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Low-Cost Internet of Things (IoT)-Based Climate Control Automation for Improved Poultry Growth and Survival in Least Developing Countries

Md. Azizul Hakim Bappy [1] , Md. Rifat Hoshen [1] , Md. Mujtuba Rafid [1] , Md. Mahabub Hossain [1] , Mst. Afroja Khatun [2]

1. Department of Electronics and Communication Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur, BGD 2. Department of Dairy and Poultry Science, Hajee Mohammad Danesh Science and Technology University, Dinajpur, BGD

Corresponding author: Md. Mahabub Hossain, mahabub@hstu.ac.bd

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Abstract

Poultry farming in areas with unpredictable or extreme climates needs practical, low-cost solutions to mitigate risks and enhance productivity of the farm. This study looks at whether using a proposed budget-friendly automation system can make poultry farming stronger and more reliable, especially in places with tricky weather in the context of southern Asia's least developed countries. This work describes a 35-day experimental deployment of a budget-friendly Internet of Things (IoT) climate control system for poultry farming in Bangladesh. The proposed automated climate-control system comprising with low-priced sensors and Arduino microcontrollers, which was installed in a shed featured for real-time monitoring and adjustment of temperature, humidity, and ammonia levels. Six DHT11 sensors were employed to monitor temperature and humidity, while a couple of MQ137 sensors measured ammonia levels. Data were recorded and crunched numbers to evaluate the effectiveness of the automated system and figure out how effective the automated system was. Side-by-side comparisons of a poultry shed equipped with an automated climate system and a standard traditional shed were investigated. It was found that there were significant improvements in how well the chickens grew and how many survived in the automated shed compared to the traditional one. Chicken growth increased by 26.19%, and deaths decreased by more than 13.33%. The statistical analysis revealed that the automated shed kept things much more consistent; temperature, humidity, and NH_3 gas levels were more stable and less likely to fluctuate wildly. This shows that this low-cost, microcontroller-based automated climate control system can be an effective way to improve poultry farming, particularly when dealing with tough weather conditions. The results and analysis presented in this paper provide a valuable pathway for future researchers, offering insights into what can be expected when applying similar low-cost IoT-based climate control systems in poultry farming in the context of least developed countries .

Categories: Agricultural Machinery and Automation, Innovation and Technology Management, Electronics Design and VLSI
Keywords: microcontroller controlled farming, farm climate control, farm automation, sensor network, poultry farming in bangladesh

Introduction

Poultry is a cornerstone of global food systems, providing essential protein and supporting livelihoods worldwide [1]. Global poultry meat production exceeded 137 million tons in 2022, with broiler meat accounting for over 90 million tons [2]. In Bangladesh, poultry is one of the fastest-growing livestock subsectors, producing nearly 3.5 million tons of meat annually and contributing about 40% of the country's total meat supply [3]. However, poultry production remains highly vulnerable to climate variability and extreme weather events. Heat stress alone is estimated to cause annual mortality rates of 5-10% in tropical regions, resulting in billions of dollars in global economic losses [4,5]. Fluctuations in environmental conditions, especially temperature and humidity, and ammonia concentration directly compromise poultry health and productivity, leading to reduced feed efficiency, disease susceptibility, increased mortality, and significant economic losses for farmers [6]. Traditional poultry farming methods often struggle to effectively mitigate these complex environmental stressors, particularly in resource-limited settings [7]. Therefore, affordable and effective climate control solutions are urgently needed to enhance the resilience and sustainability of poultry farming globally [8].

The rise of automation is evident across modern industries, yet research on poultry automation tailored to the harsh climate of southern Asia's least developed countries like Bangladesh remains sparse. This gap highlights the importance of reviewing existing literature to inform and optimize our system's design. Ni et al. [9] explored the impact of environmental factors such as ammonia, carbon dioxide, hydrogen sulfide, dust, temperature, and humidity on layer hens. Their findings, recommending temperature and humidity ranges of 15-20°C and 60-70% relative humidity, guided the thresholds for environmental control in the

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poultry shed. Lara and Rostagno [10] reviewed the effects of heat stress on poultry, particularly broilers and laying hens, noting physiological changes such as reduced feed intake and impaired reproductive function. Their strategies for mitigation environmental management, nutritional adjustment, and genetic selection provided valuable insights into managing poultry stress. Mottet et al. [11] examined climate change's impact on poultry production, highlighting thermoregulatory mechanisms like panting and metabolic adjustments. However, these mechanisms falter under extreme temperatures, underscoring the need for controlled environmental systems. Research by Zeyad et al. [12] identified optimal temperature and humidity levels for poultry farming as 20-25°C and 60-80%, respectively. Shahzad et al. [13] developed energy-efficient evaporative cooling systems capable of reducing temperatures by 5-12°C. However, considering cost constraints in Bangladesh, we adopted simpler solutions involving heaters, humidifiers, and exhaust fans. Maintaining these conditions is critical, as temperatures exceeding 26°C with relative humidity above 40% can cause heat stress [14].

The ammonia levels significantly impact poultry farming, as Naseem and King [15] and Kristensen and Wathes [16] demonstrated, with effects such as reduced weight gain, poorer feed conversion, and increased disease susceptibility. Sousa et al. [17] further emphasized the economic and environmental implications of excessive ammonia. Maintaining ammonia levels below 25 ppm, as recommended by Naseem and King [15], and Watson and Wiedemann [18], is crucial for bird health and performance. Several techniques to control ammonia emissions have been explored. Singh et al. [19] proposed using urease inhibitors to block enzyme activity in poultry litter, while Lahav et al. [20] introduced systems for converting ammonia-rich air into ammonium. Rothrock et al. [21] focused on gas-permeable membranes for ammonia recovery, and Bejan et al. [22] reviewed chemical methods, favoring electrochemical hypochlorination. These studies offer a variety of viable strategies to reduce ammonia emissions. Knowledge gaps persist, particularly in integrating multiple environmental management practices and evaluating the economic feasibility of ammonia control measures at scale.

The potential of Arduino in poultry automation has been demonstrated through various studies [23]. Soh el al. [24] developed an Arduino Uno-based automatic feeder, improving efficiency and reducing labor. Raghudathesh et al. [25] utilized Arduino Mega and Raspberry Pi for an Internet of Things (IoT)-based intelligent poultry management system, effectively monitoring and regulating environmental parameters. Kaimujjaman et al. [26] assessed sensor-based automation's viability in poultry farming, revealing improvements in the Broiler Farm Economy Index. Hofstetter et al. [27] designed a system that can sustain stable ammonia level in poultry coup. However, these studies did not specify the season and periodic timing of the experiments, leaving a critical contextual gap in understanding their full applicability.

