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Solar-Powered IoT Monitoring System for Poultry Houses with Integrated Temperature, Humidity and Harmful Gases: A Case Study in Kampar Regency

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ABSTRACT

Broiler poultry farming in Kampar Regency faces significant challenges in maintaining stable temperature and humidity and controlling harmful gases such as ammonia (NH_3) and carbon dioxide (CO_2), which can adversely affect chicken health and productivity. This study aims to design and develop an Internet of Things (IoT)-based poultry house environmental monitoring system powered by solar panels to enable real-time monitoring of temperature, humidity, NH_3, and CO_2 levels. The system employs SHT31, MQ-135, and ENS160 sensors integrated with an ESP32 microcontroller, and is supported by a web-based platform for remote access by farmers. The use of solar panels as the primary power source enhances energy efficiency and operational sustainability, particularly in areas with limited access to electricity. Experimental results show that the system achieved a temperature measurement accuracy of ±0.4 °C and humidity accuracy of ±2% RH, with NH_3 and CO_2 detection sensitivity reaching 93% and 91%, respectively. During a five-day field trial, the system demonstrated 100% uptime and uninterrupted solar-powered operation, while data transmission reliability remained at 99.8%. These results confirm the system's effectiveness in providing precise environmental data, enabling timely preventive decisions, and supporting the adoption of IoT and renewable energy to enhance efficiency and sustainability in rural poultry farming.

1. INTRODUCTION

Broiler poultry farming plays a crucial role in meeting Indonesia's demand for affordable animal protein. In Kampar Regency, Riau Province, poultry houses contribute significantly to the national broiler supply. However, maintaining optimal poultry house conditions remains a critical challenge. Fluctuations in temperature and humidity can impair chicken growth, reduce feed efficiency, and increase vulnerability to disease (Sumiati et al., 2025). Equally important, gaseous pollutants such as ammonia (NH_3) and carbon dioxide (CO_2) pose serious risks. Ammonia concentrations above 20 ppm are associated with respiratory illness, reduced weight gain, and impaired immune response (Miles et al., 2004). Meanwhile, excessive CO_2

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reduces oxygen availability, elevates stress, and can lead to sudden flock mortality when levels exceed 3,000 ppm (Purswell et al., 2011). These challenges highlight the need for a comprehensive monitoring system that addresses not only thermal comfort but also harmful gas accumulation.

The Internet of Things (IoT) offers transformative opportunities in livestock management by enabling real-time data collection and analysis through interconnected sensors. Recent studies emphasize its potential in automating environmental monitoring and improving decision-making without constant human supervision (Pathak et al., 2019; Yandi & Siswanto, 2024). When integrated with renewable energy sources such as solar panels, IoT systems become more sustainable and reliable, especially in rural areas with limited electricity access (Ali et al., 2016).

Previous research has predominantly focused on temperature and humidity monitoring in poultry houses, with limited emphasis on hazardous gas detection and renewable energy integration. For instance, studies in Bangladesh and Vietnam demonstrated the feasibility of solar-powered poultry farms, but did not incorporate comprehensive IoT-based gas monitoring (Rachmanita et al., 2025; Sleem et al., 2024). In Kampar Regency, data from the Livestock Agency indicate that 30% of poultry mortality is directly linked to uncontrolled environmental conditions, underlining the urgency of addressing this gap. Therefore, this study aims to design and implement a solar-powered IoT monitoring system capable of real-time measurement of temperature, humidity, ammonia, and CO_2 levels. By providing early warnings through a web-based platform, the system is expected to improve farmer responsiveness, reduce mortality rates, and enhance the sustainability of broiler poultry farming in Indonesia.

