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Analysis of microclimate temperature and relative humidity distribution of local poultry house in a subtropical area of Nigeria

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Abstract

The literature lacks information on the distribution of microclimate parameters, which is necessary for designing the ventilation system in poultry houses in Nigeria to guarantee optimal microclimate conditions. This study looked into the distribution patterns of relative humidity (RH) and temperature in a typical local poultry house. The specific objectives were to: i) analyze the vertical and horizontal distributions of the microclimate parameters in battery cage poultry housing and deep litter poultry housing; ii) identify whether the distribution is homogenous or heterogeneous; iii) identify the data spread of parameters. For this study, a locally located experimentally intensive naturally ventilated poultry house was used. It was made up of air-walled poultry housing systems for deep litter (DL) and battery cage (BC) birds. The RH distributions and daytime, nighttime, rainy, and dry season temperatures in the BC and DL poultry housing were examined. Day and nighttime temperature differences of about 1.2°C were noted between the poultry house and surrounding air. The poultry housing had a heterogeneous distribution of both temperature and relative humidity. The optimal values were reached by about 5% and 67-73% of the daytime and nighttime temperature data, respectively, and 37-41% of the daytime relative humidity.

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Introduction

Poultry is the most commercialized agricultural subsector in Nigeria. The livestock sector is vital for the socioeconomic development of the country, contributing approximately 9-10% of the agricultural gross domestic product (FAO, 2008). From 151 million in 2006, Nigeria's chicken population rose to approximately 180 million in 2016 (CSIRO, 2020). Of the total chicken population, 21% was commercially farmed, and the remaining 79% was shared between semi-commercial and backyard farming (CSIRO, 2020). According to CSIRO (2020), Nigeria has three common poultry production systems: extensive, semi-intensive, and intensive. The report further stated that the extensive system, also known as the free-range system, comprises nearly half of the chicken population, primarily for family consumption. Temporary roofing, supported by ordinary poles, is generally used to provide shelter. The semi-intensive system is a market-oriented, family-based subsistence production system, with a flock of 50 to 2000 birds. The intensive system is a market-oriented production system, with bird numbers exceeding 2000, and is mainly concentrated in the southwestern region of the country. Of the 180 million birds reported by CSIRO (2020) in 2016, 22%, 33%, and 45% were under intensive, semi-intensive, and extensive systems, respectively. The 2016 World Bank's living standard measurement survey shows that 57%, 16%, 14%, and 13% of the country's production was in the south, north, east, and central, respectively. The local production only accounted for 30% of the country's demand (CSIRO, 2020), which means that there is a need for much-untapped wealth in the industry. Different factors can be attributed to low production, including inadequate investment, pests and diseases, lack of credit facilities, and high cost of animal feed. In a study conducted by Fadimu *et al.* (2020), 92.5% of farmers in Lagelu local government, Oyo state, in the southern part of Nigeria, mentioned pests and diseases as a problem in production. The prevalence of diseases is related to climate in terms of higher rainfall and relative humidity (RH) (Moreda *et al*., 2014; Nayak *et al*., 2015). Heat stress is also related to tropical climates. Severe heat stress in birds results from high temperature and RH (Ayo *et al.,* 2011).

Studies have shown that climate parameters, such as temperature and RH, affect the productivity of poultry birds with heat stress being a common indicator of high temperatures in poultry. Ayo *et al.* (2011) stated that "heat stress inflicts heavy economic losses on poultry production as a result of stunted growth, decrease in hen-day production, increased production cost, high mortality rate due to suppressed immunity, and reproductive failure". Nigerian weather is characterized by two seasons: rainy and harmattan (dry season with no or less rain). At the onset of the rainy season, extreme heat stress occurs due to the combination of high ambient temperature and high relative humidity, which reduces the production of broiler and layer birds. Conversely, during the harmattan season, ambient temperature and relative humidity are low, which enhances egg and broiler production (Ayo *et al*., 2011). The optimum temperature for the performance/thermoneutral zone is – 19-22°C for laying hens and 18-22°C for growing broilers (Al *et al*. 2021; Hayes *et al*. 2013; Charles 2002). When poultry birds are in the thermoneutral zone, they do not suffer heat stress as the body temperature is constant and the birds maintain body temperature through normal evaporative cooling behavior. However, any deviation from this zone results in heat stress, which is caused by various environmental factors such as sunlight, thermal irradiation, air temperature, and humidity. Table 1 presents the temperature range categorization for poultry bird performance. A typical optimum relative humidity range for chickens after brooding is between 50% and 70% (Al *et al*., 2021; Hayes *et al*., 2013; Charles, 2002) and between 60% and 80% during brooding. Bhadauria *et al.* (2014) stated that the optimum RH is below 75% with higher humidity favoring better growth and feed conversion. However, one must be careful because higher humidity tends to cause problems with wet litter, ammonia emissions, housing, and some diseases. Instead of singly considering temperature and RH, temperature and humidity index – an index that combines the effect of the two parameters based on dry bulb and dew point temperature – was developed for humans and adapted to livestock. However, modeling energy demand for both cooling and heating when needed in livestock structures often entails knowing the setpoint temperature and/or RH (Akpenpuun, 2021a; 2021b).

