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# A remote-controlled IoT solution for environmental automation in broiler poultry housing: Enhancing welfare under unstable power conditions

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## ABSTRACT

**Background:** Broiler chickens are highly sensitive to temperature changes due to their inability to sweat, making them vulnerable to heat stress and respiratory illnesses. Manual monitoring methods are inadequate in maintaining optimal environmental conditions, especially in regions with unstable power supply. This study addresses the need for an autonomous system to regulate temperature and lighting in poultry housing. **Methods:** An IoT-based solution was developed using Arduino Uno and NodeMCU ESP8266 microcontrollers, coupled with a DHT11 temperature and humidity sensor. The system employed incandescent lamps for heating and axial fans for cooling, activated based on temperature thresholds. Real-time data were displayed on an LCD and transmitted to the Blynk mobile application for remote access. A 12V battery and inverter ensured continuous operation during power outages. **Findings:** The system maintained stable temperature conditions between 31°C and 34°C. When the temperature dropped below 31°C, the lamp activated; when it rose above 34°C, the fan turned on. Data were reliably recorded and displayed over a 24-hour period. All hardware components functioned effectively, and system performance was consistent even during transitions to backup power. **Conclusion:** This research confirms the effectiveness of a low-cost IoT-based system for automated environmental control in broiler poultry housing. The system provides a reliable, remote-controlled solution that improves animal welfare, minimizes manual labor, and ensures operational resilience in power-limited settings. **Novelty:** The proposed system combines real-time environmental monitoring, remote access, and automated actuation with a backup power feature in a compact and affordable design. It is specifically tailored for small-scale poultry operations in developing regions, filling a critical gap in accessible precision farming tools.

**KEYWORDS**: IoT systems; broiler poultry; temperature monitoring; lighting automation; Arduino NodeMCU.

## 1. Introduction

Broiler chicken farming is one of the most important sectors in the livestock industry, serving as a major source of protein for human consumption. Due to their rapid growth and high feed conversion efficiency, broiler chickens are favored by commercial and small-scale poultry farmers alike. However, maintaining the health and productivity of broilers requires careful regulation of their environmental conditions, particularly temperature and lighting. Broiler chickens are homeothermic animals that do not have sweat glands,

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making them highly susceptible to heat stress. Inappropriate environmental conditions can lead to reduced feed intake, increased water consumption, respiratory illness, and, in extreme cases, high mortality rates, thereby reducing overall farm profitability and food supply reliability (Godinho et al., 2025; Puspa et al., 2018).

In many tropical and subtropical regions, where temperature fluctuations are significant and climate control infrastructure is often lacking, broiler chickens are frequently exposed to environmental extremes. Manual monitoring and control of temperature and lighting, still common in small and medium-sized poultry operations, are often inefficient and subject to human error. These limitations hinder the ability of farmers to maintain stable and optimal conditions inside the broiler housing. Furthermore, abrupt weather changes during the day or night can go unnoticed without continuous monitoring, resulting in suboptimal living conditions that negatively impact animal welfare and farm yields. Addressing these challenges calls for a more efficient, consistent, and automated approach to environmental regulation in poultry farming (Kpomasse et al., 2021).

In response to this need, technological innovations—particularly those based on the Internet of Things (IoT)—have emerged as promising solutions. IoT systems allow for real-time monitoring and automated control of environmental parameters through interconnected sensors and actuators controlled by microcontrollers. These systems can collect data on temperature, humidity, and light intensity, transmit it wirelessly, and activate mechanisms such as fans or lighting units based on predefined thresholds. As shown in recent studies (Mumbelli et al., 2020; A. Vijay et al., 2023), IoT technology can significantly improve operational efficiency and reduce labor dependency in poultry farming. Moreover, IoT-based systems allow farmers to monitor environmental conditions remotely, offering convenience and rapid response to adverse changes.

While industrial-scale poultry farms may already employ advanced climate control systems, small-scale farmers in developing countries often lack access to such technologies due to their high cost, complexity, and energy requirements. Consequently, there is a growing need for affordable, easy-to-deploy, and reliable IoT-based solutions that can assist farmers in maintaining optimal poultry house conditions. Recent research indicates that using low-cost microcontrollers such as ESP8266 NodeMCU or Arduino Uno, in combination with basic sensors and open-source platforms, provides a viable path toward accessible automation in agriculture (Chigwada et al., 2022; Orakwue et al., 2022). This study responds to this challenge by developing and testing a cost-effective IoT solution designed specifically for broiler poultry housing, with the goal of enhancing productivity, improving animal welfare, and supporting sustainable farming practices in resource-constrained environments. Manual temperature regulation and lighting control in broiler poultry housing remain prevalent among small-scale farmers, particularly in developing regions (Sumiati et al., 2025). These manual practices are inefficient and error-prone, often resulting in environmental instability within the brooding space. Such inconsistencies can trigger stress responses in broiler chickens, decreasing feed efficiency, increasing susceptibility to disease, and in severe cases, leading to mortality. Moreover, power outages in rural regions further compromise the ability to maintain a controlled environment, undermining both animal health and farm profitability.