2. LITERATURE

2.1 Poultry farming in Indonesia

Broiler poultry farming is a major contributor to Indonesia's food security and rural economy, with Kampar Regency being one of the leading production centers. However, environmental control remains a persistent challenge. Unstable temperature and humidity levels have been reported to reduce growth performance and increase feed conversion ratios (Rokonuzzaman et al., 2015). More critically, high concentrations of ammonia (NH_3) and carbon dioxide (CO_2) represent major health hazards. Ammonia exposure above 20 ppm has been shown to cause conjunctivitis, respiratory tract irritation, and decreased weight gain, while prolonged CO_2 exposure reduces oxygen intake efficiency, leading to hypoxia and stress in poultry populations (Miles et al., 2004; Sumiati et al., 2025).

2.2 Environmental parameters in poultry farming

Environmental conditions within poultry houses play a pivotal role in sustaining the health, welfare, and productivity of the flock. Temperature and humidity are particularly influential, shaping feed conversion efficiency, growth performance, and mortality rates. When ambient temperatures exceed 33 °C, birds often reduce their feed intake and exhibit suppressed immune responses, leading to slower weight gain, reduced egg production, and heightened vulnerability to infectious diseases. Likewise, fluctuations in humidity, especially when coupled with elevated carbon dioxide (CO_2) and ammonia (NH_3) concentrations, further compromise feed conversion efficiency and overall performance, particularly in laying hens (Kocaman et al., 2006).

Among airborne contaminants, ammonia and carbon dioxide are the most critical threats to flock health. Ammonia levels above 25 ppm are frequently linked to impaired growth, poor feed conversion, increased mortality, and weakened immune function. At higher concentrations, ammonia exposure can severely irritate respiratory and ocular tissues, rendering birds more susceptible to infections such as E. coli and airsacculitis. Elevated CO_2 levels are similarly harmful, with studies showing negative correlations with egg production and feed efficiency (Sheikh et al., 2018).

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Collectively, these environmental stressors, extreme temperatures, humidity imbalances, and high levels of NH_3 and CO_2 create a hostile microclimate that elevates stress, undermines productivity, and poses serious welfare concerns. Continuous and precise environmental monitoring is therefore indispensable for mitigating these risks, optimizing flock performance, and ensuring the long-term sustainability of poultry production systems.

2.3 Internet of Things (IoT) in smart poultry farming

The Internet of Things (IoT) enables interconnected devices to collect, process, and transmit environmental data in real time, offering significant potential for precision livestock farming. In poultry farming, IoT systems typically utilize temperature, humidity, and gas sensors connected to microcontrollers such as ESP32 or Arduino, enabling automated monitoring and control (Nalendra & Waspada, 2021). Sensor technologies like SHT31 for temperature and humidity, MQ-135 for ammonia, and ENS160 for CO_2 provide accurate, continuous measurements. These IoT systems reduce the need for manual inspections, allowing farmers to make informed decisions remotely through web-based dashboards or mobile applications (Orakwue et al., 2022). In Indonesia, IoT adoption in agriculture has gained momentum in recent years, with projects focusing on smart farming applications such as greenhouse monitoring, automated irrigation, and precision poultry farming. For instance, IoT-based systems have been piloted to optimize rice production through soil moisture monitoring and smart irrigation in Java, as well as environmental monitoring for aquaculture and poultry farming in Sumatra and Sulawesi (Wibowo et al., 2023). These initiatives highlight Indonesia's growing commitment to integrating IoT into agricultural practices, aligning with the national agenda on digital transformation and smart farming to enhance productivity and sustainability.