In this study, we addressed this critical gap by investigating the potential of low-cost microcontroller-based automated climate control systems for poultry sheds. Leveraging easily available sensors and Arduino microcontrollers, we proposed an automated climate-control system comprising low priced equipment and evaluated the efficacy of such a system in maintaining stable and optimized environmental conditions specifically temperature, humidity, and air quality. Through a comparative study against traditional farming practices, we assessed the impact of this proposed automated solution on poultry growth and survival rates. This study, moreover, shows the viability and benefits of accessible technology for building climate resilience in the poultry sector, offering valuable insights for enhancing food security and promoting sustainable agricultural practices in the face of ongoing climate change. The study is summarized visually in Figure *1*.

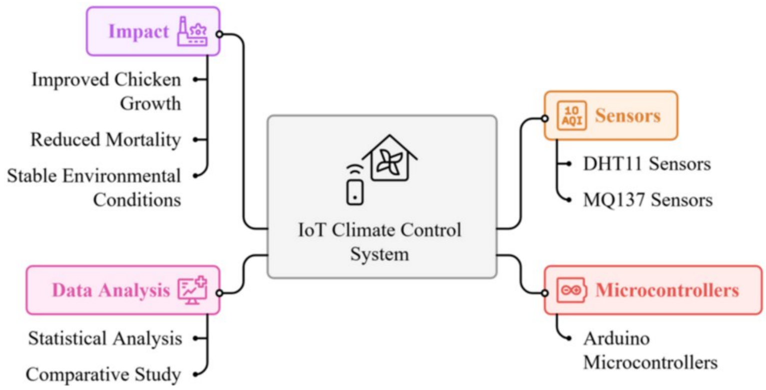

FIGURE 1: Summary of this study

Materials And Methods

Environmental setup and network system design

Study Location

Dinajpur is a northern district of Bangladesh (Figure *2*) experiences cold winters with temperatures averaging 15°C and occasionally dropping below 10°C, alongside humidity levels as low as 28%. These conditions pose challenges for poultry farming, increasing risks of respiratory issues and stress. Despite this, poultry farming remains vital for local livelihoods, food security, and nutrition in the region's agricultural landscape. Our study was conducted at Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh, where two poultry sheds were set up in collaboration with veterinary experts. This university setting ensured accessible, well-designed facilities and seamless coordination for effective monitoring and data collection, enhancing the study's scientific rigor and relevance.

FIGURE 2: Geographical context and study location. (Left) Position of Bangladesh within the broader South Asian region (Middle) highlighted Dinajpur District within Bangladesh, and (Right) specific study site within Dinajpur, Bangladesh. The red pin indicates the exact location of the experimental poultry sheds

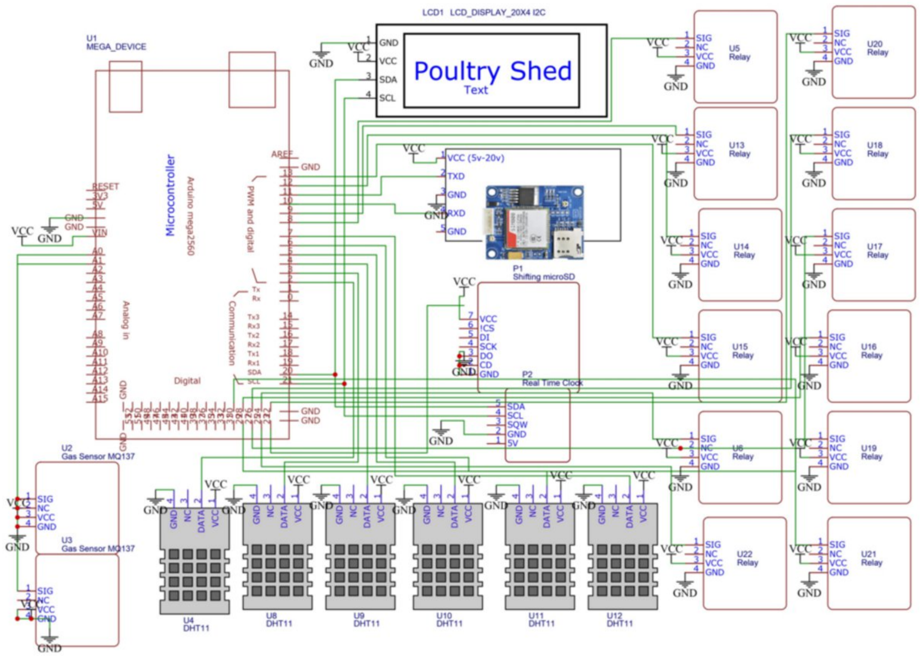

FIGURE 3: The circuit diagram shows how the relay controls the appliances in the designed network system

Name	Quantity	Manufacturer	Supplier	Measurement uncertainty	Price (USD) estimate
SIM808 Module	1	SIMCom	RoboticsBD	N/A	$38.52
Micro SD card module	1	Made in China	RoboticsBD	N/A	$0.66
Real Time Clock DS3231	1	Made in China	RoboticsBD	≈ ±0.4320 s/day (worst)	$2.05
Arduino Mega 2560 R3	1	Made in China (copy)	RoboticsBD	N/A	$11.05
Gas Sensor MQ137	2	Winsen	BDtronics	±10–±25 ppm	$13.96
DHT11 (clone)	6	Made in China (copy)	RoboticsBD	Temp: ±2.0°C; Humidity: ±5.0%RH	$1.23
Relay (10-Channel, 5V) Module	1	Techshop Bangladesh	Techshop Bangladesh	N/A	$7.37
20x4 Lcd Display I2c Module	1	Made in China	Techshop Bangladesh	N/A	$4.48
SIM Card	1	Local operator	Local Supplier	N/A	≈ $2 (typical SIM cost)
SD Card	1	SanDisk	RoboticsBD	N/A	$2.98
Ceiling Fan	1	Walton	Local Market	N/A	≈ $20 each
Light (bulb/tube)	6	Local	Local Market	N/A	≈ $2 each
Exhaust Fan	4	Walton	Local Market	N/A	≈ $15 each
Heater	2	Local	Local Market	N/A	≈ $5 each
CAT-6 Wire (per roll)	1	Local	Local Market	N/A	≈ $5
5V Adapter	1	Local	Local Supplier	N/A	≈ $2
LiPo Single-Cell Battery	1	Imported	RoboticsBD	N/A	≈ $3
AC 220V Relay	1	Local/Imported	Local Supplier	N/A	≈ $2
Humidifier	1	Imported	Local/Online Store	N/A	≈ $2

TABLE 1: Bill of materials with sensor's description

Microcontroller and Sensor Network Installation

The controlled environment shed was featured with automated systems for temperature, humidity, and ammonia gas level regulation, monitored by specialized sensors connected to an Arduino microcontroller, as shown in the network circuit setup of devices in Figure 3, while Table 1 describes the different hardware used for the project. Insulated materials maintained stable internal conditions, with heaters and humidifiers activated as needed to adjust temperature and humidity levels. In the controlled environment shed, six DHT11 sensors monitored temperature and humidity, providing comprehensive data across different sections to minimize measurement variations. Two MQ137 gas sensors at the center of the shed monitored ammonia levels, which are critical for air quality and poultry health. Both sets of sensors were strategically located to ensure representative measurements and efficient data collection. Figure 4 provides a schematic representation of the sensor distribution within the experimental poultry shed, which is crucial for comprehensive data collection. This placement strategy, informed by factors like airflow patterns and accessibility, aimed to optimize the reliability and effectiveness of the monitoring system, enabling thorough analysis of environmental conditions and their impact on poultry production.