For the extensive system in Nigeria, according to Ayo *et al.* (2011), poultry birds are predominantly subjected to the effects of heat stress, pests, and diseases due to their exposure to high temperature and RH, and controlling these climate parameters is difficult, except where temporary shade is used. In intensive systems, the microclimate environment can be easily controlled. To avoid heat stress, pests, and disease infestation, indoor temperature and RH can be maintained at optimum values through optimum building design, appropriate selection of envelope material, adequate ventilation during hot and humid days, and supplemental heating during cold nights (Al *et al*., 2021; Wang *et al*., 2019). The control level in agricultural structures often depends on the difference between outdoor and indoor climate parameters (Al *et al*., 2021; Adesanya *et al*., 2022; Akpenpuun *et al*., 2021a; 2021b; Ogunlowo *et al*., 2021). The distribution of microclimate parameters is significantly different in greenhouses, where crop positions are often fixed (Ogunlowo *et al*., 2021). In intensive deep litter (DL) systems, where birds can move freely, and in battery cage (BC) systems, where birds have less freedom to move, a heterogenous distribution of the microclimate parameters is not beneficial to the birds, particularly those within the hotspot zone.

Heat stress indicates that the poultry microclimate temperature and RH are above the optimum values. To ensure that the conditions are optimum, ventilation is required either naturally or mechanically. Designing a ventilation system requires adequate knowledge of the microclimate distribution. There are few or no studies on this aspect, particularly for sub-Saharan Africa and countries such as Nigeria. Therefore, there is a need to conduct such studies.

The main objective of this study was to statistically analyze the temperature and RH distributions in a typical local poultry house. The specific goals were to: i) analyze the vertical and horizontal distributions of the microclimate parameters in battery cage poultry housing and deep litter poultry housing; ii) identify if the distribution is homogenous or heterogeneous; iii) identify the data spread of the parameters. The results of this study will serve as a database for poultry house ventilation design, energy estimation, and allocation which can be used to improve microclimate conditions and poultry production.

Materials and Methods

Description of the poultry house

An intensive local poultry farm located at a latitude of 6°48'53.68" N, longitude of 3°11'42.65" E, and E-W orientation of 240°, in Kila, Odeda LGA, Ogun was used as the experimental poultry house for this study. The farm was located in the southwestern part of the country. It consisted of DL and BC housing sys-

Table 1. General guide to the effects of various temperature ranges on adult poultry (Bhadauria *et al*., 2014).

Temperature range (°C)	Remark
12-24	Thermal neutral zone. The temperature range within which the birds do not need to alter their basic metabolic rate or behavior to maintain body temperature
18-24	Ideal temperature range
24-30	A slight reduction in feed consumption can be expected, but if nutrient intake is adequate, production efficiency is good. Egg size may be reduced, and shell quality may suffer as temperatures reach the top of this range
30-32	Feed consumption falls further. Weight gains are lower. Egg size and shell quality deteriorate. Egg production generally suffers. Cooling should be implemented before this temperature range is reached
32-35	Feed consumption continues to drop. There is some danger of heat prostration between layers, especially among the heavier birds and those in full production. At these temperatures, cooling procedures must be carried out
35-38	Heat prostration is probable. Emergency measures may be needed. Egg production and feed consumption are severely reduced. Water consumption is very high.
>38	Emergency measures are needed to cool birds. Survival is a concern at these temperatures

tems that are physically divided. The poultry house was naturally ventilated and protected with corrugated galvanized metal sheet roofing and a wire mesh on the sides. Polyethylene sacks were used to cover the sides at night and during the rainy season. The BC had a floor length of 8.9 m, a width of 3.1 m, and a height of 2.26 m. The DL had a length of 4.9 m, a width of 3.1 m, and a height of 2.26 m. Figure 1 shows the schematic view and sensor installation in the poultry house. The design of the poultry house fitted that described by Qureshi (2001) for tropical poultry farms. Two hundred (200) birds were stocked in each system during the period of experiment.

Data collection

Battery cage poultry housing

Four Elitechlog v6.10 sensors with 0.1°C resolution and ±0.5°C accuracy were installed in the poultry house. Three sensors were installed horizontally 1 m from the floor, and one was installed 0.1 m from the floor below the center sensor. The parameters recorded were temperature and RH. The distances and positions of the sensors are shown in Figure 1. The sensors were installed to measure the temperature and relative humidity at the sides and center of the poultry house. All sensors recorded data every 10 min. Data were collected from the 8th of September to the 6th of November 2021.