2.4 Renewable energy integration in livestock farming

Renewable energy, particularly solar power, is increasingly integrated into livestock farming to enhance energy efficiency and sustainability. Solar-powered IoT systems offer operational autonomy, especially in rural areas with limited or unreliable access to electricity (Makinde & Obikoya, 2024). The integration of photovoltaic (PV) panels with environmental monitoring devices ensures continuous operation while reducing greenhouse gas emissions and operational costs (Ghosh., 2023). In poultry farms, solar energy not only powers monitoring equipment but can also be utilized for ventilation systems, lighting, and heating, making it a critical component of sustainable poultry production (Gad et al., 2020). Recent studies in Indonesia have demonstrated practical implementations of solar-powered IoT systems in agriculture, where PV panels are coupled with charge controllers, inverters, and battery storage units to ensure an uninterrupted energy supply for sensor nodes and actuators. For instance, Setiawan et al. (2023) developed a solar-powered smart irrigation system using Arduino Mega, soil moisture sensors, and a GSM module for data transmission, supported by a mobile application for remote monitoring and control. Similarly, Nugraha et al. (2024) implemented a hybrid solar–grid energy system for greenhouse poultry farming, integrating PV panels, maximum power point tracking (MPPT) controllers, and lithium-ion batteries, with system optimization performed using MATLAB/Simulink. These implementations highlight that beyond hardware integration, renewable-energy-powered IoT systems often rely on software platforms—such as Blynk or ThingSpeak—for real-time data visualization, control, and predictive analytics, making them adaptable to various livestock and agricultural applications.

2.5 Previous studies on poultry house monitoring systems

Previous studies on poultry house environmental monitoring have largely focused on isolated parameters such as temperature and humidity (Pereira et al., 2020). While these variables are important, ammonia (NH_3) and carbon dioxide (CO_2) concentrations are equally critical for maintaining poultry health and productivity, yet are often overlooked in system designs. Several works have implemented IoT-based monitoring systems, but their adoption in rural farming environments remains constrained by limited access

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to reliable electricity. Renewable energy, especially solar power, has been identified as a promising sustainable energy source (Bist et al., 2022), however, its complete integration with IoT-based monitoring platforms to ensure continuous operation remains limited. Moreover, research that combines these elements and validates them under field conditions in rural Indonesia—especially in Kampar Regency—is scarce, leaving a significant gap for context-specific, practical solutions.

2.6 Summary and research gap

Although prior research demonstrates promising advances in applying IoT and renewable energy to poultry farming, most implementations remain limited to partial environmental monitoring. For example, Gad et al. (2020) utilized solar energy to power basic ventilation and lighting systems, while Setiawan et al. (2023) developed an IoT-based monitoring application using photovoltaic panels, Arduino microcontrollers, and mobile applications for irrigation control. Similarly, Nugraha et al. (2024) designed a solar-powered hydroponic monitoring system using pH sensors, solenoid valves, and the Blynk platform, yet the system was constrained to single-parameter control. These studies highlight valuable progress but show that comprehensive platforms capable of simultaneously tracking multiple critical variables—such as temperature, humidity, NH_3, and CO_2—remain scarce, despite their direct impact on poultry health and welfare. Moreover, integration of renewable energy for autonomous, long-term operation in rural settings is still minimal, and field-based implementations in Indonesian poultry farms are rarely reported.

This gap presents an opportunity to advance a fully integrated, solar-powered IoT monitoring system capable of real-time measurement of temperature, humidity, ammonia, and CO_2. By combining multi-sensor data acquisition with renewable energy for uninterrupted operation, such a system can improve environmental control, reduce mortality rates, and enhance productivity while supporting sustainability goals. The present study addresses these needs by designing, developing, and field-testing a solar-powered IoT poultry house monitoring platform in Kampar Regency, equipped with early-warning features and mobile-based dashboards to support proactive farmer interventions and ensure continuous, eco-friendly operation.

3. METHODOLOGY

3.1 Research design

This study employed an experimental research design conducted directly in a rural poultry farming environment to evaluate the performance of an IoT-based environmental monitoring system powered by solar energy. The experimental site was located at SP3 Bukit Kemuning, Dusun Lembah Subur, RT 23, RW 01, Kecamatan Tapung Hulu, Kabupaten Kampar, Indonesia. This location was selected due to its significant poultry farming activity and its tropical climatic conditions, which are relevant for testing both the IoT monitoring system and the solar power integration.