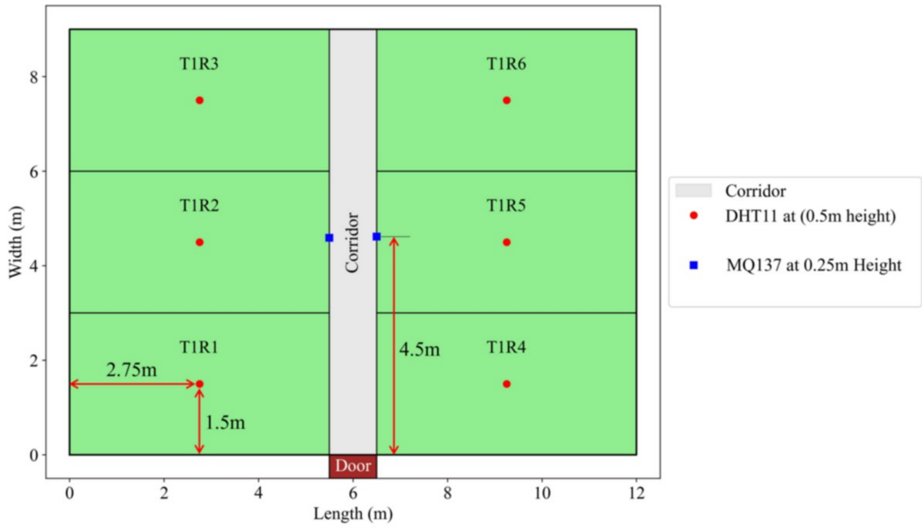

FIGURE 4: Schematic representation of the sensors placement within the experimental controlled cells in the poultry shed with same treatment (T) and several replications (R)

The system used an SD card reader to log data on temperature, humidity, and ammonia fluctuations, and daily summary reports were sent via GSM for remote monitoring. The Arduino microcontroller controlled the systems for adjusting the temperature, humidity, and ammonia levels inside the controlled shed in real time. It activated heaters and humidifiers to maintain optimal conditions, and ventilation fans when ammonia levels exceeded acceptable limits. In contrast, the traditional setup lacked automated controls, relying on standard poultry farming practices and external weather conditions, while identical chicken breeds and ages were housed in both environments. Details regarding the automated climate control system's design, including the specific environmental parameters, their trigger thresholds for automated action, and the associated appliances, are summarized in Table 2. The data collection was conducted simultaneously from both environmental sheds using sensor readings recorded at regular intervals. The overall control function is shown in Figure 5, while Algorithm 1 was implemented for the control flow.

Automation control variables			
Parameter	Appliance × Quantity	Trigger	Value taken from reference study
Temperature	Heater × 2	<20°C, >30°C	[9]
Humidity	Humidifier × 2	<50%	[9]
NH_3 concentration	Ventilation Fan × 5	>25 ppm	[12]

TABLE 2: Operational parameters, trigger thresholds, and associated appliances for the automated climate control system

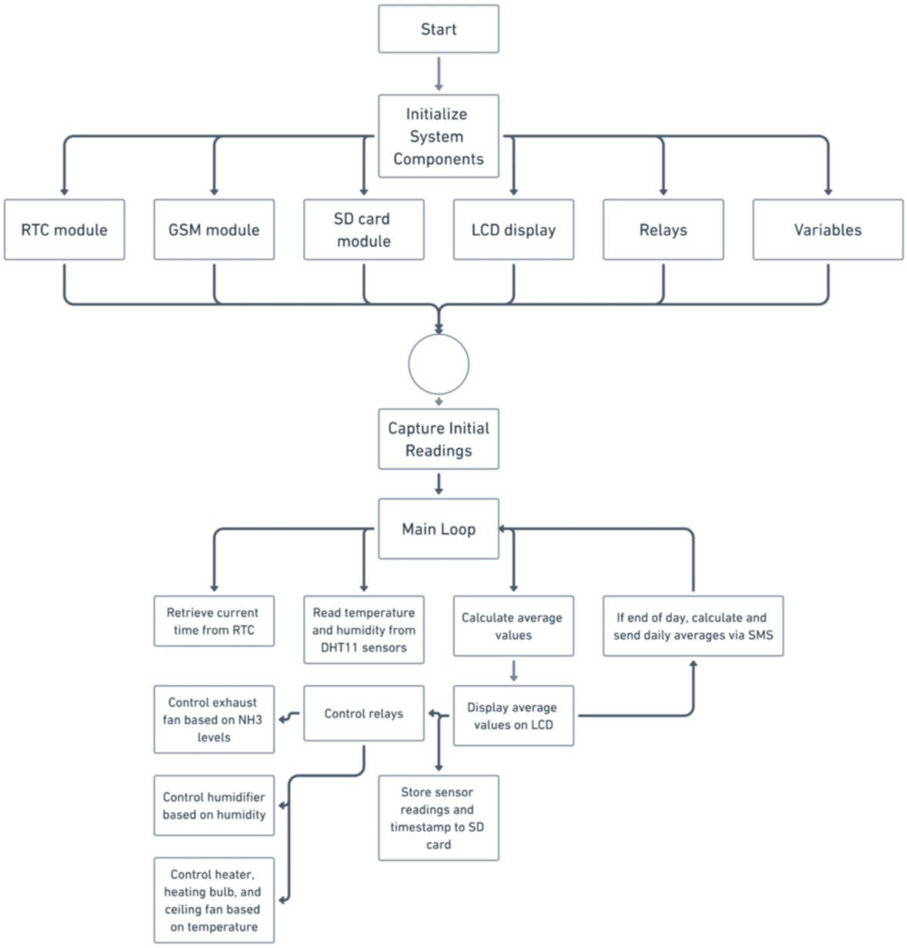

FIGURE 5: Flowchart of the working function of the automated system

Data acquisition, processing, and calibration

To ensure the accuracy, reliability, and meaningful interpretation of the environmental data collected, a structured approach to data acquisition, processing, and sensor calibration was employed. This included standardizing sensor readings, calibrating critical gas sensors, and defining the operational parameters for the automated climate control system.

