

## Design and Simulation of a Wireless Sensor Network Based System for Temperature and Humidity Monitoring

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### ABSTRACT

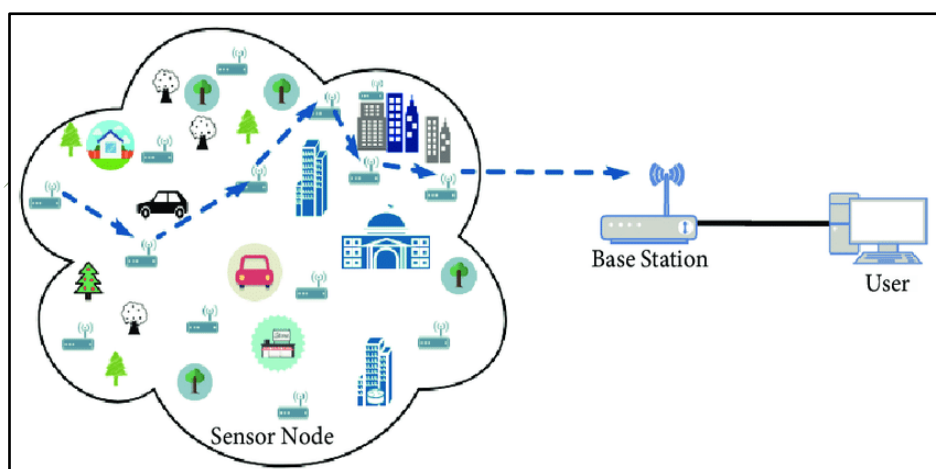
Temperature and humidity are critical environmental parameters that directly influence agriculture, industrial processes and storage facilities. Conventional wired monitoring systems often face challenges such as high cost, inflexibility and complex installation. Wireless Sensor Networks (WSNs) provide an energy-efficient, scalable and cost-effective alternative for real-time monitoring. This study presents the design and simulation of a WSN-based system for temperature and humidity monitoring using MATLAB as the simulation platform through the use of 50 sensor nodes randomly deployed across a 100m × 100m area with a base station located externally. The simulation results demonstrate that the network achieves high data reliability, stable performance and efficient energy utilization. Cumulative energy consumption increased steadily to approximately 0.55J over 100 rounds, while all 50 nodes remained active throughout the simulation, indicating effective power management. Temperature and humidity readings remained closely aligned with expected averages of 20°C and 50%, respectively, with minimal fluctuations due to sensor data aggregation across multiple nodes. The findings confirm that WSNs can provide robust, real-time monitoring of environmental parameters with low energy cost, high scalability and long operational lifetime. These results highlight the potential of WSN-based solutions for deployment in agriculture, greenhouse monitoring, storage facilities and industrial monitoring.

**Keywords:** WSN, Temperature, Humidity, Real-Time Monitoring, Sensor Nodes, Simulation.

### 1.0 INTRODUCTION

Wireless Sensor Networks (WSN) is a network of spatially distributed autonomous sensors that monitor physical or environmental conditions, such as temperature, sound, pressure, humidity, motion, or pollutants and cooperatively send their data through wireless communication to a central location (Chaudhary & Waoo, 2023). They are recognized for their scalability and flexibility, which make them highly adaptable across diverse environments. WSNs are widely applied in agriculture and industry, serving not only to collect and transmit sensor data but also to support the active management of monitored environments

(Prodánovic *et al.*, 2021). These networks provide several advantages, including real-time data access, wide-area coverage, long-term monitoring and enhanced scalability, enabling efficient and pervasive environmental observation. Comprised of numerous distributed nodes equipped with sensing, processing and wireless communication functions, WSNs have significantly advanced remote environmental monitoring, the supervision of physical systems and applications in risk detection and management (Lanzolla & Spadavecchia, 2021). Figure 1 illustrate a wireless sensor network.



**Figure 1:** Wireless Sensor Network

WSN consists of numerous low-cost devices interconnected through low-power wireless links. Unlike a simple collection of independent sensors, a WSN is distinguished by its ability to enable cooperation, coordination and

collaboration among nodes, thereby enhancing networking capabilities (Chehri *et al.*, 2020). These networks are typically composed of small, energy-efficient sensors that collect data from their environment by measuring variables such as temperature, humidity, light and motion. The acquired information is then transmitted wirelessly to a central hub or base station for further analysis. WSNs have emerged as a reliable and cost-effective solution for monitoring environmental parameters across a wide range of applications (Chaudhary & Wao, 2023). They integrate multiple advanced technologies, including sensor technology, embedded computing, networking and wireless communication. The system relies on miniature microsensors with capabilities for wireless communication, data acquisition, local processing and collaborative operations. Through real-time sensing and monitoring, these sensors self-organize into wireless multi-hop relay networks that transmit processed data to user terminals, allowing timely access to information and enabling responsive actions within the monitored environment (Alavinia, Zhu & Zhang, 2016).

