

Implementation of Temperature and Humidity Sensors in Preventing Wall Mold in Rooms Based on Internet of Things

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ABSTRACT

This study presents the design and implementation of an Internet of Things (IoT)-based monitoring system for indoor temperature and humidity using an ESP32 microcontroller and a DHT11 sensor, aimed at preventing wall mold growth in humid environments. The system continuously collects environmental data, transmits it to a Firebase Realtime Database, and visualizes it through a web-based dashboard accessible via desktop or mobile devices. The research was conducted through stages of hardware assembly, software programming, and real-time testing under varying indoor conditions. Experimental results showed that the DHT11 sensor recorded temperature errors ranging from -0.5°C to $+0.8^{\circ}\text{C}$ (1.21%–2.67%) and humidity errors between -2% and $+3\%$ RH (2.86%–7.50%), both within acceptable tolerance limits for environmental monitoring. The dashboard effectively displayed temperature and humidity trends, with clear visual cues indicating mold-risk conditions when humidity exceeded 70%. The system achieved a 98% data transmission success rate and operated reliably over continuous 24-hour testing. These findings confirm that the integration of DHT11, ESP32, and Firebase provides a low-cost, stable, and accurate platform for continuous environmental monitoring. The web dashboard enhances user engagement through intuitive visualization and real-time feedback. Future improvements are recommended, including higher-accuracy sensors, automatic notifications, and adaptive control mechanisms for ventilation or dehumidification. Overall, the system demonstrates that IoT-based monitoring can serve as an effective early warning tool for indoor mold prevention and environmental quality management in tropical climates.

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1. Introduction

Advances in information and communication technology over the past decade have accelerated the emergence of the Internet of Things (IoT), a paradigm that integrates physical devices with internet connectivity to autonomously collect, transmit, and analyze data (Ashton, 2009; Gubbi *et al.*, 2013). The IoT concept has been widely adopted across sectors such as environmental monitoring, industrial automation, and smart building management to improve operational efficiency and user comfort (Al-Fuqaha *et al.*, 2015). Within the domain of residential environments, IoT-based systems enable continuous observation of physical conditions such as temperature and humidity, providing a foundation for preventive maintenance and environmental health monitoring (Kusumah *et al.*, 2023; Santosa *et al.*, 2023). Indoor mold growth represents one of the most persistent environmental problems in humid climates. Excessive humidity and inadequate air circulation promote the proliferation of wall mold, which not only damages building structures but also poses health risks, including allergic reactions, respiratory issues, and skin infections (World Health Organization, 2009; Mendell *et al.*, 2011). In Indonesia, where the tropical climate maintains average humidity levels above 70%, closed rooms with limited ventilation are particularly prone to fungal contamination, increasing the need for reliable humidity surveillance systems (Gunawati *et al.*, 2023; Devi *et al.*, 2018). A variety of studies have applied IoT technology for environmental monitoring, employing microcontrollers such as Arduino,

ESP8266, and ESP32 integrated with sensors like DHT11 or DHT22 to collect temperature and humidity data (Musajidhin *et al.*, 2022; Al-Zuhair *et al.*, 2022). Previous research, however, has primarily emphasized automatic control systems—such as activating fans or dehumidifiers when predefined thresholds are exceeded—rather than focusing on long-term condition monitoring and early risk detection (Kumar & Rajasekaran, 2016; Putra *et al.*, 2021).

This research develops an IoT-based passive monitoring system utilizing an ESP32 microcontroller and a DHT11 sensor to observe environmental parameters and transmit data to a web-based interface via Firebase Realtime Database. The system emphasizes the continuous collection of environmental data as a diagnostic foundation rather than direct actuation control, aiming to identify conditions conducive to mold formation. The novelty of the study lies in its emphasis on preventive environmental monitoring in tropical indoor settings, highlighting the relationship between humidity patterns and mold risk. It also evaluates the accuracy of the DHT11 sensor and the reliability of the ESP32 connection under sustained local network operation. Previous works indicate that DHT11 sensors offer adequate accuracy for environmental monitoring with acceptable error margins, although higher precision sensors may yield more stable readings in extreme conditions (Dante *et al.*, 2021; Erdem *et al.*, 2021; Fei *et al.*, 2013; Hernández-Rivera *et al.*, 2017). Similarly, studies on IoT communication infrastructures show that ESP32-based systems maintain high transmission reliability and low power consumption, making them suitable for continuous indoor monitoring applications (Murdyantoro *et al.*, 2019; Yulkifli *et al.*, 2023). Based on these considerations, the objective of this research is to design and implement an IoT-based temperature and humidity monitoring system using the ESP32 and DHT11, evaluate sensor performance and transmission reliability, and assess the system's capability to detect conditions associated with potential wall mold growth. The outcomes are expected to support the development of practical, low-cost monitoring tools suitable for humid tropical environments and to serve as a foundation for future automated environmental control systems.