To address these critical challenges, a general solution is proposed in the form of a low-cost, IoT-based system that automates the monitoring and control of temperature and lighting conditions (Li et al., 2024). The system uses microcontrollers, sensors, and actuators connected through wireless networks to provide real-time, automated responses based on environmental conditions. This configuration allows for consistent thermal regulation and remote management, significantly reducing the need for constant manual intervention. The integration of a backup power system further ensures system reliability in regions prone to electrical outages (Xu et al., 2022).

Recent scientific literature supports the feasibility and effectiveness of IoT-based environmental control systems in agriculture. Vijay et al. (2023) developed a low-cost poultry monitoring system using NodeMCU microcontrollers and DHT11 sensors, capable of regulating light and temperature through automated feedback loops. Their results showed improved environmental consistency and reduced operational costs for small-scale farmers. Similarly, Mumbelli et al. (2020) designed a Raspberry Pi-based system that successfully monitored temperature and humidity, triggering actuators in real time. These solutions emphasize the importance of local data processing and affordable components in creating scalable, accessible technologies for agricultural use.

Chigwada et al. (2022) expanded the IoT-based poultry management framework by integrating advanced features such as air quality monitoring, remote alerts, and mobile application access. Their work highlighted the benefits of remote data visualization and control, allowing farmers to respond to environmental changes without being physically present. Another research similarly demonstrated how wireless systems could improve animal health outcomes and reduce labor costs (Orakwue et al., 2022). However, while these studies provided a strong foundation for IoT-based farming tools, many lacked a cost-effective and resilient design tailored for areas with frequent power disruptions and limited technical infrastructure.

Various studies have explored the use of IoT technologies for environmental monitoring and control in poultry farming, with significant progress in sensor integration, real-time data visualization, and automated actuation (Sitaram et al., 2018; Bagyam et al., 2024). For instance, Vijayaraja et al. (2023) and Pereira et.al. (2020) introduced an IoT-based system using NodeMCU and DHT11 sensors for temperature and humidity regulation. The system demonstrated that automation can help maintain environmental stability and reduce manual oversight (Vijayaraja et al., 2023; Pereira et al., 2020). However, their study acknowledged that the system lacked real-time remote access capabilities, and data storage features were not adequately addressed. This limitation reduces the system's long-term utility, particularly for farms requiring historical data analysis or continuous off-site monitoring.

Similarly, Mumbelli et al. (2020) designed a Raspberry Pi-based control system for poultry environments that integrated multiple sensors and actuators for regulating temperature and humidity. While functionally advanced, the system demanded considerable technical expertise for assembly and maintenance, limiting its applicability in rural communities where digital literacy and access to technical support may be limited. Their findings highlighted the need for simplified designs that still retain critical environmental management features but are easier to install and operate, especially by users without engineering backgrounds. These constraints pointed to the necessity for systems that balance technological functionality with accessibility.

Other studies focused on incorporating mobile and web-based interfaces to enable farmers to control and monitor poultry environments remotely (Chigwada et al., 2022). Their system included features like security alerts, air quality sensors, and remote toggling of equipment. Although these innovations improve user control and system versatility, they typically come with higher costs and energy demands, making them less suitable for smallholder farmers in developing countries. Furthermore, the reliance on stable internet connectivity, which is often unavailable in remote areas, limits the practicality of such advanced IoT solutions.

Collectively, these works underscore an important research gap: the lack of an IoT-based poultry monitoring system that is not only technically sound but also financially feasible, user-friendly, and operationally resilient in rural, low-resource settings. Most existing models prioritize technological sophistication at the expense of ease of deployment and economic sustainability. There remains a strong demand for systems that can reliably automate temperature and lighting control, are affordable for small-scale farmers, require minimal technical expertise, and can function effectively even during power and connectivity interruptions. This study addresses this gap by proposing and validating a system specifically designed with these contextual limitations and user needs in mind.

The objective of this study is to design and implement an IoT-based system for broiler poultry housing that autonomously monitors temperature and controls lighting based on real-time environmental data. The system aims to maintain optimal temperature conditions between 31°C and 34°C, with integrated monitoring of humidity levels, and ensure 24-hour operational continuity through the inclusion of a battery-powered backup. By connecting sensors and actuators to Arduino Uno and NodeMCU ESP8266 microcontrollers, the system provides real-time data visualization through both an LCD display and the Blynk mobile application. This configuration is intended to improve poultry welfare, reduce manual labor, and enhance productivity in small-scale farming environments.