Deep litter poultry housing

Three Elitechlog v6.10 sensors were installed vertically at the center of the poultry house at 0.1, 1, and 2 m above the floor to record the temperature and relative humidity in the DL. The distances and positions of the sensors are shown in Figure 1. All sensors recorded data every 10 min. Data were collected from the 8th of September to the 6th of November 2021.

Data analysis

The daytime represents the bright sunshine hours from 8 am to 6 pm whereas, the nighttime runs after 6 pm just before 8 am in the morning. Similar to the method used by Ogunlowo *et al*. (2021), the temperature and RH were measured by each sensor (Figure 1) in each poultry house and the ambient data were subjected to descriptive statistics and analysis of variance (ANOVA) using Microsoft Excel 2019 statistical package. The levels of significant variation among the sensors in the deep litter and battery cage systems were determined using horizontal and vertical distribution analysis. The sensors that differed significantly from each other were subjected to Tukey's honestly significant difference test.

Results and Discussion

Descriptive statistics

Battery cage

Table 2 presents the results of the descriptive statistics of the temperature and RH distributions in the BC system during the

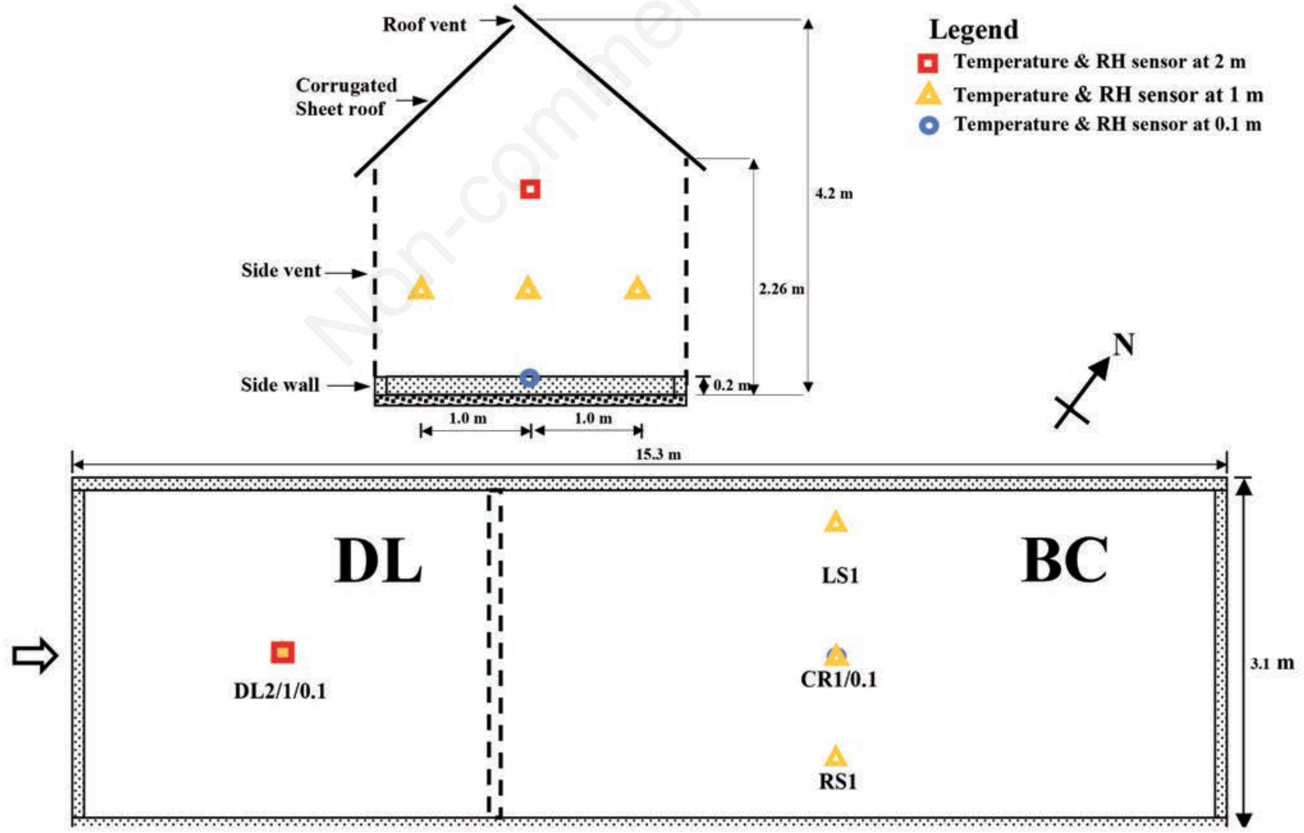

Figure 1. Dimensions and locations of the sensors in the poultry house. RH, relative humidity; DL, deep litter; BC, battery cage.