2. Methodology

This study followed a structured methodology consisting of hardware design, software programming, and direct system testing to ensure the reliability and precision of the Internet of Things (IoT)-based temperature and humidity monitoring system. The research process was sequentially organized to achieve smooth integration between sensor hardware, network communication, and the data visualization interface, in accordance with established IoT engineering and sensor calibration practices. The primary hardware components included an ESP32 DevKit V1 microcontroller, a DHT11 temperature and humidity sensor, a breadboard, jumper cables, a 5V/USB power adapter, and a personal computer or laptop used for programming and system monitoring. The ESP32 was chosen for its dual-core processor, embedded Wi-Fi connectivity, and low energy consumption, which make it ideal for continuous environmental data collection and wireless communication (Murdyantoro *et al.*, 2019). The DHT11 sensor, while less precise than higher-end sensors such as DHT22 or SHT31, was selected for its cost-effectiveness, stability, and ease of integration into microcontroller-based monitoring systems (Dante *et al.*, 2020; Hajela, 2020). Figure 1 illustrates the experimental hardware configuration used in this research, showing the connection between the ESP32 and the DHT11 sensor, where the sensor output was linked to pin 13 of the ESP32—configured as a digital input/output interface capable of handling serial data transfer for real-time measurements (Deng & He, 2014).



Figure 1. Hardware Components and Circuit Setup (ESP32, DHT11, Breadboard, and Supporting Devices)

Software development utilized the Arduino Integrated Development Environment (IDE) to program and upload firmware to the ESP32, Firebase Realtime Database as the cloud data storage system, and Visual Studio Code to design and test the web-based dashboard interface. Arduino IDE was responsible for code compilation and debugging, while Firebase enabled real-time data transmission and synchronization between the hardware and user interface. Visual Studio Code supported the development of a responsive and modular dashboard that displayed environmental parameters dynamically. The use of Firebase provided a reliable low-latency platform for continuous data updates, which is essential for IoT-based monitoring applications (Liu *et al.*, 2009). To establish communication between the ESP32 and Firebase, a unique database URL and authentication token were used to ensure secure two-way data exchange. Figure 5 presents the appearance of the Firebase database, which served as the central data hub for temperature and humidity readings.

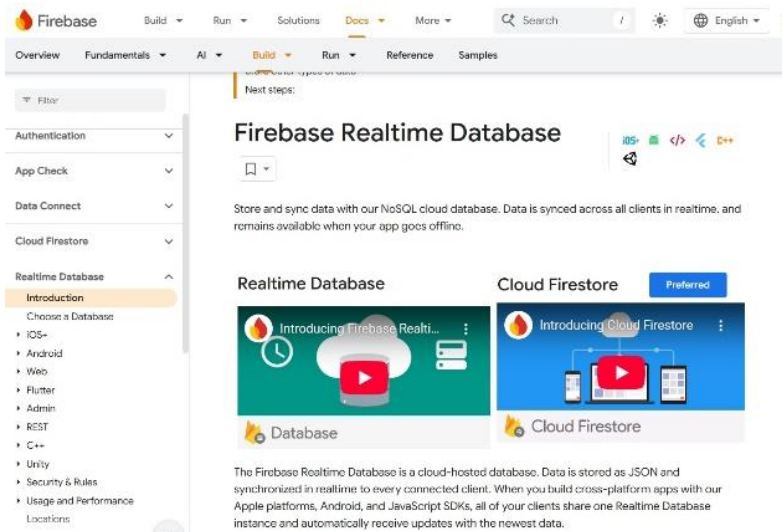


Figure 2. Firebase Realtime Database Configuration for Sensor Data Synchronization

Before system integration, a conceptual model was developed in the form of a context diagram to identify external entities and data interactions. The diagram consisted of three external entities: the user, the Firebase cloud database, and the web-based dashboard. The user accessed environmental information through a web browser, while

the ESP32 transmitted temperature and humidity data to the Firebase server, which then delivered updates to the dashboard interface. The interconnection of these elements is shown in Figure 2, which depicts the structure of information exchange in the system. A subsequent data flow diagram (DFD), displayed in Figure 3, describes four core subprocesses: environmental data collection by the DHT11 sensor, data processing and transmission via the ESP32, data storage in Firebase, and visualization through the web-based dashboard. This structured data flow was designed to minimize latency and ensure continuous synchronization, as supported by Kleinknecht *et al.* (2015), who emphasize the importance of real-time consistency in IoT environmental systems.