The novelty of this research lies in its convergence of affordability, simplicity, and resilience in system design. Unlike existing solutions that require advanced technical knowledge or expensive hardware, this system is optimized for cost-effective deployment using commonly available components and open-source platforms. Furthermore, the integration of a backup power supply addresses a critical operational vulnerability in regions with unreliable electricity. The study is justified by the hypothesis that broiler chickens, due to their biological inability to regulate internal heat, require a stable microclimate to avoid health deterioration. The proposed system is scoped specifically for small and medium-sized farms in developing countries where cost, ease of use, and reliability are paramount.

## 2. Methods

The prototype for the IoT-based temperature monitoring and lighting control system in poultry housing utilized both hardware and software components. The hardware comprised Arduino Uno and NodeMCU ESP8266 microcontrollers, a DHT11 temperature and humidity sensor, RTC DS3231 real-time clock module, IRF9540N P-Channel MOSFET, NPN 2N2222 transistor, and a light dimmer for intensity control. Display was managed using an LCD 16x2 I2C module. Actuators included a 25W incandescent bulb for heating and two axial fans for cooling. Power supply was maintained through a 12V 4A adapter, supplemented with a 12V lead-acid battery connected via an XH-M603 charge controller and a DC-to-AC inverter. Additional components included a relay (8-pin AC), resistors, jumper cables, and a safety switch with a fuse. The system also required mechanical materials such as plywood, metal frame, acrylic sheets, and standard carpentry tools. On the software side, the system was developed using the Arduino IDE for coding and uploading control logic to the microcontrollers. The Blynk application was employed to enable wireless remote monitoring and control via smartphone. Data communication between hardware and Blynk was facilitated through Wi-Fi provided by the NodeMCU ESP8266 module.

### *2.1 Microcontrollers*

#### *2.1.1 Arduino UNO*

The Arduino UNO, shown in Fig. 1(a), is a microcontroller board based on the ATmega328 chip. It features 14 digital input/output pins, six of which support Pulse Width Modulation (PWM), and six analog input pins. The board also includes a 16 MHz crystal oscillator, a USB port, a power jack, an ICSP (In-Circuit Serial Programming) header, and a reset button (Saini et al., 2024; Rehiara & Rumengan, 2021; Rikwan & Ma'arif, 2023; Modi et al., 2024). These components make it suitable for a wide range of electronics and automation projects.

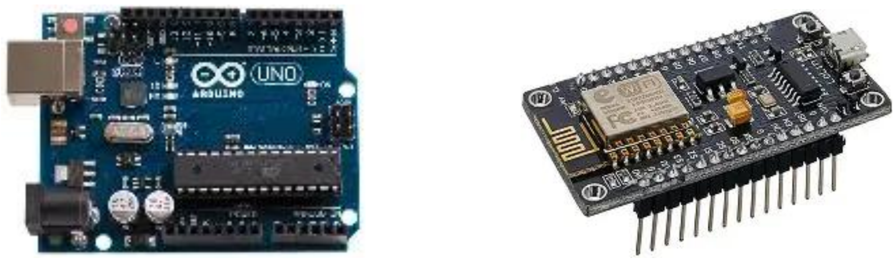
Power can be supplied to the Arduino UNO through a USB connection to a computer or using an external power source such as a DC adapter or battery. This flexibility allows it to operate both as a portable device and in a fixed installation. The board automatically selects the appropriate power source when both are connected.

Communication is another key feature of the Arduino UNO. It can communicate with a computer, another Arduino, or other microcontrollers via serial communication. The

ATmega328 chip supports UART TTL serial communication on digital pins 0 (RX) and 1 (TX). Additionally, the board has memory consisting of 32 KB of flash (including 2 KB for the bootloader), 2 KB of SRAM, and 1 KB of EEPROM for data storage and program execution.

*2.1.2 NodeMCU ESP8266*

NodeMCU is a development board that integrates the ESP8266 Wi-Fi module with microcontroller capabilities, offering an all-in-one solution for IoT (Internet of Things) applications. The module is given in Fig. 1 (b) and the board is built around the ESP-12E module and includes a USB-to-serial converter, allowing users to program the board directly using a standard USB cable. NodeMCU can be programmed using the Arduino IDE, Lua scripting language, or other development environments (Ayeni & Adesoba, 2025; Muthekar et al., 2024; Jalil et al., 2021; Saini et al., 2024).



(a) (b)

Fig. 1 (a) Arduino UNO; (b) NodeMCU

The primary advantage of NodeMCU is its built-in Wi-Fi capability, which enables direct wireless communication and cloud integration. It supports common protocols such as HTTP, MQTT, and WebSocket, making it suitable for smart home devices, data logging, and remote monitoring systems. Its compact size, low cost, and ease of use have made it one of the most popular boards for hobbyists and professionals working with wireless microcontroller applications.