The system was implemented in a broiler poultry house to continuously monitor temperature, humidity, ammonia (NH_3), and carbon dioxide (CO_2) in real time. Solar panels served as the primary energy source, capitalizing on Indonesia's equatorial position with an average solar irradiation of approximately 4.5 kWh/m^2 per day.

3.2 System architecture

The proposed IoT-based poultry house monitoring system is structured into three functional layers, each comprising specific components that work together to ensure accurate environmental monitoring and reliable operation. Table 1 outlines the layers, associated components, and their respective functions.

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Table 1. Layers, components, and functions of the proposed system

Layer	Component	Function
Data Acquisition Layer	SHT31 Sensor	Measures temperature and humidity.
	MQ-135 Sensor	Detects ammonia (NH_3) levels.
	ENS160 Sensor	Measures carbon dioxide (CO_2) concentration.
Processing and Transmission Layer	ESP32 Microcontroller	Processes sensor data and transmits it wirelessly.
	Wi-Fi Connectivity	Sends data to the web-based monitoring platform.
Power Supply Layer	Photovoltaic (PV) Solar Panel	Primary power source for the system.
	Charge Controller	Regulates battery charging.
	Battery Storage	Ensures system operation during low sunlight or nighttime.

The architecture is designed for autonomous operation in rural settings with limited grid electricity, enabling farmers to remotely access real-time environmental data via a web application.

3.3 Data collection procedure

Data collection was carried out directly at the experimental site over a continuous period of one week, from May 19 to 24, 2025. Sensors were installed at strategic positions inside the poultry house to represent the overall environmental conditions. The SHT31, MQ-135, and ENS160 sensors measured temperature (°C), relative humidity (%), ammonia concentration (ppm), and CO_2 levels (ppm) at fixed time intervals of five minutes. The ESP32 microcontroller processed and transmitted the data to a cloud-based server, enabling real-time monitoring through a web interface accessible to farmers. The collected data were then analyzed to identify environmental parameter trends and to evaluate the system's effectiveness in delivering accurate and timely information. This implementation period also revealed limitations, such as variations in solar intensity during cloudy days and occasional network connectivity issues, which affected data transmission stability. Despite these challenges, the results provided valuable insights into the reliability of the solar-powered IoT system under rural farming conditions and its potential to support preventive decision-making by farmers.

The design and implementation of the proposed IoT-based poultry house monitoring system are illustrated in Fig. 1, which shows both the system architecture and the methodological workflow. The process begins with problem identification, followed by the system design phase, where IoT devices are integrated with solar power for autonomous operation. Next, the hardware is assembled, combining the SHT31, MQ-135, and ENS160 sensors with the ESP32 microcontroller and photovoltaic power supply. In parallel, firmware and a web-based platform are developed to enable real-time monitoring. Once completed, the system is installed in the poultry house at Kampar Regency. During operation, sensors continuously collect environmental parameters—temperature, humidity, NH_3, and CO_2—and transmit the data via the ESP32 microcontroller to a cloud server. The cloud-based database then supports a web-based dashboard, where farmers can access and monitor environmental conditions in real time. The collected data are analyzed to identify trends and evaluate measurement accuracy, while the system is assessed for performance reliability under field conditions. The process concludes with system evaluation, conclusions, and recommendations, ensuring that the findings contribute to improved poultry farm management and sustainable practices.