entire study period. Considering the entire period, the highest and lowest mean temperatures of 26.08±3.62°C and 25.91±3.30°C were recorded at the right side (RS1) and center (CR1), 1 m above the floor, respectively. These values were consistent with the temperature sum at the sensor points. The mode of the temperatures measured in the BC system was 24°C. The highest range (15.70°C) was recorded at the center, 0.1 m above the floor (CR0.1) and RS1, whereas the lowest (14.0°C) was recorded at CR1. The highest and lowest daytime mean temperatures (29.43±3.21°C and 28.96±2.84 °C) were recorded at CR0.1 and CR1, respectively, and were consistent with the temperature sum of the two points. The modes for CR1 and left side at 1 m above the floor (LS1) were similar (30.50°C), but higher for CR0.1 (31.40°C) and lower for RS1 (25.40°C). The highest range (15.50°C) was recorded at RS1, whereas the lowest (13.60°C) was at CR1. In contrast, the highest and lowest mean nighttime temperatures of 23.74±1.24°C and 23.44±1.29°C were recorded at CR1 and CR0.1, respectively, and were consistent with the temperature sum of the two points. The mode for the entire period (24.00°C) was the same for all sensor points. The highest range (7.80°C) was recorded at RS1, whereas the lowest (7.00°C) was recorded at CR1. The ambient temperature compared to that at CR1 was lower by 0.56°C and 1.4°C during the whole and day periods, respectively but a similar value during the night. For the entire experiment, the highest and lowest mean RH of 85.51±10.26% and 84.82±10.26% were recorded at CR1(±8.49), RS1(±9.16), and CR0.1, respectively. These values were consistent with the RH sum at these sensor points. The result shows a mode of approximately 92.30% for the poultry house. The highest range (43.30%) was recorded at CR0.1, whereas the lowest (37.4%) was at CR1. The highest and lowest mean daytime RH (78.03±8.35% and 75.46±9.68%) were recorded at CR1 and CR0.1, respectively, and were consistent with the RH sum of the two points. The highest mode (77.0%) was recorded at CR0.1 and the lowest (75.50%) was recorded at CR1. The highest range (42.5%) was recorded at CR0.1, whereas the lowest (37.2%) was at CR1. In contrast, for nighttime data, the highest and lowest mean RH of 91.50±2.52 and 90.86±2.23% were recorded at CR0.1 and LS1, respectively, whereas the lowest RH sum was recorded at CR1. The mode for the entire study period was the same for all sensor points. The highest range (37.4%) was recorded at RS1, whereas the lowest (14.4%) was at LS1. Compared to CR1, the entire period, daytime and nighttime mean ambient RH were 4.27, 2.78, and 5.33%, respectively.

The results show a lower temperature at the center (CR1) during the day due to shading and hotspots at night because it takes a longer time for the energy loss by the birds to be transferred to the lower ambient temperature. This agrees with reports by Ogunlowo *et al*. (2021) and Wang *et al*. (2019). The results also confirmed an inverse relationship between temperature and RH, as reported by other researchers (Akpenpuun *et al.*, 2021; Ogunlowo *et al*., 2021).

Deep litter

Table 3 presents the descriptive statistics of temperature and RH distributions in the DL system based on the entire, daytime, and nighttime data. Based on the entire data, the highest and lowest mean temperatures of 26.18±3.57°C and 25.32±2.67°C were recorded at height 0.1 m (DL0.1) and height 2 m (DL2) above the floor, respectively. These values also corresponded to the temperature sum at the sensor points. The highest mode (24°C) was recorded at DL0.1 and the lowest (22.9°C) was recorded at DL2. The highest range (15.1°C) was recorded at DL0.1, whereas the lowest (11.6°C) was recorded at DL2. For daytime data, the high-

Table 2. Descriptive statistics of temperature and relative humidity distributions in the battery cage system based on the entire, daytime, and nighttime data.