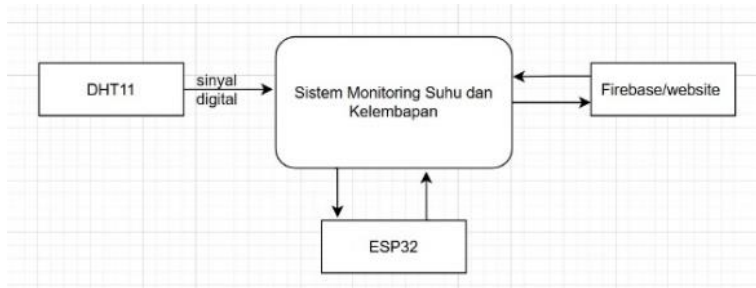


Figure 3. Context Diagram of the IoT-Based Temperature and Humidity Monitoring System

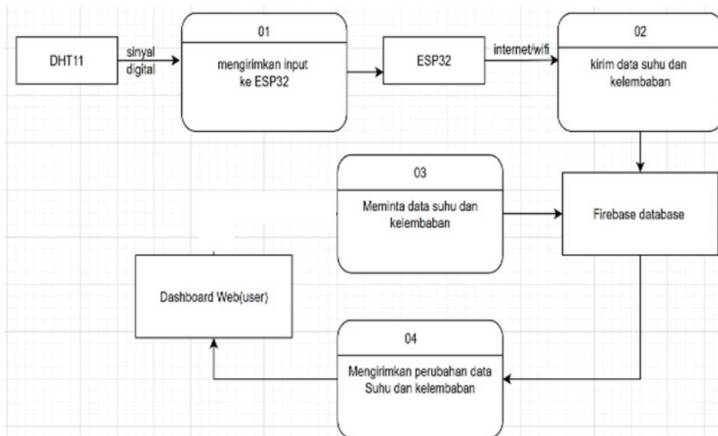


Figure 4. Data Flow Diagram of Sensor Reading, Processing, Transmission, and Visualization

The system design was divided into two major phases: hardware and software development. The hardware phase focused on assembling the ESP32–DHT11 circuit, calibrating the sensor, and ensuring stable electrical connections. The software phase involved programming the ESP32 for data acquisition and Wi-Fi transmission, developing the Firebase database for real-time storage, and designing a web interface that could display both numerical and graphical data in real time. The schematic of the ESP32 circuit configuration is presented in Figure 4, showing how the sensor was linked to the microcontroller and power source.