The automated system continuously monitored key environmental parameters within the poultry sheds, namely temperature (T), relative humidity (H), and ammonia concentration (NH_3). To obtain a comprehensive and representative understanding of the environmental conditions, particularly where multiple sensors were deployed for a single parameter an average value was computed. The mean value ($\bar{X}$) for a given parameter from (N) individual sensor readings (X_i) was calculated as:

$$\bar{X} = \frac{1}{N}\sum_{i-1}^{N} X_i$$

(1)

This aggregation method minimized localized fluctuations and provided a more robust measure of the overall climate within the controlled environment. These processed values were logged to an SD card with timestamps and used for real-time control decisions as described in Algorithm 1.

The MQ137 gas sensors, crucial for monitoring air quality, underwent a specific calibration procedure to enhance the accuracy of ammonia concentration measurements. Ammonia sensors can exhibit a baseline offset, which needs to be accounted for. To quantify this inherent error, each MQ137 sensor was systematically placed in multiple distinct, air-tight containers, each meticulously confirmed to contain zero ammonia concentration. The sensor readings (Rj) from these control environments ($M_{containers}$)

were recorded, and an average measured error ($Error_{avg}$) was determined:

$$Error_{avg} = \frac{1}{M_{container}} \sum_{j-1}^{M_{container}} R_j \quad (2)$$

This $Error_{avg}$ value represents the sensor's baseline reading in the absence of ammonia. During the 35-day experimental deployment in the poultry sheds, the actual ammonia concentration in parts per million ($NH_{3,actual}$) was then calculated by subtracting this calibrated average error from the real-time sensor reading ($NH_{3,reading}$):

$$NH_{3,actual} = NH_{3,reading} - Error_{avg} \quad (3)$$

This calibration ensured that the system's response to ammonia levels was based on accurate measurements, thereby optimizing the ventilation strategy for poultry health.

Algorithm 1: The Pseudo Code for The System

```
Algorithm 1: Environmental Monitoring and Control System

Initialize Serial and GPRS serial communication.

Initialize RTC, LCD, MQ137, SD card, DHT sensors, relays, and SIM808 module.

Main Loop:

Read current time from RTC.

Read data from six DHT sensors; compute average temperature and humidity.

Read NH₃ concentration from MQ137.

Update hourly accumulators with avgTemp, avgHum, avgNH₃ and increment hourly count.

Update daily accumulators with avgTemp, avgHum, avgNH₃ and increment daily count.

Display averages (Temp, Hum, NH₃) on LCD and Serial output.

Apply control rules per zone:

    If Temp > TEMP_HIGH → Cooling ON.

    If Temp < TEMP_LOW → Cooling OFF, Heating ON.

    If Hum < HUM_LOW → Humidifier ON.

    If NH3 > NH3_HIGH → Exhaust ON.

Log sensor readings with timestamp to SD card.

Hourly Task (trigger: minute = 0)

If hourly readings exist:

    Compute hourly averages.

    Construct HTTP GET request with averages.
```

Use SIM808 to establish TCP, send request, close connection.

Reset hourly accumulators and counters.

Daily Task (trigger: 23:59)

If daily readings exist:

Compute daily averages (Temp, Hum, NH_3).

Format SMS: “Daily Avg - Temp: X °C, Hum: Y%, NH_3: Z PPM”.

Send SMS to predefined contacts via SIM808.

Reset daily accumulators and counters.

The effectiveness of the automated system was quantitatively assessed by comparing key biological outcomes between the controlled and traditional poultry sheds. Specifically, the percentage improvement in chicken growth rate and the percentage reduction in mortality rate was calculated. The percentage improvement in chicken growth rate was determined using the following formula:

$$GrowthImprovement(\%) = \frac{Weight_{avg.controlled} - Weight_{avg.traditional}}{Weight_{avg.traditional}} \times 100\%$$

(4)

Similarly, the percentage reduction in mortality rate was calculated as:

$$MortalityReduction(\%) = \frac{MortalityRate_{Traditional} - MortalityRate_{controlled}}{MortalityRate_{traditional}} \times 100\%$$

(5)

To quantitatively assess the effectiveness of the automated climate control system on biological outcomes (final chicken weight and survival rates), descriptive and inferential statistical analyses were performed. For each treatment group (controlled and traditional), the mean ($\bar{W}$) and standard deviation (*s*) were calculated to summarize central tendency and variability, using the formulas:

$$\bar{W} = \frac{1}{N}\sum_{i-1}^{N} W_i$$

(6)

$$s = \sqrt{\frac{1}{n-1}\sum_{n-1}^{n}\left(W_i - \bar{W}\right)^2}$$

(7)

where *Xi* is an individual observation and *n* is the number of observations. To determine statistical significance between the two groups, an independent samples Welch's t-test was conducted, calculating the t-statistic (*t*) as:

$$t = \frac{W_i - \bar{W}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

(8)

where $\bar{W}$, s^2, *n* represent the mean, variance, and sample size for groups 1 and 2, respectively. A significance level (α) of 0.05 was used, with p-values less than α indicating a statistically significant difference. All analyses were performed using Python (SciPy library). These calculations provided a clear, quantifiable measure of the direct benefits of the automated climate control system on poultry performance, as elaborated in the following sections.

Results And Discussion

Environmental conditions: stability achieved in the controlled shed

The environmental data within the controlled environment shed equipped with the automated climate control system were collected throughout the 35-day study period. The aim was to maintain conditions within optimal ranges despite external fluctuations, particularly during the challenging winter months.

Figure 6 illustrates the temperature profile within the controlled shed. Figure 6a, showing hourly temperatures over 35 days, reveals a discernible diurnal cycle, with temperatures typically lowest in the early morning hours (around 20°C) and peaking in the late afternoon (reaching up to 27°C on some days). However, the lines demonstrate remarkable consistency in this daily pattern across the entire study duration. Figure 6b, the box plot, further highlights this stability, showing that the daily temperature distributions were tightly clustered, with most days exhibiting median temperatures between approximately 22°C and 24°C. The relatively short box lengths and whiskers indicate limited intra-day variability, and the consistency of the box plot positions across the 35 days confirms that similar temperature ranges were maintained day after day.

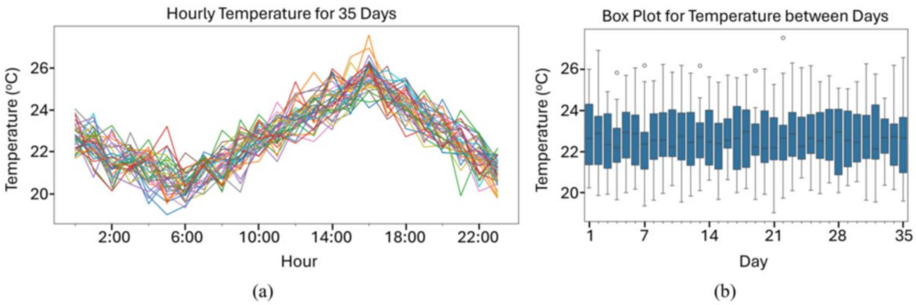

FIGURE 6: Temperature conditions inside the controlled environment shed over the 35-day study period. (a) Hourly temperature levels recorded each day, showing characteristic diurnal fluctuations. (b) Box plot summarizing the distribution of daily temperature levels across the 35 days, illustrating overall stability

Figure 7 displays the relative humidity levels inside the controlled shed. Figure 7a shows the hourly humidity data, indicating an inverse diurnal cycle compared to temperature, with humidity generally higher at night and lower during the day. The relative humidity consistently remained within a range primarily between 65% and 88% over the 35 days. Figure 7b's box plot reinforces this, illustrating that the daily humidity distributions were quite stable over the study period, with most days having median humidity levels between 70% and 80%. The box plots show a contained spread of daily values and consistent distributions across the days, reflecting the system's ability to manage humidity within a predictable range.