*2.2 Sensor and timer*

*2.2.1 DHT11 Sensors*

The DHT11 is a digital temperature and humidity sensor that provides calibrated data output, making it a simple and cost-effective solution for environmental monitoring. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and outputs the data through a digital signal pin. The sensor is known for its good stability and quick response time, making it suitable for both indoor and outdoor applications. Fig. 2 (a) shown the physical system of the DHT11 Sensors (Satria et al., 2025; Oliveira et al., 2025; Rehiara et al., 2023; Gomathi & Renuka Devi, 2024).

One of the notable features of the DHT11 is its internal calibration system, with coefficients stored in its OTP (One-Time Programmable) memory. This ensures accurate readings directly from the sensor without the need for complex calibration circuits. Due to its affordability and ease of use, the DHT11 is widely used in hobbyist projects, weather stations, and home automation systems.

*2.2.2 RTC DS3231*

The DS3231 Real-Time Clock (RTC) module is a low-cost, highly accurate timekeeping device that includes an integrated temperature-compensated crystal oscillator. It is capable of keeping track of seconds, minutes, hours, days, dates, months, and years—even when the main power supply is disconnected—thanks to its onboard battery backup. This module communicates via the $I^2C$ interface, making it easy to integrate into microcontroller-based systems, where given in Fig. 2 (b) (Hasibuan et al., 2024; M. Dochev et al., 2024; Mujmule et al., 2024; Reshma & Rajmohan, 2025).

(a) (b)

Fig. 2 (a) DHT11; (b) RTC DS3231

One of the standout features of the DS3231 is its built-in temperature sensor, which adjusts the timekeeping oscillator to maintain high accuracy regardless of environmental changes. This makes it especially suitable for applications requiring reliable and consistent timekeeping, such as data logging, clocks, alarms, and scheduling tasks in embedded systems. Its stability and precision outperform typical RTC modules that rely on external crystal oscillators.

### *2.3 Supporting components*

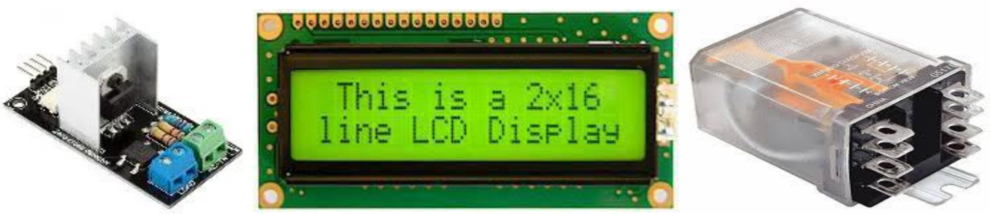
#### *2.3.1 AC light dimmer and LCD 12C*

The AC light dimmer module is designed to regulate the brightness of AC-powered lamps and control the power delivered to AC appliances. It operates using a triac component and a zero-crossing detector, which allows for precise phase-angle control. This means the microcontroller can adjust the exact point in the AC cycle when the triac is triggered, effectively modifying the average power output. The physical system of the dimmer is shown in Fig. 3 (a). This dimmer module can be controlled using Arduino or other microcontrollers and is ideal for smart lighting, fan speed control, and similar AC-based automation tasks. The built-in safety mechanisms and compact design make it easy to integrate into a variety of DIY or industrial applications. Its phase-control capability ensures energy-efficient operation and offers finer control over connected loads.

The 16x2 LCD (Liquid Crystal Display) with an I2C interface is a compact display module capable of showing 2 lines with 16 characters each, as given in Fig. 3(b) . It is commonly used to display text, symbols, and basic graphics in embedded systems. The I2C interface significantly reduces the number of data lines needed to communicate with the LCD, simplifying the wiring and leaving more pins available on the microcontroller for other uses. Due to its clarity, low power consumption, and ease of integration, the LCD 16x2 is widely used in projects requiring user feedback or status display, such as digital thermometers, clocks, and control panels. Adjustable contrast and backlight options allow customization to different lighting conditions. Its compatibility with Arduino libraries further streamlines development and implementation in both educational and commercial projects.

#### *2.3.3. AC relay*

An 8-pin AC relay is an electromechanical switch used to control high-voltage devices using a low-voltage signal. It operates through an internal electromagnetic coil that, when energized, causes the internal contacts to either open or close, as shown in Fig. 3 (c). This allows safe and isolated switching of AC loads like fans, lamps, or other appliances.