Period	Description	T (°C)					RH (%)				
		CR0.1	LS1	CR1	RS1	Amb	CR0.1	LS1	CR1	RS1	Amb
Whole	Mean	25.94	26.01	25.91	26.08	25.35	84.82	85.07	85.51	85.51	89.78
	Mode	24.00	24.00	24.00	24.00	22.94	92.50	92.30	92.50	92.50	98.31
	SD	3.74	3.50	3.30	3.62	2.35	10.26	9.16	8.49	9.16	9.47
	Range	15.70	14.80	14.00	15.70	10.20	43.30	39.50	37.40	41.80	36.94
	Min.	20.30	20.60	20.80	20.60	20.98	52.30	55.30	56.90	55.90	63.06
	Max.	36.00	35.40	34.80	36.30	31.18	95.60	94.80	94.30	97.70	100.00
	Sum	39837.30	39955.20	39799.20	40062.00	38935.40	130278.80	130666.00	131347.80	131343.30	137899.18
	Count	1536	1536	1536	1536	1536	1536	1536	1536	1536.00	1536.00
Day	Mean	29.43	29.28	28.96	29.40	27.56	75.46	76.87	78.03	77.69	80.81
	Mode	31.40	30.50	30.50	25.40	28.40	77.00	75.90	75.50	70.80	77.12
	SD	3.21	2.97	2.84	3.16	1.66	9.68	8.82	8.35	9.11	7.71
	Range	15.30	14.50	13.60	15.50	7.76	42.50	38.90	37.20	39.10	33.38
	Min.	20.70	20.90	21.20	20.80	23.42	52.30	55.30	56.90	55.90	63.06
	Max.	36.00	35.40	34.80	36.30	31.18	94.80	94.20	94.10	95.00	96.44
	Sum	18835.30	18737.00	18531.50	18817.20	17640.48	48293.90	49198.70	49936.40	49724.60	51716.59
	Count	640	640	640	640	640	640	640	640	640.00	640.00
Night	Mean	23.44	23.68	23.74	23.71	23.77	91.50	90.92	90.86	91.09	96.19
	Mode	24.00	24.00	24.00	24.00	22.94	92.50	92.30	92.50	92.50	98.31
	SD	1.29	1.29	1.24	1.35	1.23	2.52	2.44	2.23	3.14	3.57
	Range	7.40	7.40	7.00	7.80	7.46	16.80	14.40	14.70	37.60	24.81
	Min.	20.30	20.60	20.80	20.60	20.98	78.80	80.40	79.60	60.10	75.19
	Max.	27.70	28.00	27.80	28.40	28.44	95.60	94.80	94.30	97.70	100.00
	Sum	21002.00	21218.20	21267.70	21244.80	21294.92	81984.90	81467.30	81411.40	81618.70	86182.59
	Count	896	896	896	896	896	896	896	896	896	896

T, temperature, RH, relative humidity; CR0.1, center, 0.1 m above the floor; LS1, left side at 1 m above the floor; CR1, center 1 m above the floor; RS1, right side 1 m above the floor; BC, battery cage; SD, standard deviation; Min, minimum; Max, maximum; Amb, ambient parameter; Sum, summation of all data points.

est and lowest mean temperatures of 29.50±3.08°C and 27.76±2.2°C were recorded at DL0.1 and DL2, respectively, and were confirmed by the temperature sum of the two points. The modes for DL0.1 and at height 1 m above the floor (DL1) were similar (27.0°C and 27.7°C, respectively), but the highest (30.50°C) was recorded at DL2. The highest range (14.60°C) was recorded at DL0.1, whereas the lowest (11.40°C) was recorded at DL2. In contrast, based on the nighttime data, the highest and lowest mean temperatures of 23.99±1.2°C and 23.57±1.22°C were recorded at DL1 and DL2, respectively, and were confirmed by the temperature sum of the two points. The mode for the entire study period was 24.00°C, 23.50°C, and 22.90°C, at a height of 0.1 m, 1 m, and 2 m, respectively. The highest range (7.30°C) was recorded at DL0.1, whereas the lowest (6.70°C) was recorded at DL2. The ambient temperature compared to the DL0.1 shows a lesser value of 0.83°C and 1.14°C during the whole and day periods, respectively but a similar value during the night.

For the entire experiment, the highest and lowest mean RH of 88.09±7.97% and 84.76±8.83% were recorded at DL1 and DL0.1, respectively. These values also corresponded to the RH sum at these sensor points. The highest mode (approximately 93.90%) was recorded at DL1 and the lowest (91.0%) was recorded at DL0.1. The highest range (41.40%) was recorded at DL0.1, whereas the lowest (34.0%) was recorded at DL2. During the daytime, the highest and lowest mean RH of 81.82±6.77% and 76.92±8.7% were recorded at DL2 and DL0.1, respectively, and were confirmed by the RH sum of the two points. The highest mode (87.6%) was recorded at DL0.1, and the least (74.2%) was recorded at DL1. The range recorded at each point was similar to that recorded during the entire study period. In contrast, based on the nighttime data, the highest and lowest mean RH of 93.13±1.99% and 90.35±2.09% were recorded at DL1 and DL0.1, respectively; these were confirmed by the RH sum recorded at the two points. The mode for the entire study period was the same for all sensor points. The highest range (18.9%) was recorded at DL1, whereas the lowest (12.5%) was recorded at DL0.1. Compared to that at DL0.1, the ambient mean RH values were higher by 5.02, 3.89, and 5.81% based on the entire, daytime, and nighttime data.

The results indicated a hotspot at the floor area (DL0.1) with a temperature value reduction along with the height during all periods. The temperature differences between the floor and roof areas were 0.86, 1.74, and 0.24°C during the entire period, the day and night, respectively. This may be attributed to the energy gain by the point owing to the birds' proximity loss. In addition, because the sides were wide open, the movement of air across the building facilitated reducing the heat at higher points. This agrees with reports by Ogunlowo *et al*. (2021) and Rasheed *et al*. (2019) on the temperature distribution in greenhouses with wide side openings. The results also confirmed an inverse relationship between temperature and RH, as reported by other researchers (Akpenpuun *et al.*, 2021; Ogunlowo *et al*., 2021).