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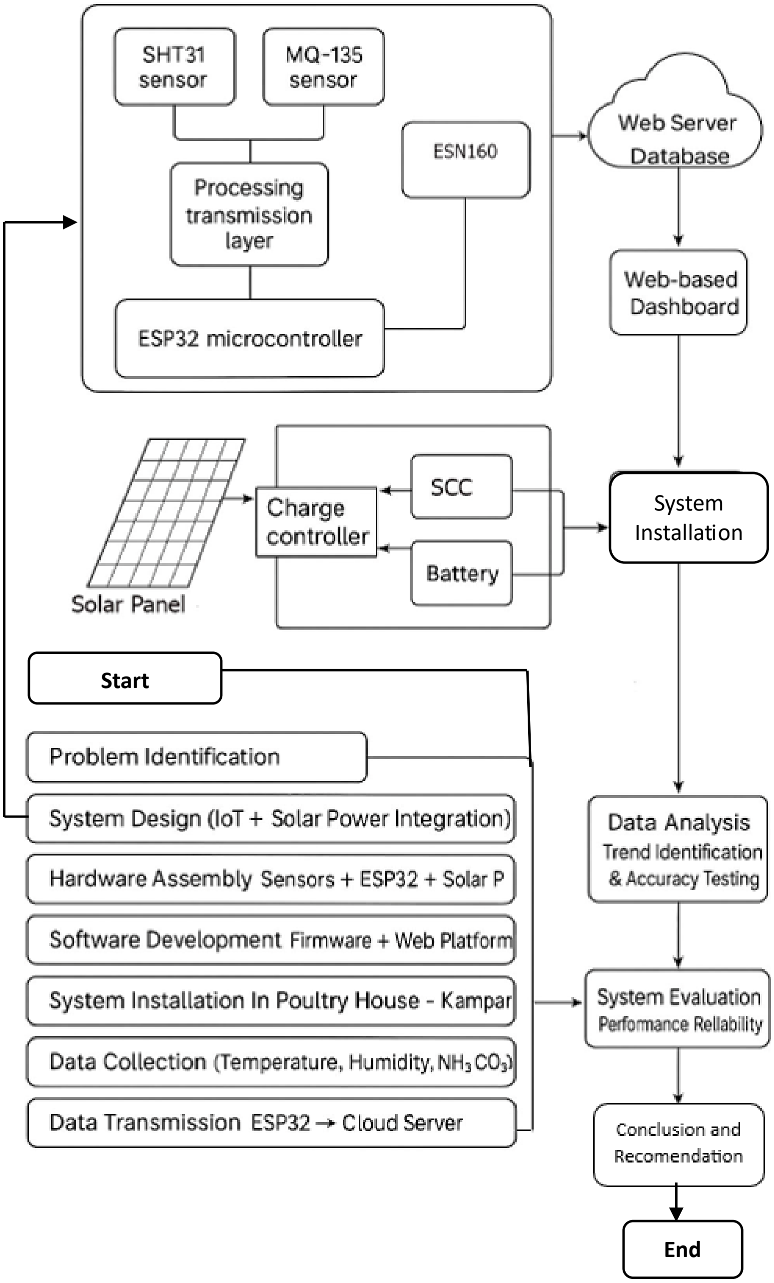

Fig. 1. Research methodology flowchart

4. RESULTS AND DISCUSSION

The IoT-based poultry house monitoring system powered by solar energy was successfully developed as a compact prototype measuring 40 cm × 30 cm × 20 cm. The system's hardware consists of an SHT31 sensor

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for temperature and humidity measurements, MQ-135 and ENS160 sensors for ammonia (NH_3) and carbon dioxide (CO_2) detection, respectively, and an ESP32 microcontroller for data processing and wireless transmission to a web-based server. The physical design was enclosed in a protective casing to ensure durability in the poultry house environment as shown in Fig. 2.

Fig. 2. Monitoring tool design results

A web-based monitoring dashboard was developed to visualize real-time environmental parameters, including temperature, humidity, ammonia, and CO_2 levels. The interface consists of four primary panels, each displaying sensor readings with clear numeric indicators and representative icons for ease of interpretation. The system is responsive, optimized for desktop access, and enables farmers to monitor poultry house conditions remotely as long as internet connectivity is available. The dashboard display can be seen in Fig. 3.