(a) (b) (c)

Fig. 3 (a) AC Light Dimmer; (b) LCD 12C; (c) AC Relay

Each pin in the relay has a distinct function: pins 1 and 2 typically form the normally closed (NC) contacts, pins 3 and 4 are the normally open (NO) outputs, pins 5 and 6 receive the control voltage (coil terminals), and pins 7 and 8 function as the common (COM) connections. This configuration enables flexible switching logic and integration with microcontroller-controlled systems. Relays are commonly used in automation systems, protection circuits, and smart home applications for their robustness and electrical isolation.

*2.4 Experiments, analytical, and statistical methods*

The experiment was conducted in a controlled poultry environment located in Manokwari, Papua, starting from September 2023. Data collection focused on temperature and humidity levels inside the poultry housing across different time periods—morning, afternoon, evening, and dawn—within a 24-hour cycle. The DHT11 sensor provided real-time temperature and humidity readings, which were recorded locally and transmitted to the Blynk platform. The system behavior was observed under varying conditions: when the temperature dropped below 31°C, the incandescent bulb was activated to warm the enclosure; when the temperature exceeded 34°C, the fans were triggered to dissipate heat. In case of power outages, the system seamlessly switched to battery power to maintain operation. Performance metrics such as voltage, current, and power consumption were measured using a digital wattmeter to validate energy efficiency and system responsiveness.

The collected environmental data (temperature, humidity) and system performance metrics (voltage, current, power) were analyzed through descriptive statistical methods. Measurements were tabulated and evaluated hourly to determine the system's effectiveness in maintaining optimal conditions. Specific thresholds were established based on the comfort zone for broiler chickens (31°C–34°C with 50–70% humidity), and each system reaction—either activation of the lamp or the fan—was recorded in correspondence to sensor readings. Cos φ (power factor) was calculated to assess electrical efficiency. The results were cross-referenced with target parameters to evaluate accuracy and reliability. This analytical approach validated the system’s performance against its intended functional objectives. The power factor is calculated based on power formulation as follows (Rachmanto et al., 2023). Where $P$ is the active power (watt), $V$ is the voltage (Volt), and $I$ is current flow (Ampere).

$$P = VI \cos\varphi \quad \text{(Eq. 1)}$$

## 3. Results and Discussion

*3.1 Overview of system implementation*

The IoT-based poultry environmental control system was designed and implemented to maintain the temperature and lighting conditions of a broiler chicken cage. The system architecture integrated two microcontrollers—Arduino Uno and NodeMCU ESP8266—working in tandem to process environmental inputs and trigger corresponding outputs. A

DHT11 sensor was used for detecting temperature and humidity levels inside the cage. The hardware components were arranged within a custom-built poultry cage constructed using a metal frame, plywood walls, and an acrylic viewing panel. The placement of sensors, actuators, display units, and controllers was optimized for performance and accessibility. System components and wiring diagram of this system are given in Fig. 4.

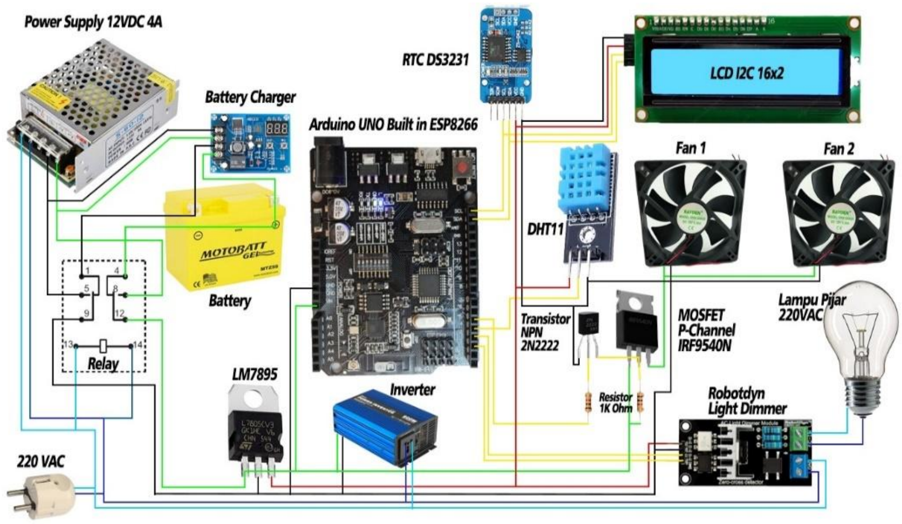



Fig. 4 Wiring diagram

The environmental control system was tested at a poultry site in Manokwari, Papua, with preliminary trials conducted in a laboratory setting. Data from the DHT11 sensor were continuously relayed to the Arduino Uno, which controlled the actuators based on programmed temperature thresholds. NodeMCU ESP8266 managed wireless communication, enabling real-time data visualization via the Blynk mobile application. A 12V battery and inverter setup was incorporated to ensure uninterrupted system operation during power outages, a frequent challenge in the region. The implementation demonstrated a successful combination of low-cost hardware and reliable remote monitoring capabilities.