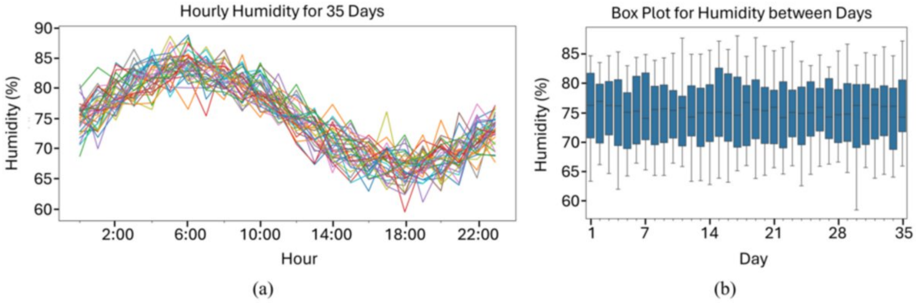

FIGURE 7: Relative humidity conditions inside the controlled environment shed over 35 days. (a) Hourly relative humidity levels recorded each day, showing characteristic diurnal fluctuations. (b) Box plot summarizing the distribution of daily relative humidity levels across the 35 days, illustrating overall stability

Finally, Figure *8* details the ammonia gas levels recorded within the controlled environment. Figure *8a*, the hourly data, suggests a diurnal pattern in gas levels, potentially linked to daily activity cycles within the shed. The concentrations consistently stayed within a range of approximately 16 ppm to 21 ppm. Figure *8b*, the box plot, further supports the observation of stability, showing consistent daily distributions of ammonia levels over the 35 days. Most daily medians fall between roughly 17.5 ppm and 19.5 ppm, with limited variability indicated by the box lengths and whiskers.

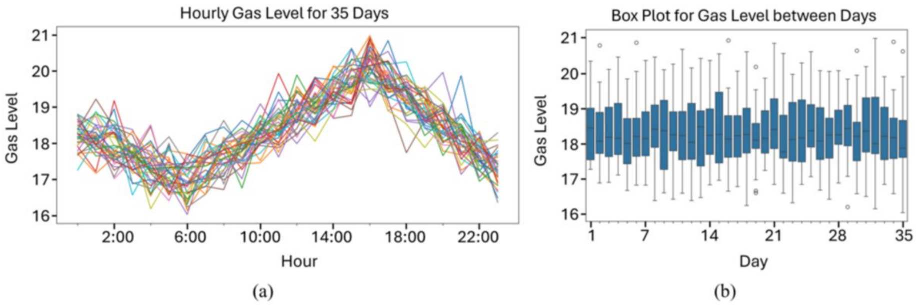

FIGURE 8: Ammonia gas levels recorded inside the controlled environment shed over 35 days. (a) Hourly ammonia gas concentrations recorded each day. (b) Box plot summarizing the distribution of daily ammonia gas levels across the 35 days, illustrating overall stability

Collectively, Figure *6*, Figure *7*, and Figure *8* demonstrate that the automated climate control system successfully maintained the temperature, relative humidity, and ammonia gas levels within relatively consistent and predictable ranges over the entire 35-day study period. While natural diurnal cycles were still present, the system ensured that the overall environmental conditions remained stable and within the bounds designed to be conducive to poultry health and growth, laying the foundation for the biological outcomes observed.

Environmental conditions: comparative analysis

To quantify the effectiveness of the automated system, a direct comparison of the environmental conditions in the controlled environment shed and the traditional shed was conducted over the 35-day study period. This analysis aimed to demonstrate the degree of stability and control achieved by the automated system relative to conventional practices during challenging winter conditions.

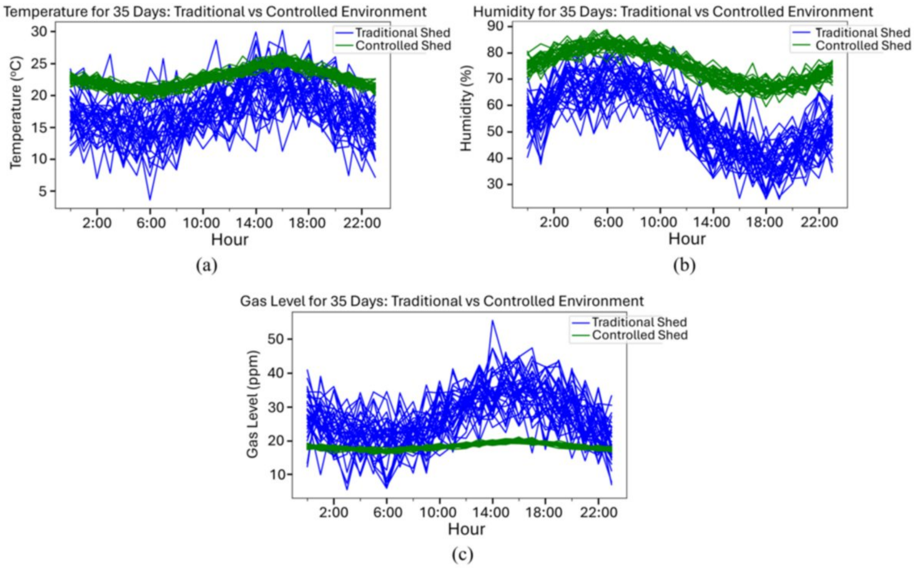

FIGURE 9: Comparative analysis of environmental conditions between the traditional and controlled environment sheds over 35 days. (a) Hourly temperature levels, (b) hourly relative humidity levels, and (c) hourly gas levels, showing the range and variability in both environments

Figure 9 provides a visual overlay of the hourly temperature, relative humidity, and gas levels recorded in both sheds over the 35 days. Figure 9a clearly shows that while the controlled shed (green lines) maintained temperatures within a relatively narrow band (primarily 20-27°C), the traditional shed (blue lines) experienced much wider and more extreme fluctuations, dropping significantly lower (down to around 5°C) and occasionally peaking higher than the controlled environment. Similarly, Figure 9b illustrates the humidity levels. The controlled shed consistently kept humidity within a desired range (around 65-88%), whereas the traditional shed saw humidity swings wildly from very low (below 30%) to very high (above 80%). Figure 9c highlights the dramatic difference in NH_3 level. The controlled shed maintained consistently low levels (around 16-21 ppm), while the traditional shed experienced highly volatile and significantly higher concentrations, frequently exceeding 30 ppm and spiking above 50 ppm.