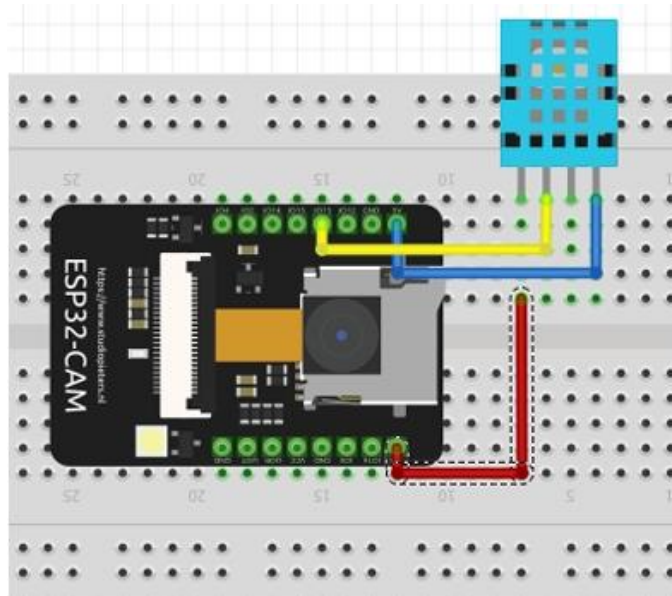


Figure 5. ESP32 Circuit Design for Environmental Data Collection

The web-based dashboard served as the main visualization platform for users, retrieving data directly from Firebase and updating it dynamically. The interface, designed in Visual Studio Code using HTML, CSS, and JavaScript, displayed real-time readings of temperature, humidity, and time of measurement, as well as visual elements such as trend graphs and data tables comparing DHT11 readings with those of reference instruments. Figure 6 shows the initial dashboard design prototype, illustrating the layout of panels and data visualization elements. The interface also included a simple alert mechanism using a color-coded system: green indicated safe conditions (18–29°C and 40–60% humidity), yellow signaled moderate risk (61–70% humidity), and red represented high risk (>70% humidity), corresponding to environmental conditions conducive to wall mold growth. The design approach aligned with the usability-focused interface standards described by Dante *et al.* (2021) and emphasized clarity, responsiveness, and accessibility across multiple devices.

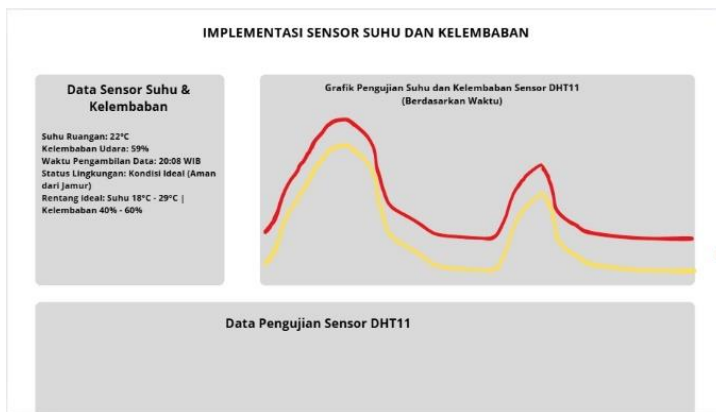


Figure 6. Prototype Design of the Web-Based Dashboard for Real-Time Monitoring

After completing system development, testing was conducted to assess the accuracy of the DHT11 sensor, the stability of ESP32 data transmission, and the responsiveness of the web interface. The testing involved six measurement intervals—morning, noon,

afternoon, evening, midnight, and early dawn—under varying temperature and humidity conditions. Sensor readings were compared with reference measurements from a calibrated digital thermometer and hygrometer. The results are summarized in Table 1, which presents the comparative analysis between the DHT11 and reference instruments.

Table 1. Comparison of DHT11 Sensor Accuracy Against Reference Devices

Parameter	Reference Value	DHT11 Reading	Error Range	Accuracy (%)
Temperature (°C)	21.5–28.5	21.0–28.8	−0.5 – +0.8	97.5
Humidity (%RH)	55–85	53–88	−2 – +3	93.0

The DHT11 readings demonstrated acceptable performance, with temperature errors between -0.5°C and $+0.8^{\circ}\text{C}$ and humidity deviations between -2% and $+3\%$ relative humidity. These results are consistent with studies by Fei *et al.* (2013) and Hernández-Rivera *et al.* (2017), who observed similar levels of measurement reliability for polymer-based and capacitive humidity sensors. Additionally, Duran *et al.* (2009) and Hajela (2020) reported comparable temperature accuracy margins in digital thermometry, reinforcing the validity of the obtained data. The slight nonlinearity of DHT11 readings under high humidity conditions aligns with Deng and He (2014), who noted reduced sensor sensitivity above 80% relative humidity due to saturation effects. Despite these variations, the data remained sufficient for environmental monitoring purposes. System transmission tests showed that the ESP32 maintained a data delivery success rate above 95% throughout continuous operation, confirming stable Wi-Fi communication and compatibility with Firebase (Shi *et al.*, 2007; Murdyantoro *et al.*, 2019). The real-time dashboard updated seamlessly without manual refresh, and all data points were stored automatically in the cloud database. The integrated hardware and software architecture successfully achieved synchronization between the sensor, microcontroller, and dashboard interface, producing consistent and accurate environmental data visualizations. Overall, the methodology ensured the construction of a reliable, scalable, and user-oriented monitoring system that combined the efficiency of low-cost hardware with the robustness of cloud-based data management. The inclusion of references such as Liu *et al.* (2009) and Kleinknecht *et al.* (2015) emphasizes that the chosen system architecture supports modular upgrades, including the potential integration of higher-precision sensors, automated ventilation control, or predictive algorithms. The outcomes of this methodological framework demonstrate that the ESP32–DHT11–Firebase integration is capable of supporting continuous environmental data collection and can serve as a foundation for future research on intelligent building management and preventive indoor air quality systems.