### *3.2 Functional testing of components*

Each component of the system underwent a series of functional tests to ensure its reliability and compatibility within the integrated framework. The Arduino Uno successfully processed sensor inputs and executed control commands to the lamp and fan based on temperature thresholds. The NodeMCU ESP8266 established a stable Wi-Fi connection and transmitted data seamlessly to the Blynk application.

The LCD module correctly displayed temperature and humidity readings in real time, and the relay system accurately toggled the power supply to actuators based on control signals. Further tests were performed on the battery backup system. In the event of a simulated power failure, the inverter promptly switched power from the grid to the 12V battery without system interruption. The light dimmer, powered through a relay and MOSFET configuration, responded accurately to control commands, providing consistent lighting adjustments. All electronic components met operational expectations, validating the system's design for both controlled and unpredictable environmental conditions.

### *3.3 Temperature and humidity monitoring results*

Environmental monitoring was conducted over a continuous 24-hour period, with data collected hourly to assess system responsiveness and sensor accuracy. The DHT11 sensor consistently measured temperature and humidity values within a stable range. During nighttime, recorded temperatures ranged from 30.7°C to 31.6°C, while humidity levels remained between 72% and 81%. These values were cross-validated with readings from a manual thermometer to ensure accuracy, and discrepancies remained within an acceptable margin of ±0.5°C, where shown in Table 1.

Table 1. Temperature and humidity data

| Jam | DHT11 temperature (°C) | Thermometer temperature (°C) | Humidity (%) | Lamp condition | Fan condition |
|---|---|---|---|---|---|
| 19.00 | 31.60 | 32 | 72.60 | OFF | OFF |
| 20.00 | 31.00 | 31 | 76.50 | OFF | OFF |
| 21.00 | 30.90 | 31 | 81.00 | ON | OFF |
| 22.00 | 30.70 | 31 | 78.60 | ON | OFF |
| 23.00 | 31.40 | 31 | 77.40 | OFF | OFF |
| 24.00 | 31.20 | 31 | 78.60 | OFF | OFF |

Daytime monitoring revealed a gradual increase in temperature, with the highest readings occurring in the afternoon when the external temperature peaked. The sensor accurately detected these variations, allowing the system to maintain optimal cage conditions. Data trends were consistent and displayed in real time on the LCD and remotely via the Blynk application. The accuracy and consistency of environmental data confirmed the DHT11 sensor's suitability for practical poultry housing applications.

### *3.4 Actuation behavior and environmental regulation*

The automated control system demonstrated effective environmental regulation through actuator response to temperature thresholds. When sensor readings fell below 31°C, the incandescent lamp was activated, providing necessary warmth for the broiler chicks. Conversely, when temperatures exceeded 34°C, the fan system was triggered to dissipate excess heat. These control actions were initiated promptly and maintained stable environmental conditions within the brooding cage. Fig. 5 shows the blynk portal in action.

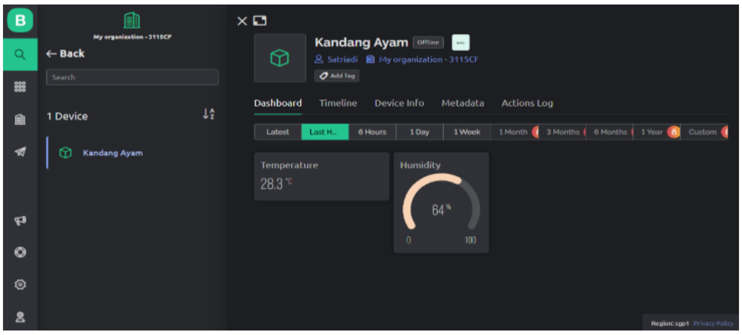


Fig. 5 Blynk portal

All actuation responses were logged and confirmed through observations and data captured in the Blynk interface. The lamp and fan each operated as intended, without delays or malfunctions. The integration of actuators with control logic not only ensured consistency in maintaining thermal comfort but also reduced the need for human intervention. These results validated the system's capacity to autonomously maintain optimal living conditions for poultry based on real-time environmental inputs.

### *3.5 Power consumption and efficiency analysis*

The system's electrical performance was evaluated through voltage, current, and power measurements under different load conditions. Using a digital wattmeter, power consumption data were collected during lamp and fan activation as well as idle states. The system consumed approximately 33.8 W during lamp operation and 18.5 W during fan activity. When both actuators were inactive, the system maintained a low idle consumption of around 8.7 W. These values indicate a favorable power profile suitable for continuous operation.