Statistical values	Traditional			Controlled		
	Temperature	Humidity	Gas level	Temperature	Humidity	Gas level
count	840.00	840.00	840.00	840.00	840.00	840.00
mean	17.60	54.97	27.00	22.70	75.11	18.31
std	4.12	12.86	7.83	1.57	6.23	0.95
min	3.63	24.32	5.59	18.87	59.51	16.00
25%	14.82	45.40	21.59	21.51	69.71	17.57
median	17.46	55.57	26.57	22.54	75.30	18.25
75%	20.35	65.15	32.73	23.89	80.67	19.04
max	30.17	85.06	55.47	26.92	88.87	21.11

TABLE 3: Summary statistics (count, mean, standard deviation, minimum, quartiles, and maximum) of temperature, humidity, and gas levels recorded in the traditional and controlled environment sheds over the 35-day study period

Table 3 provides a statistical summary of the collected data for temperature, humidity, and gas levels in both sheds. This table quantitatively supports the visual differences seen in Figure 9. The mean temperature in the controlled shed was 22.70°C, closer to optimal poultry ranges, compared to a much lower mean of 17.60°C in the traditional shed. More crucially, the standard deviation for temperature in the controlled shed was only 1.57°C, indicating very low variability, whereas the traditional shed had a standard deviation of 4.12°C, reflecting significant fluctuations. Similar patterns are observed for humidity and gas levels. The controlled shed maintained a higher mean humidity (75.11%) with lower variability (std: 6.23%) compared to the traditional shed's lower mean (54.97%) and much higher variability (std: 12.86%). For gas levels, the controlled shed achieved a significantly lower mean (18.31 ppm) with minimal variability (std: 0.95 ppm), starkly contrasting with the traditional shed's high mean (27.00 ppm) and substantial variability (std: 7.83 ppm). The minimum and maximum values in Table 3 further emphasize the extreme range experienced in the traditional shed compared to the controlled environment. The spatial and temporal distribution of these parameters is further visualized using heatmaps in Figure 10. The heatmaps for the traditional shed show significant color variations across hours and days, indicating frequent and large shifts in temperature, humidity, and gas levels. In stark contrast, the heatmaps for the controlled shed display much more uniform coloring, particularly evident for gas levels and temperatures, confirming that conditions remained within a tighter, more consistent range throughout the day and across the study period.

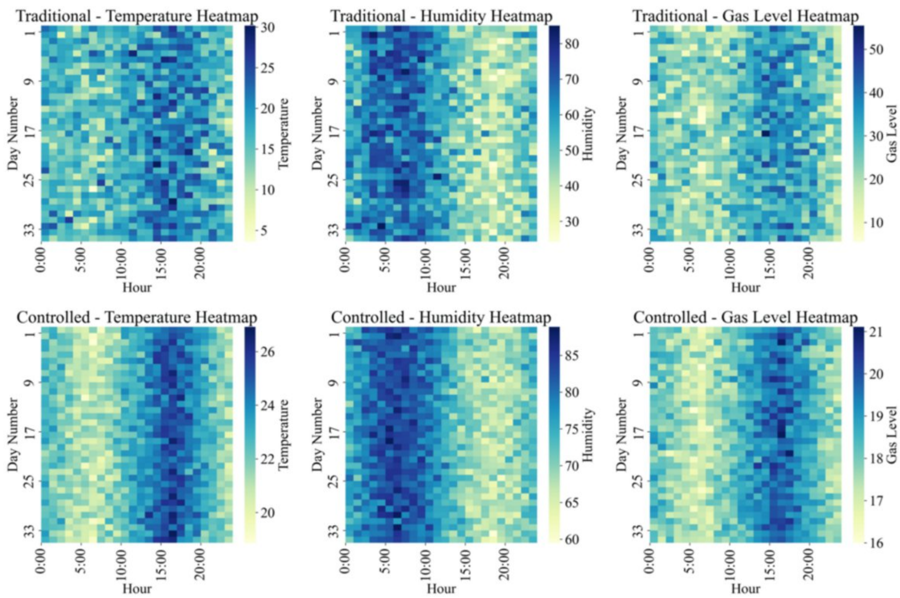

FIGURE 10: Heatmap visualization comparing the environmental conditions (temperature, humidity, and gas level) by hour and day for the traditional (left column) and controlled environment (right column) sheds, highlighting differences in variability and range

Figure 11 presents correlation heatmaps showing the relationships between temperature, humidity, and gas levels within each shed. In the traditional shed (Figure 11a), while some correlations exist, the relationships appear less defined, likely due to the erratic nature of the environment. In the controlled shed (Figure 11b), stronger, more consistent correlations are observed, such as a clear negative correlation between temperature and humidity (-0.65) and a positive correlation between temperature and gas level (0.80), suggesting that even within the stable range, the system allowed for natural physical relationships between these variables to manifest more predictably.

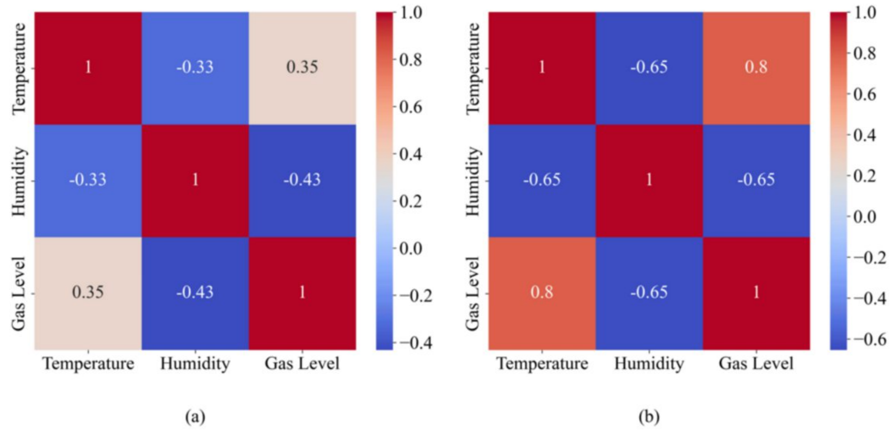

FIGURE 11: Correlation heatmaps showing the Pearson correlation coefficients between temperature, humidity, and gas level within (a) the traditional shed and (b) the controlled environment shed

Figure 12 provides scatter plots and regression lines further illustrating the relationships between pairs of environmental variables in both sheds. These plots visually reinforce the correlation findings from Figure 11, showing a wider scatter and less defined relationships in the traditional shed, while the controlled shed displays tighter clusters and clearer linear trends between the variables, consistent with a more stable and controlled environment. In summary, the comparative analysis conclusively demonstrates that the automated climate control system in the controlled shed successfully mitigated the harsh winter conditions observed in the traditional setup. By actively managing temperature, humidity, and gas levels, the automated system created a significantly more stable and less variable environment, maintaining conditions within ranges more suitable for poultry, thereby setting the stage for improved biological performance.