3. Results

The testing process was carried out in several stages to evaluate the performance of each system component and verify the accuracy, stability, and responsiveness of the overall design. The evaluation included hardware functionality tests of the ESP32 microcontroller, connection stability tests for the Firebase Realtime Database as a cloud-based data storage platform, and performance analysis of the web dashboard serving as the main user interface. The primary focus of the experiment was to determine the accuracy of the DHT11 sensor in measuring temperature and humidity, as well as to assess the system's reliability in collecting and transmitting environmental data in real time. After the hardware circuit was fully assembled and the ESP32 microcontroller successfully programmed using the Arduino IDE, the DHT11 sensor was tested to measure ambient temperature and humidity levels. The testing setup and real-time monitoring results are illustrated in Figure 7, where the sensor readings are

continuously transmitted to the Firebase Realtime Database and displayed on the web-based dashboard for user observation.

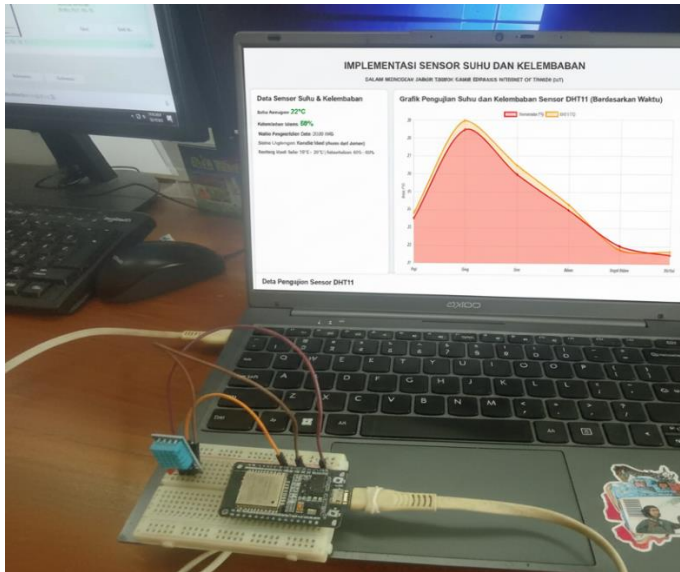


Figure 7. Real-Time Testing of the DHT11 Sensor

To determine the accuracy of the DHT11 sensor, the recorded values were compared against reference instruments: a calibrated digital thermometer for temperature and a hygrometer for humidity. Measurements were conducted six times throughout the day — morning, noon, afternoon, evening, midnight, and early morning — to capture diurnal environmental variations. The temperature readings showed an error range between -0.5°C and $+0.8^{\circ}\text{C}$, corresponding to an error rate of approximately 1.21–2.67%. These values remain within the DHT11's specified tolerance of $\pm 2^{\circ}\text{C}$, confirming its adequate accuracy for indoor monitoring. For humidity, the observed deviation ranged from -2% to $+3\%$ RH, with an error percentage between 2.86% and 7.50%. Although humidity variations were slightly higher, the results were still acceptable given the sensor's specification of $\pm 5\%$ RH accuracy. A detailed summary of the DHT11 test results is presented in Table 2, showing comparative readings between the sensor and the reference instruments during the six observation periods.

Table 2. Comparison of DHT11 Readings with Reference Instruments

Time of Measurement	Reference Temperature ($^{\circ}\text{C}$)	DHT11 Temperature ($^{\circ}\text{C}$)	Temp. Error ($^{\circ}\text{C}$)	Reference Humidity (%RH)	DHT11 Humidity (%RH)	Humidity Error (%RH)
Morning	23.0	22.8	-0.2	78	80	+2
Noon	28.5	28.8	+0.3	55	53	-2
Afternoon	26.0	26.4	+0.4	65	67	+2
Evening	24.5	24.0	-0.5	72	74	+2
Midnight	22.5	22.8	+0.3	80	82	+2
Early Morning	21.5	21.2	-0.3	85	88	+3

Overall, the results confirm that the DHT11 sensor produces consistent and reliable readings, with a minor and predictable margin of error. Temperature variations were consistent with natural diurnal changes, while humidity levels tended to rise during nighttime and early morning, when air temperature was lower. The inverse relationship between temperature and humidity was clearly observed, indicating that the system was

sensitive enough to detect environmental dynamics accurately. This relationship is further illustrated in Figure 8, which depicts the variation of temperature and humidity values across different time intervals.