The cos φ (power factor) was calculated to be 1.0, demonstrating efficient power usage with minimal reactive load. Comparative analysis between grid power and inverter output revealed slightly reduced voltage stability in battery mode, yet system functionality remained unaffected. The inclusion of a power backup system ensured uninterrupted operation, offering significant resilience in regions with frequent power interruptions. These findings underscore the system's energy efficiency and robustness in field conditions.

### *3.6 Remote monitoring and user interaction*

The system’s remote monitoring capabilities were validated through successful integration with the Blynk application. Real-time temperature and humidity readings were transmitted wirelessly from the NodeMCU ESP8266 to the Blynk server, allowing users to access data via a smartphone interface. The application provided clear visualizations and reliable data refresh intervals, ensuring continuous monitoring without requiring proximity to the cage. Fig. 6 shows the poultry monitoring via blynk software.

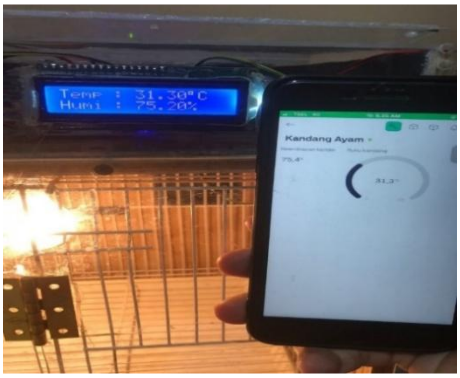


Fig. 6 Poultry monitoring

Users were able to observe system behavior and actuator status directly through the Blynk dashboard. This included visual indicators of fan and lamp activity based on temperature thresholds. The intuitive interface made it accessible for users with basic technical knowledge, while also enabling remote diagnosis in case of component failure. The reliable data transmission and user-friendly controls support the system’s applicability for small-scale poultry operations seeking simple but effective digital solutions.

### *3.7 Comparison with related studies*

Compared to similar IoT-based poultry monitoring systems in recent literature, the proposed solution achieved comparable environmental control with added affordability and reliability. For instance, previous studies (Vijay et al., 2023; Mumbelli et al., 2020) focused primarily on sensor integration and data monitoring. In contrast, this system incorporated a complete feedback loop with automated actuation, enhancing its utility in real-time environmental regulation.

Additionally, the incorporation of a power backup system distinguishes this design from many previous works, which often overlook energy resilience in rural settings. This feature addresses a key practical limitation and enhances the operational reliability of the system. When evaluated against other studies emphasizing advanced control features, the simplicity and cost-effectiveness of this design provide significant advantages for targeted users—small to mid-scale poultry farmers in developing regions.

### *3.8 Scientific and practical implications*

Scientifically, this study contributes to the development of IoT applications in precision livestock farming by demonstrating the feasibility of integrating real-time environmental sensing, actuation, and mobile communication in a cost-efficient system. It shows how basic microcontrollers and sensors can be leveraged to support animal welfare through consistent environmental management, laying groundwork for further enhancements with additional variables and AI-based optimization.

Practically, the system empowers farmers with a tool that reduces dependency on manual labor, minimizes thermal-related stress in poultry, and increases operational efficiency. The ability to access real-time data remotely allows for timely decision-making and early intervention, particularly valuable in settings where human resources are limited. The low-cost and modular design further enhances its scalability and potential for widespread adoption in rural agricultural communities.

### *3.9 Economic analysis*

The economic feasibility of the IoT-based poultry monitoring and control system was assessed through a detailed cost analysis of all components and their operational requirements. The total cost for system development amounted to approximately IDR 735,000, covering microcontrollers (Arduino Uno and NodeMCU ESP8266), sensors (DHT11), actuators (lamp, fans), power supply, battery, inverter, and ancillary materials such as the LCD module, resistors, and relay, where its detail is given in Table 2.

Tabel 2. Components prices

| No | Components | Amount | Price (IDR) |
|---|---|---|---|
| 1 | Power Supply Adaptor 12VC 4A | 1 | 30,000 |
| 2 | IC 7805 | 1 | 1,000 |
| 3 | Arduino UNO | 1 | 45,900 |
| 4 | NodeMCU ESP8266 | 1 | 29,500 |
| 5 | RTC DS3231 | 1 | 20,000 |
| 6 | DHT 11 Sensor | 1 | 9,500 |
| 7 | Transistor NPN 2N2222 | 1 | 2,000 |
| 8 | Resistor 1K Ohm | 1 | 2,000 |
| 9 | Mosfet P-Channel IRF9540N | 1 | 5,000 |
| 10 | Light Dimmer | 1 | 200,000 |
| 11 | LCD 12C 16x2 | 1 | 23,000 |
| 12 | Lamp 25 Watt | 1 | 10,500 |
| 13 | Fan | 2 | 8,000 |
| 14 | Cable and Jumper | 3 | 6,900 |
| 15 | Relay AC | 1 | 24,000 |
| 16 | Battery charger XH-M603 | 1 | 40,000 |
| 17 | Battery | 1 | 159,000 |
| 18 | Inverter | 1 | 75,000 |
| 19 | Switch | 1 | 5,000 |
| 20 | Fuse | 1 | 2,000 |
| $\sum$ | | | 735,000 |