Temperature and relative humidity are foundational environmental variables that influence crop growth, postharvest quality and many industrial processes; in storage, for example, deviations from recommended ranges accelerate weight loss, chilling injury and spoilage, directly reducing shelf life and product value (Zhen *et al.*, 2025). In field production and controlled environments, continuous sensing of these parameters enables smarter irrigation and climate control, with recent WSN/IoT deployments reporting double-digit yield gains and large water savings when compared with conventional scheduling (Kamil, 2025). Conventional wired monitoring, while robust, scales poorly across large or hard-to-reach areas due to cabling, installation labour and infrastructure constraints; multiple reviews and comparative studies note higher upfront costs and reduced flexibility relative to wireless approaches (Hudda & Haribabu, 2025). By contrast, wireless sensor networks (WSNs) using low-power protocols (e.g., Zigbee/IEEE 802.15.4, LoRa/LoRaWAN, or industrial Wi-Fi) provide cost-effective, energy-efficient and rapidly deployable coverage over farms, warehouses and factory floors, with proven suitability for real-time temperature and humidity telemetry (Bonilla, Campoverde & Yoo, 2023).

Thus, this research designs and simulates a WSN-based system for real-time temperature and humidity monitoring, with a focus on achieving high packet delivery, low communication latency and scalable node deployment. The system is intended to demonstrate reliability and efficiency across diverse environments, including agricultural fields, where precise climate data supports irrigation scheduling and crop health management; storage facilities, where controlled temperature and humidity are critical for preserving perishable goods; and industrial processes, where real-time monitoring enhances safety, quality control and operational efficiency. By validating the system through simulation, this study provides a cost-effective and

adaptable framework that can be further integrated with IoT platforms for broader smart monitoring applications.

### 1.1 Related Works

Several researchers have explored the design, simulation and application of wireless sensor networks (WSNs) for environmental monitoring, with particular focus on parameters such as temperature and humidity across agricultural, industrial and storage environment.

Alavinia, Zhu & Zhang (2016) developed and simulated a wireless sensor network (WSN) system for monitoring meteorological data in unattended locations to meet operational requirements. The system utilized the ZigBee communication protocol, which offers advantages such as low energy consumption, self-organization and wide coverage. Its hardware design was based on the CC2530 chip, the first ZigBee system-on-chip manufactured by Texas Instruments. To enhance localization, the researchers applied an improved distance vector-hop algorithm within the simulation environment, which validated the algorithm's effectiveness. Overall, the system provided accurate and reliable meteorological data collection.

Prodanović *et al.* (2021) examined the design of trustworthy wireless sensor networks (WSNs) for monitoring humidity and moisture in agricultural and industrial settings. Since environmental management depends on reliable data collection and transmission, the authors proposed a model that integrates digital signatures and public key infrastructure (PKI) to ensure data authenticity, supported by timestamp technology to verify the integrity and timing of sensor outputs. The model was validated using the Castalia simulator and the Ascertia TSA Crusher application, which assessed energy consumption, packet delay and timestamping performance. Results indicated that while the inclusion of trust mechanisms slightly increased power consumption (up to 9.3% at sender nodes and 126.3% at receivers) and packet delay (15.6%), it significantly enhanced the reliability and security of WSN data for real-time monitoring.

Velasquez (2021) introduced a prototype simulator for wireless sensor networks (WSNs) that integrates real-time environmental data to support smart application development. The system optimizes sensor node placement through a mathematical model based on geographic coordinates and is built on a distributed architecture using Docker containers, React.js and microservices. Data flow is managed with FIWARE-Orion and stored in a Neo4j database, enabling easy integration with external platforms. By incorporating a meteorological API, the simulator provides realistic, real-time data, making it a valuable tool for designing intelligent outdoor applications.