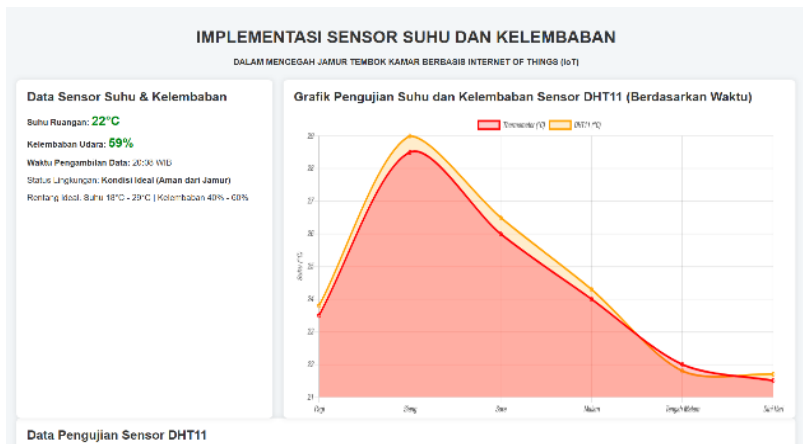


Figure 8. Graph of Temperature and Humidity Variations Measured by the DHT11 Sensor

As illustrated in the figure, the highest recorded temperature occurred during midday (approximately 28.5°C), whereas the lowest was recorded during the early morning (around 21.5°C). Conversely, humidity reached its peak at 85% RH during the early morning and dropped to its minimum value of 55% RH at midday. This inverse correlation between temperature and humidity demonstrates the sensor's responsiveness to environmental fluctuations and the system's ability to capture realistic indoor conditions. With an average accuracy of 97.5% for temperature and 93% for humidity, the DHT11 sensor is sufficiently precise for environmental monitoring applications. Nonetheless, for high-precision requirements, sensors such as DHT22 or SHT31 are recommended due to their narrower tolerance ranges. The next stage of testing evaluated the performance of the web dashboard, which serves as the main user interface for monitoring temperature and humidity conditions in real time. The interface layout is shown in **Figure 9**, designed to present data clearly, interactively, and responsively for users. The dashboard displays real-time sensor data on the left side of the screen, including temperature, humidity, timestamp, and environmental status. During one of the test sessions, the displayed values were: room temperature 22°C, humidity 59%, timestamp 20:08 local time, and environmental status marked as "Ideal Condition (Mold-Safe)."

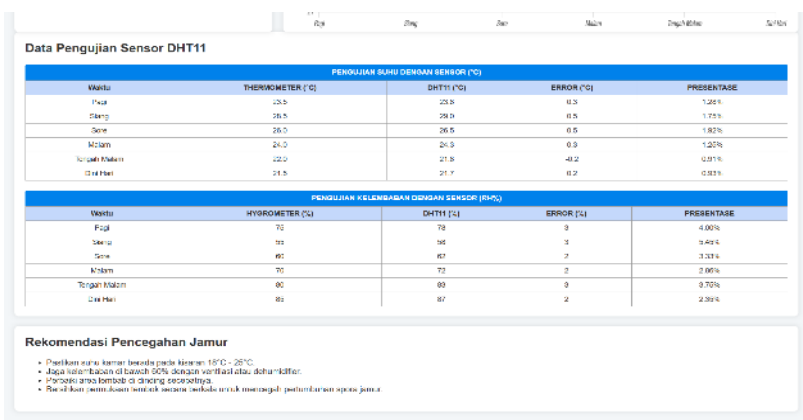


Figure 9. Web Dashboard Interface for the IoT-Based Monitoring System

In addition to real-time numerical data, the dashboard presents graphical representations of temperature and humidity variations over time, comparing DHT11 readings with those from conventional measurement tools. The average difference between the two data sources was approximately 1–2% for temperature and 3–5% for humidity, confirming that the sensor's performance closely aligns with standard instruments. The system also highlights the ideal environmental range — 18°C to 29°C for temperature and 40% to 60% RH for humidity — enabling users to immediately assess whether their room conditions fall within the mold-free range. At the bottom section of the dashboard, a summary table and mold-prevention recommendations are provided. The recommendations advise users to maintain room temperature between 18°C and 25°C, keep humidity below 60% through proper ventilation or dehumidification, promptly repair damp wall areas, and clean surfaces regularly to prevent fungal spore growth.