The affordability of the system was further underscored by the use of open-source software and free mobile applications like Blynk, which eliminated licensing and subscription fees. The low power consumption (ranging between 6 W and 34 W under different load conditions) supports long-term operational cost efficiency, especially in resource-limited rural areas. When compared to commercial alternatives or manual labor costs associated with daily temperature monitoring and light switching, the system presents a high return on investment (ROI). Automation reduces labor dependency and human error, while improved thermal control contributes to healthier broiler growth, reduced mortality rates, and higher feed conversion efficiency. Additionally, the inclusion of a backup power system mitigates losses due to power outages, which are frequent in many rural areas. Considering its one-time cost and long-term benefits in productivity and labor reduction, the proposed system is economically viable and accessible for small and medium-sized poultry farmers, aligning with sustainable and inclusive agricultural practices.

*3.10 Limitations and challenges*

Despite the successful implementation, the system exhibits limitations that must be addressed in future iterations. The monitoring function is currently restricted to temperature and humidity, without inclusion of other crucial factors such as air quality, ammonia levels, or light intensity adjustment based on broiler age. This limits the comprehensiveness of environmental management and may affect long-term poultry productivity. Another challenge lies in the technical knowledge required to assemble, program, and maintain the system. While the hardware components are low-cost and readily available, the setup process may be difficult for users with minimal electronics experience. Additionally, dependency on a stable internet connection for remote access may hinder real-time monitoring in areas with poor network infrastructure. Addressing these limitations through modular add-ons and simplified interfaces would improve the system's usability.

The study achieved its objectives by demonstrating a functional, automated, and remote-controlled IoT-based system for temperature and lighting management in broiler poultry housing. The system maintained the target temperature range of 31°C–34°C, responded reliably to environmental changes, and provided continuous operation through a power backup setup. The integration of data visualization on LCD and smartphone platforms ensured accessibility and real-time awareness for users. Key findings also include the system's efficient energy usage, low component cost, and robustness under variable power conditions. Compared with existing models, this system offers a practical and scalable solution for small-scale poultry operations, particularly in developing regions. These results validate the hypothesis that broiler productivity and welfare can be significantly improved through simple and affordable automation.

## 4. Conclusions

This study has successfully designed, developed, and evaluated a low-cost IoT-based system for automated temperature monitoring and lighting control in broiler poultry housing. The system, which integrates Arduino Uno and NodeMCU ESP8266 microcontrollers, a DHT11 temperature and humidity sensor, and actuators such as fans and incandescent lamps, demonstrated consistent performance in maintaining optimal environmental conditions (31°C–34°C). The system's autonomous control logic, coupled with real-time data visualization on an LCD screen and through the Blynk mobile application, provided a reliable and user-friendly interface for poultry farmers. The backup power mechanism ensured uninterrupted operation during power outages, further enhancing the system's reliability and practicality in rural settings. The findings show that the system met its objectives by (i) enabling autonomous environmental regulation, (ii) maintaining optimal thermal conditions within the poultry cage, and (iii) providing reliable data logging and access across a 24-hour monitoring period. The system's cost-effectiveness and ease of assembly further underscore its suitability for deployment in small to medium-scale poultry operations, particularly in rural and under-resourced settings.

From an economic standpoint, the system proved to be both affordable and efficient. With a total development cost of approximately IDR 735,000, the solution remains financially accessible for small and medium-scale poultry farmers. Operational costs were minimized through low power consumption and the use of open-source software. Compared to labor-intensive conventional methods, this automated system reduces manual oversight, improves animal welfare, and enhances productivity, leading to long-term cost savings. The inclusion of a battery-powered backup system also protects against potential economic losses from power failures. Therefore, this solution not only addresses the technical and environmental challenges in poultry farming but also offers a scalable, economically sustainable approach for improving farming outcomes in resource-constrained regions. Future development may focus on extending system capabilities to include additional environmental variables such as air quality and light intensity control based on poultry age. Simplifying the installation and user interface could further increase adoption among rural farmers with limited technical expertise. Overall, the proposed system contributes to the advancement of precision agriculture and demonstrates the significant potential of IoT technologies in promoting sustainable, resilient, and economically viable livestock management practices.

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The authors declares no conflicts of interest related to this research.

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