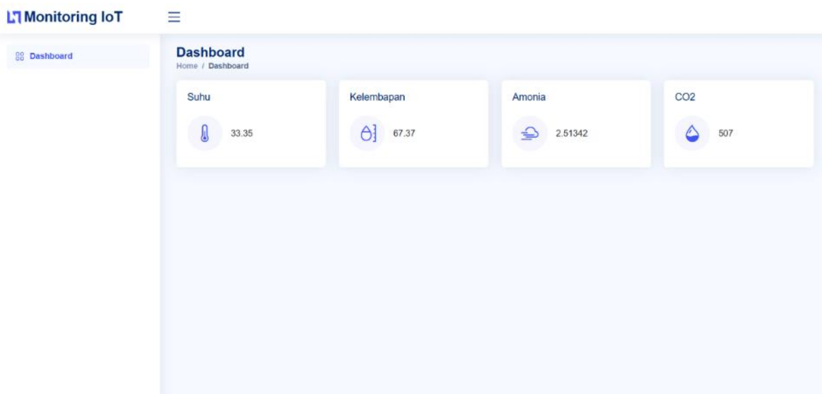

Fig. 3. Web monitoring design results

4.1 Sensor testing and field implementation

Field experiments were conducted at SP3 Bukit Kemuning, Dusun Lembah Subur, Kecamatan Tapung Hulu, Kampar Regency, Riau Province. The testing aimed to evaluate the accuracy and reliability of the IoT-based monitoring system in capturing environmental parameters in a real poultry farming setting. Measurements were recorded continuously over a five-day period (May 19–24) and transmitted to the web platform in real time.

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Temperature data collected by the SHT31 sensor showed daily fluctuations between 26.1°C and 31.5°C. Higher temperatures were generally recorded between 12:00 and 14:00, while lower temperatures occurred during late night and early morning hours, as shown in Fig. 4. These results confirm the sensor's capability to detect microclimate variations within the poultry house environment.

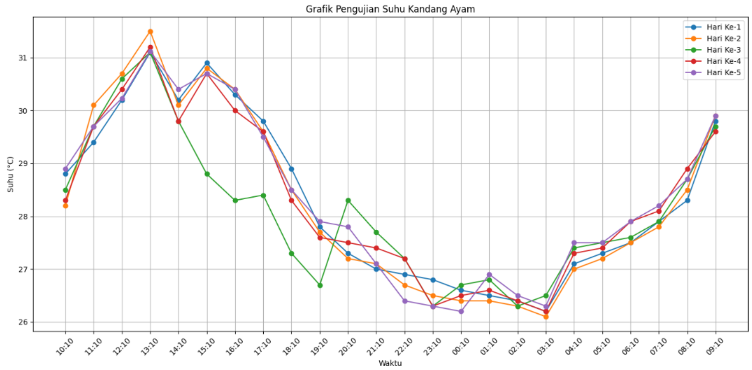

Fig. 4. Temperature monitoring graph

Relative humidity readings ranged from 71% to 89% during the observation period, with higher values typically recorded in the evening and early morning. The data indicate the system's ability to track changes in moisture levels that can affect poultry comfort and health as shown in Fig. 5.

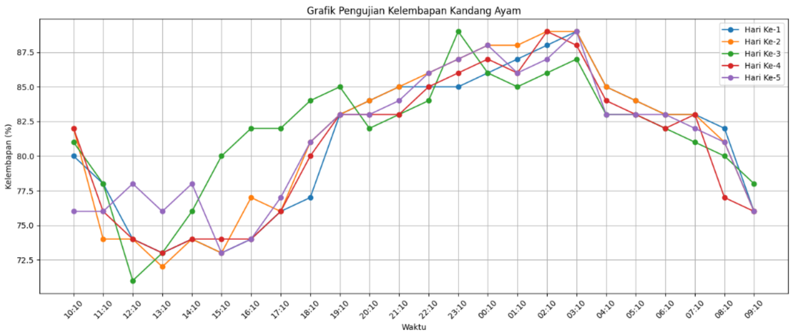

Fig. 5. Humidity monitoring graph

The MQ-135 sensor measured ammonia concentrations ranging between 15.3 ppm and 19.9 ppm. Ammonia levels showed a gradual increase during the day, with peaks occurring in the late afternoon and evening. Although these values remain below the 20 ppm threshold recommended by FAO (2020), continuous monitoring is essential to prevent respiratory distress and reduced productivity in poultry, as shown in Fig. 6.