Table 4 shows the differences between the measured and ambient temperatures during the rainy and dry seasons. In the BC system, during the daytime, the CR1 temperature was higher than the ambient temperature in both the rainy and dry seasons by 0.6°C and 0.53°C, respectively. In addition, the dry season temperature was higher than that of the rainy season by 1.26°C. Although the RH value was also higher in the dry season by 3.52%, it was lower by 3.36% during the rainy season. There was no substantial difference between the seasons, with a value of 1.03% compared to the

Table 3. Descriptive statistics of temperature and relative humidity distributions in the deep litter system based on the entire, daytime, and nighttime data.

Period	Description			T (°C)					RH (%)		
		DL0.1	DL1	DL2	Amb	DL0.1	DL1	DL2	Amb		
Whole	Mean	25.94	26.01	25.91	26.08	25.35	84.82	85.07	85.51	85.51	89.78
	Mode	24.00	24.00	24.00	24.00	22.94	92.50	92.30	92.50	92.50	98.31
	SD	3.74	3.50	3.30	3.62	2.35	10.26	9.16	8.49	9.16	9.47
	Range	15.70	14.80	14.00	15.70	10.20	43.30	39.50	37.40	41.80	36.94
	Min.	20.30	20.60	20.80	20.60	20.98	52.30	55.30	56.90	55.90	63.06
	Max.	36.00	35.40	34.80	36.30	31.18	95.60	94.80	94.30	97.70	100.00
	Sum	39837.30	39955.20	39799.20	40062.00	38935.40	130278.80	130666.00	131347.80	131343.30	137899.18
	Count	1536	1536	1536	1536	1536	1536	1536	1536	1536.00	1536.00
Day	Mean	29.43	29.28	28.96	29.40	27.56	75.46	76.87	78.03	77.69	80.81
	Mode	31.40	30.50	30.50	25.40	28.40	77.00	75.90	75.50	70.80	77.12
	SD	3.21	2.97	2.84	3.16	1.66	9.68	8.82	8.35	9.11	7.71
	Range	15.30	14.50	13.60	15.50	7.76	42.50	38.90	37.20	39.10	33.38
	Min.	20.70	20.90	21.20	20.80	23.42	52.30	55.30	56.90	55.90	63.06
	Max.	36.00	35.40	34.80	36.30	31.18	94.80	94.20	94.10	95.00	96.44
	Sum	18835.30	18737.00	18531.50	18817.20	17640.48	48293.90	49198.70	49936.40	49724.60	51716.59
	Count	640	640	640	640	640	640	640	640	640.00	640.00
Night	Mean	23.44	23.68	23.74	23.71	23.77	91.50	90.92	90.86	91.09	96.19
	Mode	24.00	24.00	24.00	24.00	22.94	92.50	92.30	92.50	92.50	98.31
	SD	1.29	1.29	1.24	1.35	1.23	2.52	2.44	2.23	3.14	3.57
	Range	7.40	7.40	7.00	7.80	7.46	16.80	14.40	14.70	37.60	24.81
	Min.	20.30	20.60	20.80	20.60	20.98	78.80	80.40	79.60	60.10	75.19
	Max.	27.70	28.00	27.80	28.40	28.44	95.60	94.80	94.30	97.70	100.00
	Sum	21002.00	21218.20	21267.70	21244.80	21294.92	81984.90	81467.30	81411.40	81618.70	86182.59
	Count	896	896	896	896	896	896	896	896	896	896

T, temperature, RH, relative humidity; CR0.1, center, 0.1 m above the floor; LS1, left side at 1 m above the floor; CR1, center 1 m above the floor; RS1, right side 1 m above the floor; BC, battery cage; SD, standard deviation; Min, minimum; Max, maximum; Amb, ambient parameter; Sum, summation of all data points.

ambient value of 5.56%. At night, there were no substantial differences between the temperature during the various seasons and between the reference point temperature and ambient temperature. There was also no significant difference between the seasons at the reference point RH, the ambient RH was higher by 5.79% and 4.98% during the rainy and dry seasons, respectively.

In the DL system, during the daytime, there was an approximately 1°C difference between the floor area center point (DL0.1) and the ambient temperature during the two seasons, with a higher temperature inside the poultry house. The microclimate dry season temperature was higher than that during the rainy season, contrary to lower ambient temperature during the dry season as reported by Ayo *et al.* (2011). For the nighttime temperature and daytime and nighttime RH, the trends were similar to those in the BC.

Homogeneity test

To test if there were significant differences in the distributions of the microclimate parameters within the BC and DL systems and the ambient conditions during daytime and nighttime, ANOVA was conducted. The results show that P-values were less than 0.05, indicating that one or more positions were significantly different among the sensor positions in both systems. Tukey pairwise comparisons of the position parameters based on the day- and nighttime data are shown in Figures 2 and 3 for the BC and DL systems, respectively. Figure 2a shows a significant difference between the daytime ambient temperature and other microclimate points, including CR0.1, CR1, and RS1. In addition, there was a significant difference between CR0.1 and other points during nighttime (Figure 2b). For the day and nighttime RH, Figure 2c shows only similarities among the 1 m sensors (LS1, CR1, and RS1).

