity. The automatic mode design in the Smart Room system enhances energy efficiency and minimizes electricity waste during routine usage.

3.4 Discussion

The result of the design and testing shows that the ESP32-based Smart Room system successfully performs its monitoring and device control functions. The temperature, humidity, light, and motion sensors work stably, and all data can be viewed directly on the web page. The device settings work as they should in both manual and automatic modes. The lights, fans, and buzzers all respond quickly to changes in the room.

Using the web interface makes it easy for users to control devices without having to directly touch the equipment. Automatic mode has proven to be effective in regulating devices based on environmental conditions, thereby reducing the use of unnecessary devices. The system also records every change in device conditions, allowing users to monitor activities that occur. However, the system still has some shortcomings, such as the light sensor only being able to detect light or dark conditions, as well as its dependence on a local WiFi network. Nevertheless, overall, the Smart Room system that was created has been running well and shows that the approach of room automation can be effectively applied on a small scale.

4. Conclusion

Based on the results of the design and testing that has been carried out, the Smart Room system that was created works according to its main objective, which is to automatically regulate room conditions based on light, temperature, and movement. The PIR, LDR, and DHT22 sensors are able to provide stable room condition data, and all information is displayed directly on the web page. Device settings such as lights, fans, and buzzers can be adjusted in manual or automatic mode and respond quickly. The automatic mode has proven to work well because the devices only operate when necessary. The lights turn on when the room is dark, the fan activates when the temperature rises, and the buzzer sounds when there is movement while security mode is enabled. This operation prevents the devices from running continuously, resulting in more efficient energy usage. Observations show that the operating time of lights and fans has decreased significantly, and no devices remain on without user intervention. Overall, the ESP32-based Smart Room system demonstrates good performance, is easy to use via the web page, and enhances the efficiency of electrical device usage in the room. This system also has potential for further development by adding sensor types or features that support greater energy savings.

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