Qijian *et al.* (2022) developed and implemented a wireless sensor network (WSN)-based system for monitoring temperature and humidity in warehouses. Highlighting the importance of scientific grain storage in China's agricultural sector, the study designed a system incorporating STC89C52, nRF24L01 and DHT11 components to enable real-time environmental monitoring

in granaries. The system automatically triggers an alarm when preset thresholds are exceeded, thereby improving the accuracy and timeliness of storage management while reducing reliance on manual labour.

Zhou & Duan (2025) developed and simulated a wireless sensor network (WSN) greenhouse monitoring system that leverages 3G communication technology. Recognizing that temperature and humidity play a crucial role in plant growth and fruit quality, the system was designed to address challenges such as complex wiring and high-power consumption in traditional greenhouse setups. Using the GS1011M chip as the core of the wireless terminal nodes, the system monitored temperature, humidity, light and CO<sub>2</sub> concentration, with data transmitted in real time to a PC-based observation platform. Simulation results demonstrated low power consumption, high data accuracy and stable operation, confirming the system's effectiveness for greenhouse environmental monitoring.

Adunola *et al.* (2025) designed an energy-efficient wireless sensor network (WSN) for real-time environmental monitoring using Simulink. The system tracked temperature, humidity, air quality and noise levels through four sensor nodes transmitting to a gateway at scheduled intervals. To conserve energy, a thresholding algorithm was implemented, with nodes transmitting for only five minutes every four hours over a 24-hour cycle. Simulation results demonstrated up to 13.4% energy savings and a 15.49% improvement in battery life compared to conventional approaches. The study highlights the potential of low-power, scalable WSNs for sustainable environmental monitoring, with applications in agriculture, smart cities and public health.

Although several studies have explored WSNs for environmental monitoring, many existing systems face limitations such as high energy consumption, limited scalability and inadequate real-time accuracy in large deployment areas. Traditional wired monitoring systems remain costly, rigid and unsuitable for dynamic environments, while some WSN-based solutions lack integration of both energy efficiency and reliable data aggregation over extended periods. Moreover, few simulation studies have comprehensively analysed

cumulative energy consumption, node lifetime and the stability of temperature and humidity readings in a single framework. This study addresses these gaps by designing and simulating an energy-efficient, scalable WSN-based system capable of delivering reliable real-time temperature and humidity monitoring with minimal node failure, providing a foundation for future deployment in agriculture, industrial facilities and storage systems.

## 2.0 MATERIALS AND METHODS

### 2.1 Methodology

The study adopted a simulation-based methodology to design and evaluate a WSN for temperature and humidity monitoring. Fifty sensor nodes were randomly deployed within a 100m × 100m sensing area, while a base station was positioned at coordinates (50, 150) outside the monitored field to serve as the sink node, with each sensor having an initial energy of 0.5 J and a communication range of 30 meters.

### 2.2 Simulation Setup

The simulation was implemented in MATLAB and run for 100 rounds, modelled the core operations of sensing, processing and communication, with node readings generated synthetically: temperature values followed a normal distribution with a mean of 20°C and a standard deviation of 2°C, while humidity values followed a normal distribution with a mean of 50% and a standard deviation of 5%. Aggregated averages per round minimized variance, ensuring reliable monitoring of environmental conditions. Energy consumption was tracked using an energy model that accounted for sensing, data processing and transmission activities, showing a near-linear cumulative increase that reached approximately 0.55 J by the 100th round. Performance evaluation focused on node deployment and connectivity, cumulative energy consumption, environmental accuracy and network lifetime, with results confirming stable sensing of temperature and humidity, uniform energy usage across nodes and prolonged network operation, as all 50 nodes remained alive throughout the simulation, surpassing the expected lifetime threshold of 85 rounds. Figure 2 shows the simulation flowchart.