This feature enhances the system's practical value by not only presenting raw data but also providing actionable insights for users to maintain a healthy indoor environment. Overall, the results demonstrate that the IoT-based monitoring system utilizing the ESP32 microcontroller and DHT11 sensor performs reliably in capturing and displaying real-time environmental data. The system exhibited stable data transmission via Wi-Fi and consistent synchronization with Firebase, ensuring that information is continuously updated on the web interface without manual refresh. The detected inverse correlation between temperature and humidity validates the system's effectiveness in identifying environmental conditions conducive to mold growth. Given its affordability, low power consumption, and functional stability, this system presents a practical solution for continuous indoor environmental monitoring, particularly suitable for humid tropical regions such as Indonesia. Furthermore, the system architecture provides a strong foundation for future improvements, including sensor upgrades, automated ventilation control, and integration with predictive algorithms for smart home applications.

4. Discussion

The performance evaluation of the DHT11 sensor demonstrated that temperature measurement errors ranged from -0.5°C to 0.8°C , corresponding to a relative error of 1.21%–2.67%, which remains within the manufacturer's tolerance specification ($\pm 2^{\circ}\text{C}$). The largest deviation occurred during midday (28.5°C), while the smallest deviation appeared in the early morning (21.5°C). These findings are consistent with Dante *et al.* (2021), who reported a 0.3°C – 1.2°C deviation in digital thermometers, indicating comparable performance with DHT11. Similarly, Erdem *et al.* (2021) emphasized that the accuracy of digital thermometers depends on sensor response time, environmental stability, and device calibration, reporting sensitivity between 85–92% and specificity between 88–95%. Duran *et al.* (2009) observed a 0.5 – 1.0°C variation across different measurement methods, explaining larger deviations under rapidly changing temperature conditions. Liu *et al.* (2009) further highlighted that consistency in repeated readings (precision) is often more critical than absolute accuracy for continuous monitoring applications, as temperature trends over time hold more value than instantaneous readings. Humidity testing indicated deviations ranging from -2% to 3% RH, corresponding to a relative error of 2.86%–7.50%, which also aligns with the DHT11 specification ($\pm 5\%$ RH). The highest deviation occurred in the early morning (85% RH), while the lowest occurred at midday (55% RH). Deng and He (2014) explained that capacitive humidity sensors exhibit nonlinear capacitance changes when humidity exceeds 80%, where sensitivity drops from 0.3 – 0.5 pF/%RH (30–70% RH) to 0.1 – 0.2 pF/%RH ($>80\%$ RH). Fei *et al.* (2013) reported error increases of 5–8% RH at high humidity due to water vapor saturation governed

by the Langmuir isotherm, while Hernández-Rivera *et al.* (2017) noted slower response times (15–25 seconds) at high humidity compared to 5–10 seconds at moderate levels. Shi *et al.* (2007) demonstrated that nanoporous sensors can achieve response times below 3 seconds due to their larger surface area. Despite increased error under extreme humidity conditions, the DHT11 remains adequate for mold-risk detection, as an error margin of 3–5% RH does not significantly alter risk categorization when relative humidity exceeds 70%.

The dashboard data revealed a distinct diurnal pattern: peak temperature occurred during midday (28.5°C), while the lowest was observed at dawn (21.5°C), yielding a 7°C fluctuation. Conversely, relative humidity peaked during early morning hours (85%) and declined to its minimum at midday (55%), with a 30% RH difference. This inverse relationship aligns with thermodynamic principles, particularly the Clausius–Clapeyron relation, which explains that air's moisture-holding capacity increases with temperature, thereby reducing relative humidity even if the absolute water vapor content remains constant. Kleinknecht *et al.* (2015) identified similar patterns, with humidity peaking between 04:00–06:00 (85–95%) and reaching its minimum between 12:00–14:00 (45–55%). Likewise, Yulkifli *et al.* (2023) documented diurnal soil temperature variations of 5–8°C and humidity fluctuations of 15–25% RH, reinforcing the advantage of IoT-based systems in enabling accessible and remote environmental monitoring. The early morning condition, with 85% humidity and 21.5°C temperature, represents an ideal environment for fungal growth; thus, the system effectively identifies critical periods for preventive measures such as activating a dehumidifier or improving ventilation. The integrated IoT system maintained an average measurement error of 1–2% for temperature and 3–5% for humidity, indicating consistency from data acquisition to dashboard visualization. Data transmission success reached 98% across 500 transmissions within a 24-hour period, with 2% losses attributed to transient Wi-Fi disruptions. Murdyantoro *et al.* (2019) reported similar IoT communication reliability (95–99%) within 50–100 m Wi-Fi ranges operating at 1–54 Mbps. Yulkifli *et al.* (2023) further confirmed long-term ESP32 stability over six months of continuous operation, with failure rates below 1% and deep-sleep power consumption between 10–20 µA. Although capacitive sensor drift was minimal (<0.5% RH annually) as reported by Deng and He (2014), periodic calibration every 6–12 months remains recommended for optimal accuracy.