As shown in Figure 3a, there was a similarity only between the DL2 temperature and ambient temperature during the day, whereas in Figure 3b, the similarity was between the DL0.1 temperature and ambient nighttime temperature. For RH, while there was only a significant difference between DL0.1 and other points during the day (Figure 3c), during the night, all points were significantly different from each other (Figure 3d).

Table 5 shows there was a significant difference between the season's temperature and RH during the day and night except for the night temperature in the BC system. In the case of the DL system as shown in Table 6, while the significance difference was during the season's day temperature, the difference was during the season's night RH.

Data spread

Figure 4 shows the distributions of temperature and RH in the BC during the day and night. The spread shows that during the day, 5.15%, 51.89%, and 42.97% of the data in the BC were within the optimum environmental temperatures of 18-24°C, 24-30°C, and above 30°C, respectively (Bhadauria *et al*. 2014). At night, the ranges 18-24°C, 24-30°C, and above 30°C were 73.43%, 26.56%, and 0%, respectively. The RH spread indicates that during the day, 37.81% and 62.19% of the data in the BC were within the poultry optimum RH of <75% and >75% (Nayak *et al*., 2015), respectively. Whereas during the night, the RH above 75% was 100%.

Figure 5 shows the temperature and RH distributions during the day and night in the DL. The spread of the data indicates that during the day, 5.10%, 43.59%, and 51.40% of the data in DL were

Table 4. Descriptive statistics of the seasonal daytime and nighttime temperature and RH distributions in the BC and DL systems.

Period	Season	BC						DL					
		T (°C)			RH (%)			T(°C)			RH (%)		
		CR1_T	Amb_T	Diff.	CR1_RH	Amb_RH	Diff.	DL0.1_T	Amb_T	Diff.	DL0.1_RH	Amb_RH	Diff.
Day	Rain	27.37	26.77	0.60	79.93	83.29	-3.36	27.76	26.77	0.99	79.79	83.29	-3.50
	Dry	28.63	28.09	0.53	80.96	77.43	3.52	29.18	28.09	1.08	79.61	77.43	2.17
	Diff.	-1.26	-1.32	nv	-1.03	5.86	nv	-1.41	-1.32	nv	0.19	5.86	nv
Night	Rain	23.73	23.27	0.46	90.82	96.61	-5.79	23.81	23.27	0.54	89.98	96.61	-6.63
	Dry	23.55	23.82	-0.27	91.35	96.33	-4.98	23.59	23.82	-0.23	91.16	96.33	-5.17
	Diff.	0.18	-0.56	nv	-0.53	0.28	nv	0.22	-0.56	nv	-1.18	0.28	nv

BC, battery cage; DL, deep litter; T, temperature; RH, relative humidity; CR1, center 1 m above the floor; Amb, ambient parameter; Diff, difference; DL0.1, height 0.1 m above the floor; nv, no value; -, dry and ambient parameter is higher.

Table 5. ANOVA results for the seasonal temperature and relative humidity in the battery cage system.

Period	SoV	T (°C)				RH (%)			
		df	F	p	F crit	df	F	p	F crit
Day	Season	1, 699	48.90	p<0.05	3.85	1, 699	5.27	p<0.05	3.85
Night	Season	1, 979	3.03	ns	3.85	1, 979	27.84	p<0.05	3.85

SoV, source of variation; T, temperature; RH, relative humidity; df, degree of freedom; F, F-statistics; F crit, F critical (p<0.05); ns, non-significant.

Table 6. ANOVA results for the seasonal temperature and relative humidity in the deep litter system.

Period	SoV	T (°C)				RH (%)			
		df	F	p	F crit	df	F	p	F crit
Day	Season	1, 559	40.45	p<0.05	3.86	1, 559	1.90	ns	3.86
Night	Season	1, 783	0.00	ns	3.85	1, 783	34.65	p<0.05	3.85

SoV, source of variation; T, temperature; RH, relative humidity; df, degree of freedom; F, F-statistics; F crit, F critical (P<0.05); ns, non-significant.