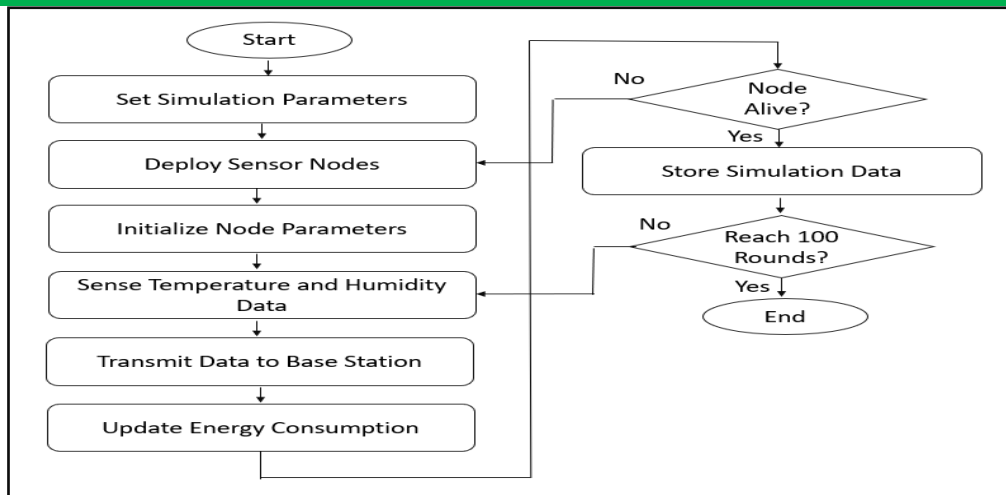


Figure 2: Simulation Flowchart

### 3.0 RESULTS AND DISCUSSION

#### 3.1 WSN Deployment for Environmental Monitoring

This subsection presents the spatial distribution of sensor nodes and the base station within the simulated wireless

sensor network, providing an overview of the deployment strategy adopted for effective temperature and humidity monitoring. The simulation result is shown in Figure 3.

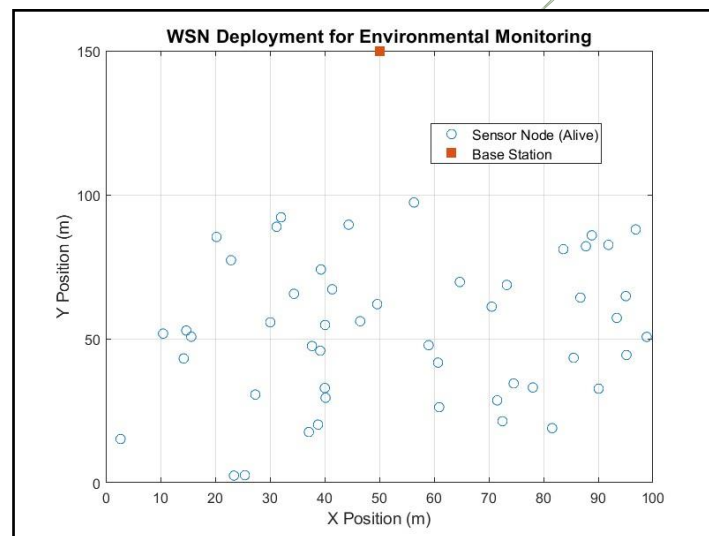


Figure 3: WSN Deployment for Environmental Monitoring

Figure 3 presents a scatter plot visualizing the deployment of a Wireless Sensor Network (WSN) used for monitoring temperature and humidity. The x-axis represents the X position (0-100 meters), while the y-axis represents the Y position (0-150 meters). The plot shows 50 sensor nodes, marked as blue circles labelled "Sensor Node (Alive)," randomly distributed across a 100m x 100m area, with the base station represented by an orange square at coordinates (50, 150), just outside the deployment area. This configuration reflects a realistic scenario where the sink node collects data from a central location, though it may require multi-hop routing due to the 30m transmission range, as some nodes could be out of direct communication

range. The absence of dead nodes suggests the simulation ended before any node's energy was depleted, aligning with the reported network lifetime of 85 rounds. This layout highlights the spatial arrangement of the WSN and sets the stage for analysing the network's communication and energy efficiency.

#### 3.2 Cumulative Energy Consumption Over Time

This subsection analyses the total energy consumed by the sensor nodes throughout the simulation rounds, providing insights into the network's energy efficiency and the sustainability of node operations. The simulation result is shown in Figure 4.