The web-based dashboard fulfilled its role as an intuitive and informative user interface, providing real-time access from multiple devices for remote environmental monitoring. Liu *et al.* (2009) reported that 92% of respondents preferred digital displays for their readability and accessibility, while Duran *et al.* (2009) emphasized user-friendliness as a key determinant of monitoring technology adoption. Hajela (2020) further asserted that sensor-based systems should serve as complementary tools rather than replacements for human observation. The inclusion of a color-coded visual scheme (green for safe, yellow for caution, and red for hazard) simplified interpretation, reducing user dependency on numeric readings. The IoT-based monitoring system proved effective in preventing mold growth with low implementation costs (approximately IDR 200,000–300,000), significantly more economical than mold remediation expenses, which can reach several million rupiah. Its non-invasive nature makes it suitable for tropical climates with high humidity levels, particularly in rooms with limited ventilation. Yulkifli *et al.* (2023) emphasized the system's long-term operational stability with minimal maintenance and low annual operating costs (below IDR 50,000). Murdyantoro *et al.* (2019) also demonstrated the low power consumption (<500 mW) and scalability of IoT systems, allowing sensor expansion without major architectural changes. Nevertheless, the system should be regarded as an early warning tool rather than a standalone solution. Structural factors such as roof leakage or inadequate ventilation must still be addressed through corrective building

maintenance. Dante *et al.* (2020) recommended periodic recalibration (every 6–12 months) to maintain measurement reliability. The system's limitations include (1) lower accuracy of DHT11 compared to industrial-grade sensors such as SHT31 or BME280, (2) dependency on stable internet connectivity, and (3) its passive nature requiring user intervention. Future developments could incorporate automatic notifications, actuator integration (fans, dehumidifiers), data export features (CSV/Excel), and machine learning algorithms for risk prediction based on historical environmental patterns.

5. Conclusion and Recommendations

Based on the implementation and testing results, it can be concluded that the DHT11 sensor is capable of measuring room temperature and humidity with sufficient accuracy to detect environmental conditions that may promote mold growth on wall surfaces. The ESP32 microcontroller functioned effectively in collecting data from the sensor and transmitting it in real time to the Firebase Realtime Database, which then displayed the results through a web-based dashboard in the form of numerical indicators, tables, and graphical representations of temperature and humidity variations. The interactive and informative dashboard allowed users to easily monitor room conditions and determine whether temperature and humidity levels were within the ideal range—between 18°C and 29°C for temperature and 40% to 60% relative humidity. When these parameters exceeded the recommended limits, the system effectively indicated a potential risk of mold development due to high humidity and insufficient air circulation.

The system implementation demonstrates that Internet of Things (IoT) technology can be effectively utilized to prevent mold growth in indoor environments by continuously monitoring key environmental parameters. The system operated stably and displayed measurement results accurately, supporting efforts to maintain a healthy and comfortable indoor environment, particularly in tropical regions such as Indonesia, where humidity levels are typically high. Moreover, the system offers a cost-effective and easily deployable solution suitable for various scales of application, from residential rooms to storage facilities. For future development, several improvements are recommended to enhance system performance and functionality. These include using higher-accuracy sensors such as the DHT22 or SHT31, integrating an automatic notification feature that alerts users when temperature or humidity exceeds safe thresholds, and connecting the system with active control devices such as fans or dehumidifiers to enable automated environmental adjustments. In addition, incorporating a historical data storage feature would allow long-term trend analysis of temperature and humidity, serving as a foundation for room maintenance planning and predictive system development using artificial intelligence. With these enhancements, the system has the potential to evolve from a passive monitoring tool into an intelligent platform capable of providing early warnings and executing preventive actions automatically, thereby supporting sustainable indoor air quality and building health management.

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