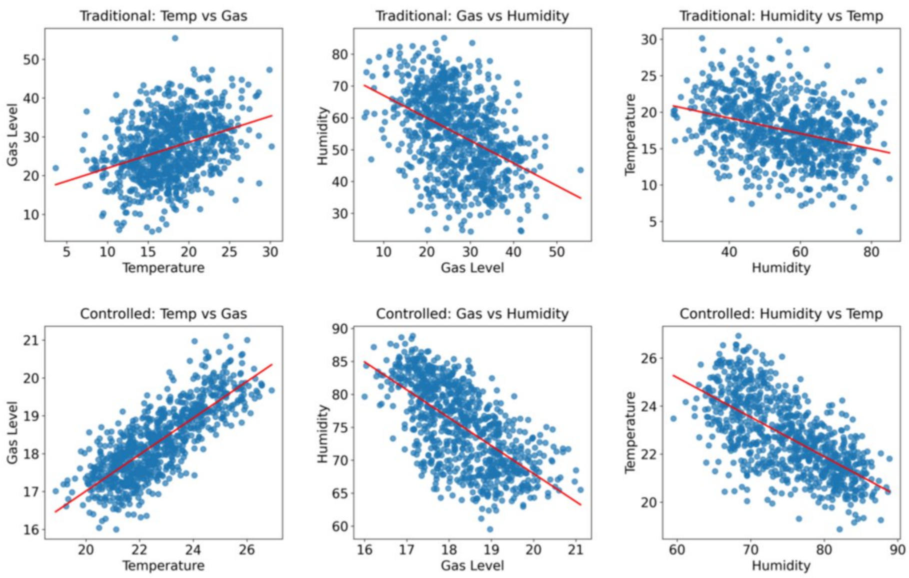

FIGURE 12: Scatter plots with superimposed regression lines showing the relationship between pairs of environmental variables (temperature vs. gas, gas vs. humidity, humidity vs. temperature) in the traditional (top row) and controlled environment (bottom row) sheds over the 35-day period

Biological outcomes: impact on growth and survival

The ultimate measure of the automated system's effectiveness lies in its impact on the poultry itself. The comparative living performance of chickens raised in the controlled environment shed versus those in the traditional setup, focusing on growth rates and survival (mortality), was observed over the 35-day study period.

Figure 13 illustrates the weight gain trajectory of the chickens in both environmental conditions. The plot clearly shows a divergence in growth between the two groups over time. Chickens raised in the controlled environment consistently gained weight at a faster rate than those in the traditional shed, particularly as the study progressed and the environmental differences became more pronounced.

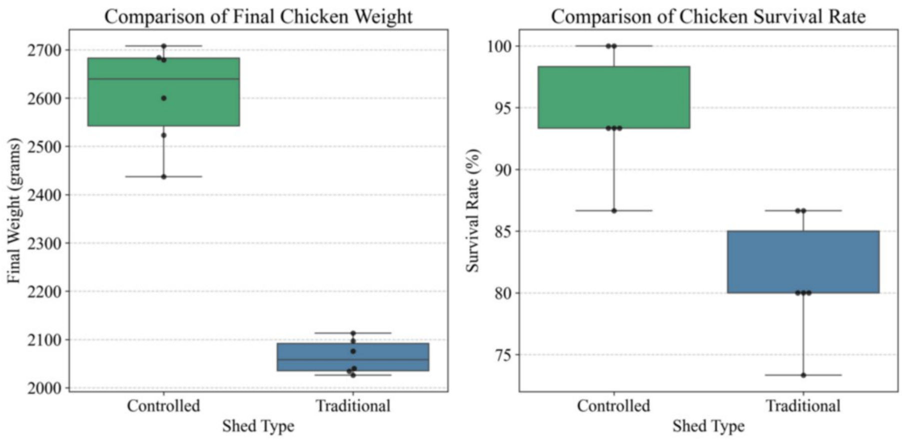

FIGURE 13: Average weight gain of chickens raised in the controlled environment shed (green line) compared to those in the traditional shed (blue line) over the 35-day study period

Table 4 provides a statistical summary of the key biological outcomes: average chicken weight at the end of the study and overall mortality rates, including individual replicate data. To quantitatively assess the impact of the automated climate control system, an independent samples t-test (Welch's t-test, assuming unequal variances due to potentially different variances between groups, which is robust for small samples) was performed on both the final average chicken weight and the survival rates, comparing the controlled environment shed (T1) with the traditional shed (T2).

For chicken weight gain, the average final weight in the controlled shed was 2605.17 g (±107.05 g SD). This was significantly higher than the 2064.33 g (±36.20 g SD) observed in the traditional shed (t(9.56) = 11.72t(9.56) = 11.72, p < 0.001 p < 0.001). This represents a remarkable 26.19% increase in growth in the controlled environment. Regarding survival, the mean survival rate in the controlled shed was 94.44% (±5.02% SD), which was also found to be significantly higher than the 81.11% (±5.02% SD) in the traditional shed (t(10) = 4.60, p = 0.001). This corresponds to a substantial 13.33% reduction in mortality attributed to the stable conditions provided by the automated system. These statistical findings confirm that the environmental stability provided by the automated system translates directly into enhanced productivity and resilience of the poultry flock. The t-test report is summarized in Table 5.

	Controlled shed (T1)						Traditional shed (T2*)					
	T1R1	T1R2	T1R3	T1R4	T1R5	T1R6	T2R1	T2R2	T2R3	T2R4	T2R5	T2R6
0-14 days	335	324	298	320	341	338	330	314	305	325	306	303
14-21 days	886	793	779	870	895	810	798	749	75	793	763	754
21-28 days	1768	1664	1772	1629	1904	1795	1414	1401	1383	1450	1408	1470
28-35 days	2523	2679	2684	2708	2437	2600	2026	2034	2040	2076	2113	2097
Weight gain	26.19%											
Initial count	15	15	15	15	15	15	15	15	15	15	15	15
Final count	14	14	15	14	15	13	12	11	12	13	12	13
Survival rate	94.4%						81.1%					
Survival improvement	13.33%											
*T2: Treatment 2												

TABLE 4: Summary of biological outcomes, including average chicken weight at the end of the 35-day study and overall mortality rates, for chickens raised in the traditional and controlled environment sheds.