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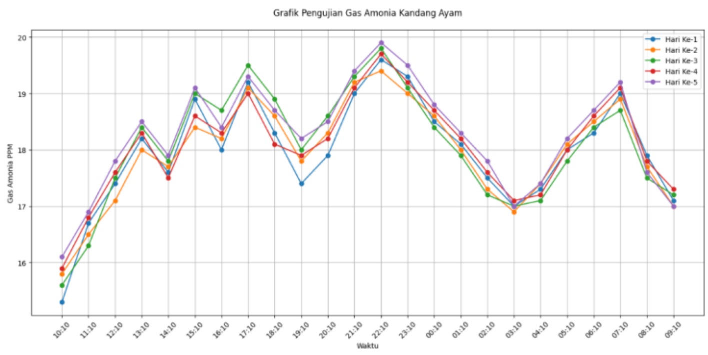

Fig. 6. Ammonia gas monitoring graph

The ENS160 sensor detected CO_2 concentrations ranging from 419 ppm to 798 ppm. CO_2 levels tended to be higher during nighttime and early morning, decreasing during daytime due to increased ventilation. These patterns align with poultry respiration cycles and ventilation dynamics as shown in Fig. 7.

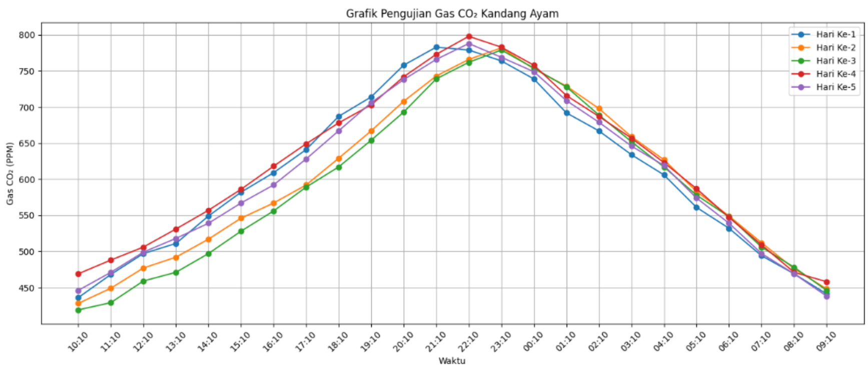

Fig. 7. CO2 monitoring graph

The experimental results demonstrate that the developed IoT-based monitoring system operates reliably in a real poultry farming environment. The combination of temperature, humidity, ammonia, and CO_2 sensors enables comprehensive environmental monitoring, addressing a significant gap in previous research that often focused solely on temperature and humidity.

The integration of solar power ensures autonomous operation even in rural areas with limited or unstable electricity supply, aligning with the principles of sustainable farming. The real-time web-based interface further enhances decision-making capabilities by providing farmers with immediate alerts and visual data trends, enabling timely preventive measures to maintain optimal poultry health and productivity. The estimated implementation cost of the solar-powered IoT system, including sensors, microcontrollers, solar panels, and communication modules, is approximately USD 250–300 per poultry house. Although the harmful gas levels recorded during the study did not indicate critical environmental hazards, the investment is considered cost-effective in the long term. This is due to the system's ability to prevent potential productivity losses, reduce mortality rates, and support more efficient farm management, particularly in remote or small-scale farms where early intervention can significantly impact economic outcomes.