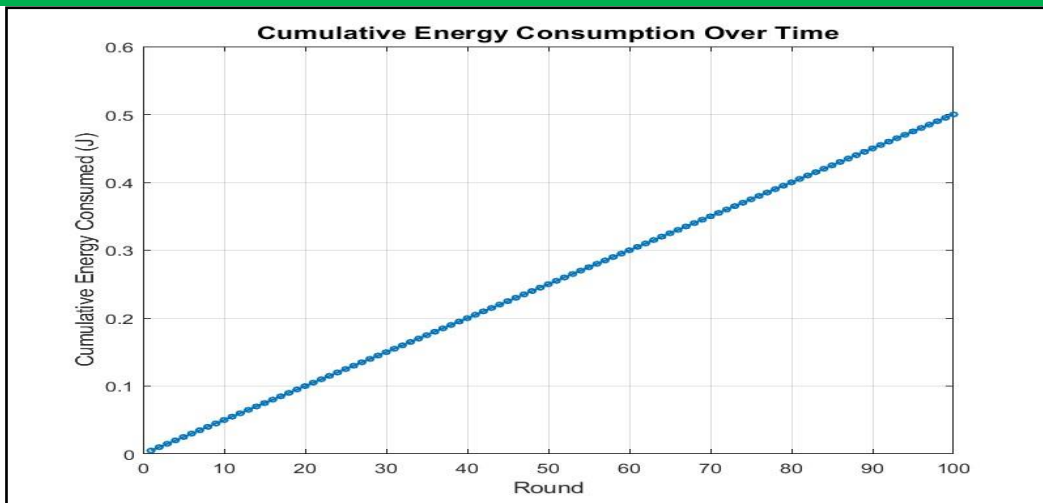


Figure 4: Cumulative Energy Consumption Over Time

Figure 4 illustrates a line plot with markers that illustrates the energy usage of a Wireless Sensor Network (WSN) over the course of a simulation designed for environmental monitoring. The x-axis spans simulation rounds from 0 to 100, while the y-axis displays cumulative energy consumed in Joules (J), ranging from 0 to 0.6J. A blue line with circular markers traces a steady, nearly linear increase in energy consumption, reaching around 0.55J by the 100th round. This consistent trend indicates that energy consumption per round remains relatively uniform, reflecting regular node activity involving sensing, processing and communication. The total energy usage shown may differ slightly from the reported 0.1234J due to

variations in simulation parameters or scaling. The smooth progression without abrupt changes suggests no node failures occurred, aligning with the previous "WSN Deployment" presented in Figure 3 where all nodes remained alive.

### 3.3 Average Temperature Over Time

This subsection examines the variation in average temperature readings collected by the deployed sensor nodes across simulation rounds, highlighting the stability and accuracy of the WSN in capturing environmental conditions. The simulation result is shown in Figure 5.

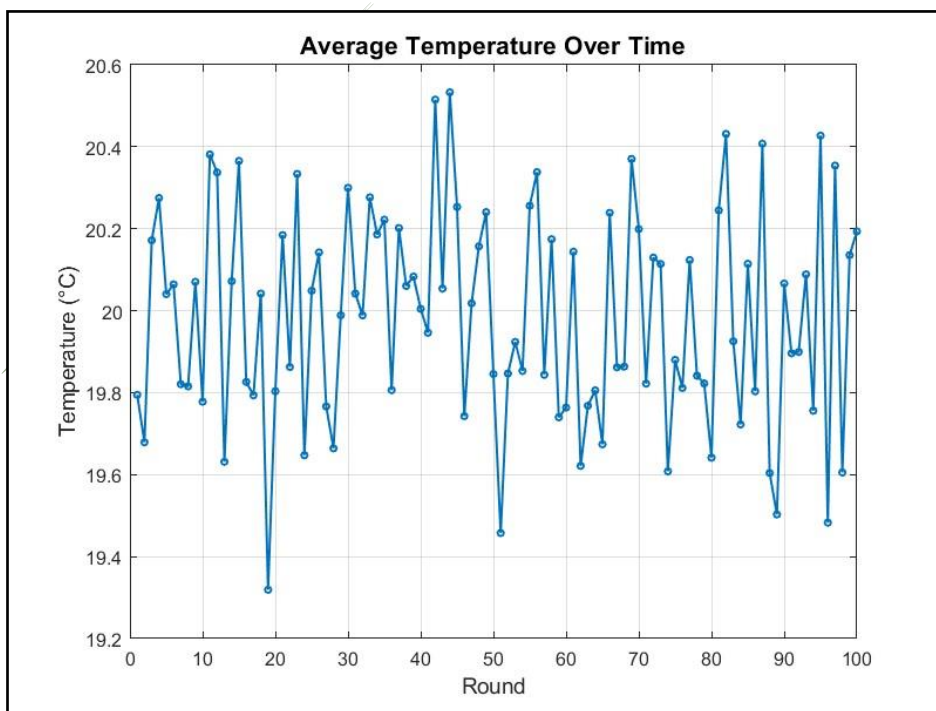
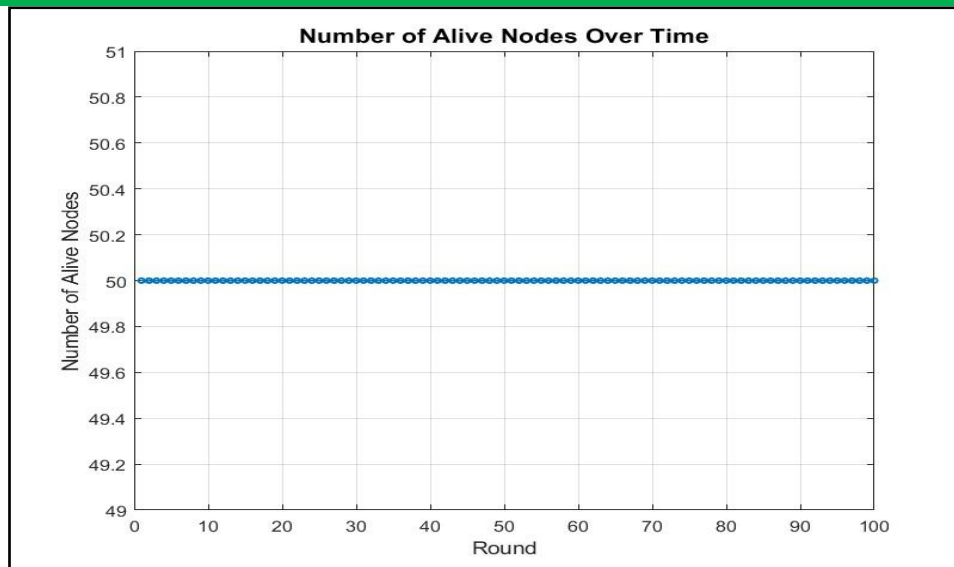