Outcome	Group	Mean	Standard Deviation (SD)	t-statistic (df)	p-value	Significance (α = 0.05)
Final weight (g)	Controlled (T1)	2605.17	107.05	11.72 (9.56)	<0.001	Significant
	Traditional (T2)	2064.33	36.20			
Survival rate (%)	Controlled (T1)	94.44	5.02	4.60 (10)	0.001	Significant
	Traditional (T2)	81.11	5.02			

TABLE 5: Statistical comparison of biological outcomes between controlled and traditional sheds

These findings underscore the direct and significant benefits of maintaining optimal and stable environmental conditions in poultry farming during challenging weather. The improved growth rate means chickens reached market weight faster, while the reduced mortality rate indicates a healthier flock and fewer losses for farmers. Collectively, the data demonstrate that the environmental stability provided by the automated system translates directly into enhanced productivity and resilience of the poultry flock.

Finally, Table 6 presents a comparative analysis of existing automated poultry environment control systems alongside our proposed solution, highlighting key differences in environmental parameters, automation scope, cost-effectiveness, and suitability for climate-challenged regions like Bangladesh. The practical deployment is depicted in Figure 14.

Study/Project	Environmental parameters controlled	Automation scope	Cost, installation complexity, adaptability	Unique contributions	Limitations
[21]	Temperature, Humidity, Ammonia	Feeding, Watering, Climate Control	Moderate, Moderate, High	-	Did not specified season of the experiment
[22]	Temperature, Humidity, Ammonia	Feeding, Cooling, Ventilation	Moderate, Moderate, Moderate	-	Focused on specific parameters
[23]	Ammonia concentration, Temperature, Humidity	Controlled NH_3 release and removal	Expensive, Complex, Moderate	-	Designed for controlled environments
This work	Temperature, Humidity, Air Quality (NH_3)	Heating, Cooling, Ventilation	Very Low, Easy, Very High	Field-tested in extreme climates; cost-effective implementation, robust statistical testing	N/A

TABLE 6: Comparison of automated poultry climate control systems with emphasis on applicability in low-resource environments

FIGURE 14: System deployment and components. (a) Humidifier in operation within the shed, (b) overview of the automated controlled shed, (c) MQ137 ammonia sensor installed, (d) exhaust fan for ventilation, (e) main control circuit board (Arduino, relays, display, RTC, GSM), (f) Chickens in the controlled shed, (g) LCD dashboard displaying real-time environmental data, (h) DHT11 temperature and humidity sensor

Discussion, limitation and future work

Our study definitively established that the low-cost IoT-based automated climate control system successfully created a significantly more stable and optimal environment within the poultry shed compared to traditional practices. The dramatic reduction in the standard deviations for temperature, humidity, and ammonia levels within the controlled shed, as summarized in Table *3* and visually depicted in Figure *9* and Figure *10*, provides robust quantitative evidence of this capability. During challenging winter conditions, where the traditional shed experienced wide and often extreme fluctuations, the automated system consistently maintained parameters within desired physiological ranges for poultry. This environmental stability directly addresses a major vulnerability in poultry farming in least developed countries, where external climate variability often leads to stress and compromised productivity. The observed correlations between environmental variables in the controlled shed (Figure *11b*) also suggest a more predictable and manageable internal ecosystem, in contrast to the erratic and less defined relationships in the traditional setup. This sustained consistency is crucial for reducing stress on birds and optimizing their physiological functions, laying the groundwork for improved biological outcomes.

The profound impact of the automated climate control system was unequivocally reflected in the biological performance of the poultry. The remarkable 26.19% increase in average chicken growth rate and the 13.33% reduction in mortality rate in the controlled shed are compelling indicators of the system's effectiveness.

These statistically significant improvements (Table *5*) underscore how a stable, optimized environment directly translates into enhanced productivity and resilience for the flock. Faster growth rates mean quicker turnover and higher yield for farmers, while reduced mortality rates indicate a healthier bird population and fewer economic losses. These findings are particularly pertinent for least developed countries, where even marginal gains in productivity can significantly impact food security and farmer livelihoods. Our results align with the existing literature emphasizing the detrimental effects of environmental stressors on poultry performance and highlight the potential of accessible automation to mitigate these challenges effectively.

This study has certain limitations that should be acknowledged. The experimental deployment was conducted during a single season, specifically in January, when Dinajpur experiences cold and harsh winter conditions. As a result, the findings primarily reflect system performance under winter stressors, such as low temperatures and high variability in humidity and ammonia levels. Furthermore, the investigation was limited to a single geographical location and farm setting, which may not fully capture the diversity of climatic and operational conditions faced by poultry farmers in other regions of Bangladesh or similar least developed countries.

Future work should extend this research across multiple seasons and locations to evaluate the robustness and adaptability of the system under varying climatic conditions. In particular, assessing performance during the summer months, when high temperatures and extreme humidity are prevalent, will provide a more comprehensive understanding of the system’s capabilities and limitations, potentially necessitating the integration of cooling mechanisms. Broader field trials across different poultry farms, with varying infrastructure and management practices, would also help to refine the system for wider adoption. Additionally, integrating advanced features such as machine learning for predictive control and comprehensive long-term economic analyses could further enhance the system's resilience, optimize resource utilization, and solidify its potential for sustainable, year-round effectiveness in diverse environmental contexts.

Conclusions

This study successfully demonstrated the significant positive impact of a proposed budget-friendly low-cost, IoT-based automated climate control system on poultry farming in a least developed country during harsh winter conditions. By actively stabilizing critical environmental parameters like temperature, humidity, and ammonia levels, the system mitigated extreme fluctuations observed in traditional sheds. This environmental control directly translated into remarkable biological benefits: a 26.19% increase in chicken growth rate and a 13.33% reduction in mortality rate, statistically affirming the system's effectiveness in enhancing poultry health and productivity. Furthermore, the statistical analysis showed that the automated shed kept much more consistent temperature, humidity, and NH_3 gas levels were all more stable and less likely to fluctuate wildly. By integrating sensors and automated fans, we maintained a healthy indoor environment, reducing the risk of respiratory ailments among poultry. These findings underscore the potential of the proposed low-cost microcontroller-based automated climate control system to enhance stability, sustainability and resilience in poultry farming, particularly in regions prone to tough and frequently variant weather events.

Despite being tested in a single winter season and location, this budget-friendly solution offers a vital pathway for building climate resilience and food security in resource-constrained regions. Future research should expand deployments across diverse seasons and locations, integrate additional cooling mechanisms for summer conditions, and conduct comprehensive economic feasibility analyses to encourage wider adoption. Such advancements will further solidify the role of accessible technology in promoting sustainable and efficient poultry farming globally.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Md. Mahabub Hossain, Md. Azizul Hakim Bappy, Md. Rifat Hoshen

Acquisition, analysis, or interpretation of data: Md. Mahabub Hossain, Md. Azizul Hakim Bappy, Md. Rifat Hoshen, Md. Mujtuba Rafid, Mst. Afroja Khatun

Critical review of the manuscript for important intellectual content: Md. Mahabub Hossain, Md. Azizul Hakim Bappy, Md. Rifat Hoshen, Md. Mujtuba Rafid, Mst. Afroja Khatun

Supervision: Md. Mahabub Hossain

Drafting of the manuscript: Md. Azizul Hakim Bappy

Disclosures

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