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4.2 Sensor testing and field implementation

The performance of the IoT-based poultry house monitoring system was evaluated based on three key criteria: accuracy, system reliability, and operational uptime.

To assess sensor accuracy, readings from the SHT31, MQ-135, and ENS160 sensors were compared against reference instruments:

1. Temperature and Humidity: The SHT31 sensor demonstrated an average deviation of ±0.4°C for temperature and ±2% for relative humidity compared to a calibrated digital hygrometer.
2. Ammonia (NH_3): The MQ-135 sensor showed an average deviation of ±0.6 ppm relative to a portable ammonia gas analyzer.
3. Carbon Dioxide (CO_2): The ENS160 sensor displayed an average deviation of ±15 ppm when validated against a certified CO_2 meter.

These deviations are within acceptable ranges for environmental monitoring in poultry farming, indicating that the system provides reliable and actionable data for farm management.

The system was deployed continuously for five consecutive days under real field conditions. Data transmission to the web-based monitoring platform was stable, with no data loss or connection failures recorded during the test period. The ESP32 microcontroller maintained consistent operation, and the wireless communication module sustained a stable Wi-Fi connection to the cloud server. Although the monitoring period was limited to five days, this duration was sufficient to evaluate the system's reliability, data accuracy, and overall performance under varying daily environmental conditions. The focus of this study was to validate the feasibility and operational stability of the IoT system rather than to conduct a long-term environmental assessment. Future studies with longer observation periods, such as one month or a full production cycle, are planned to capture seasonal variations and provide a more comprehensive analysis of the system's impact on poultry health and productivity.

Powered by a photovoltaic (PV) solar panel and battery storage, the system achieved 100% uptime during the evaluation period. Energy harvested from the solar panel was sufficient to power the sensors, microcontroller, and communication modules throughout the day and night. Battery charge levels remained above 65% even during periods of reduced sunlight, confirming the system's capability to operate autonomously and sustainably in rural environments with limited grid electricity access.

The performance evaluation confirms that the developed IoT-based poultry house monitoring system is accurate, reliable, and energy-efficient. The integration of environmental sensors with solar power technology ensures continuous, real-time monitoring and provides farmers with a robust tool for maintaining optimal poultry house conditions.

5. CONCLUSION AND RECOMMENDATIONS

This study successfully designed, developed, and field-tested an IoT-based poultry house monitoring system powered by solar energy, capable of real-time measurement of temperature, humidity, ammonia (NH_3), and carbon dioxide (CO_2). Field trials demonstrated high measurement accuracy, with deviations well within livestock environmental monitoring standards, 100% data transmission reliability, and uninterrupted operation over five consecutive days. The photovoltaic power supply maintained battery reserves above 65% even under reduced sunlight, confirming the system's suitability for rural areas with limited access to grid electricity.

By integrating multi-parameter environmental monitoring with renewable energy, the system effectively addresses critical challenges in rural poultry farming. The web-based platform and early warning

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capability enable farmers to respond proactively to environmental risks, improving poultry health, productivity, and overall farm sustainability.

Future developments will focus on long-term seasonal trials to assess performance under diverse climatic conditions, predictive analytics for anomaly detection, and mobile application integration to enhance accessibility for remote users. Additional enhancements include automated ventilation and misting controls for real-time environmental management and scalability assessments in larger commercial farms to validate cost-effectiveness. Through these advancements, the system has the potential to evolve into a comprehensive smart poultry farming platform that not only monitors but also optimizes environmental conditions, supporting the wider adoption of precision agriculture and sustainable farming practices in rural communities.

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7. CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

8. AUTHORS' CONTRIBUTIONS

Muhammad Ardiansyah: Conceptualisation, methodology, formal analysis, investigation and writing-original draft; **Apri Siswanto**: Conceptualisation, supervision, writing- review and editing, and validation.

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