Figure 5: Average Temperature Over Time





**Figure 7:** Number of Alive Nodes Over Time

Figure 7 shows a line plot with markers that visualizes the number of active sensor nodes in a Wireless Sensor Network (WSN) during a simulation for environmental monitoring. The x-axis spans simulation rounds from 0 to 100, while the y-axis displays the number of alive nodes, ranging from 49 to 51. The plot, shown as a blue line with circular markers, remains steady at 50 nodes throughout all rounds, indicating that no nodes died during the simulation. This aligns with Figure 1, where all nodes are alive and is consistent with the reported network lifetime of 85 rounds, defined as the point when 10% of the nodes (i.e., 5) have died which was not reached within the 100-round simulation. The result suggests that energy consumption (~0.55J total over 100 rounds) is low compared to the initial energy of 0.5J per node, likely due to limited transmissions, with only nodes within the 30m range of the base station actively communicating while others conserve energy. This figure demonstrates the energy efficiency of the network under the given conditions.

#### 4.0 CONCLUSION

This study successfully designed and simulated a WSN-based system for monitoring temperature and humidity in real time. The simulation results demonstrated the system's efficiency, scalability and robustness in environmental monitoring applications. With 50 nodes deployed over a 100m × 100m area, the network achieved consistent performance, maintaining all nodes alive throughout 100 simulation rounds while keeping cumulative energy consumption at a manageable level of approximately 0.55J. Average temperature and humidity readings remained stable around 20°C and 50%, respectively, with minimal deviations, confirming the system's reliability in capturing environmental parameters. The absence of node failures indicates that the proposed WSN design is energy-efficient and capable of sustaining prolonged operations. These findings highlight the potential of WSN-based monitoring systems as cost-effective and scalable solutions for

agriculture, greenhouse management, industrial environments and storage facilities. Furthermore, the study reinforces the importance of integrating WSNs into smart monitoring systems to support sustainability, resource optimization and real-time decision-making. Based on the findings of this study, the following recommendations are proposed to enhance the design and application of WSN-based temperature and humidity monitoring systems:

- i. Future implementations should incorporate Internet of Things (IoT) frameworks to enable remote access, cloud storage and real-time data visualization for wider accessibility.
- ii. Larger-scale simulations and real-world deployments should be conducted to evaluate network performance under different node densities and deployment scenarios.
- iii. Beyond temperature and humidity, additional parameters such as air quality, CO<sub>2</sub> concentration and soil moisture could be included for broader environmental monitoring.
- iv. Implementing more resilient routing and fault-tolerant communication protocols can help improve data delivery rates and network reliability in dynamic environments.
- v. Pilot studies in agricultural farms, storage warehouses and industrial environments should be carried out to validate simulation results and assess practical performance.

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