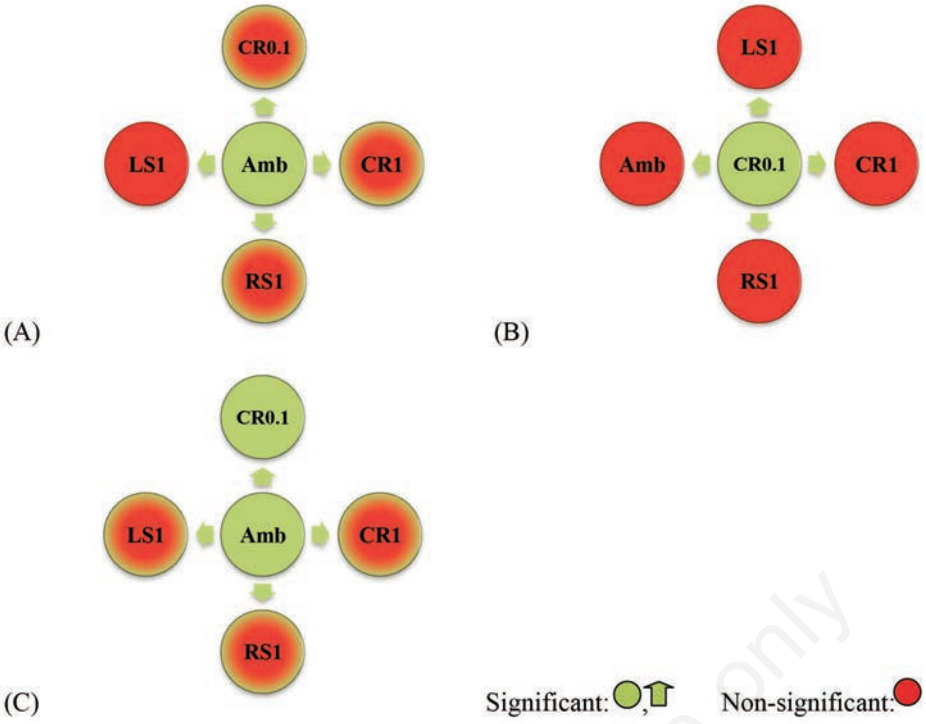

Figure 2. Tukey pairwise comparison among the sensor positions for (**A**) daytime temperature, (**B**) nighttime temperature, and (**C**) daytime and nighttime relative humidity in the battery cage system. Note: The green arrows indicate a significant difference to other points; the solid red circle indicates a non-significant difference to the mixed-red; and the solid green circle indicates a significant difference to the mixed-green circle. Amb, ambient parameter; CR0.1, center, 0.1 m above the floor; LS1, left side at 1 m above the floor; CR1, center 1 m above the floor; RS1, right side 1 m above the floor.

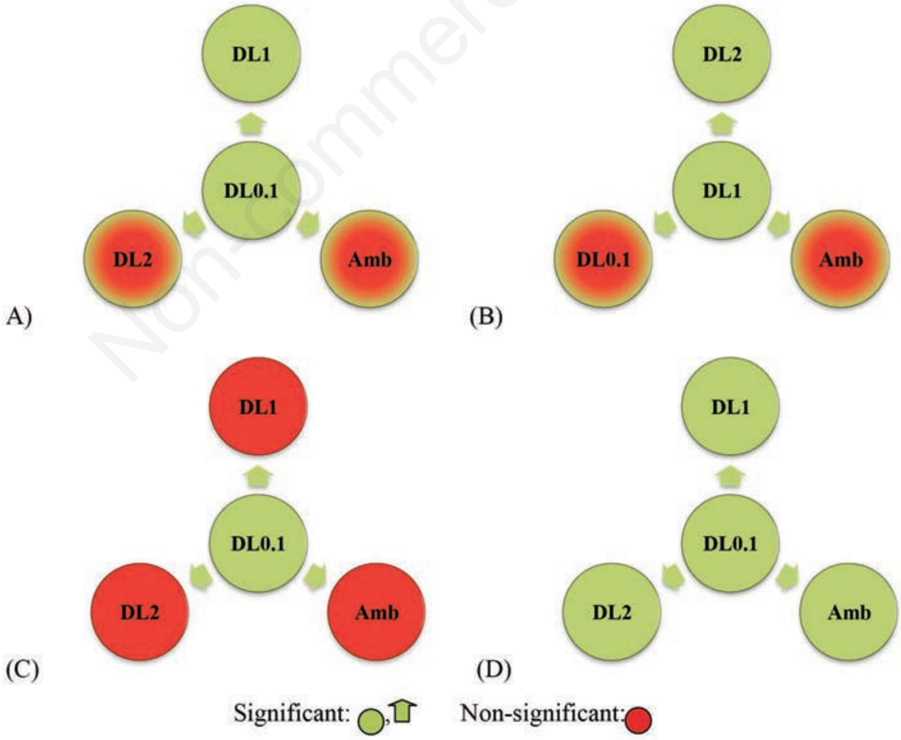

Figure 3. Tukey pairwise comparison among the sensor positions for (**A**) daytime temperature, (**B**) nighttime temperature, (**C**) daytime relative humidity, and (**D**) nighttime relative humidity in the deep litter system. Note: the green arrows indicate a significant difference to other points; the solid red circle indicates a non-significant difference to the mixed-red; and the solid green circle indicates a significant difference to the mixed-green circle. Amb, ambient parameter; DL, deep litter, DL1, height 1 m above the floor; DL2, height 2 m above the floor; DL0.1, height 0.1 m above the floor.

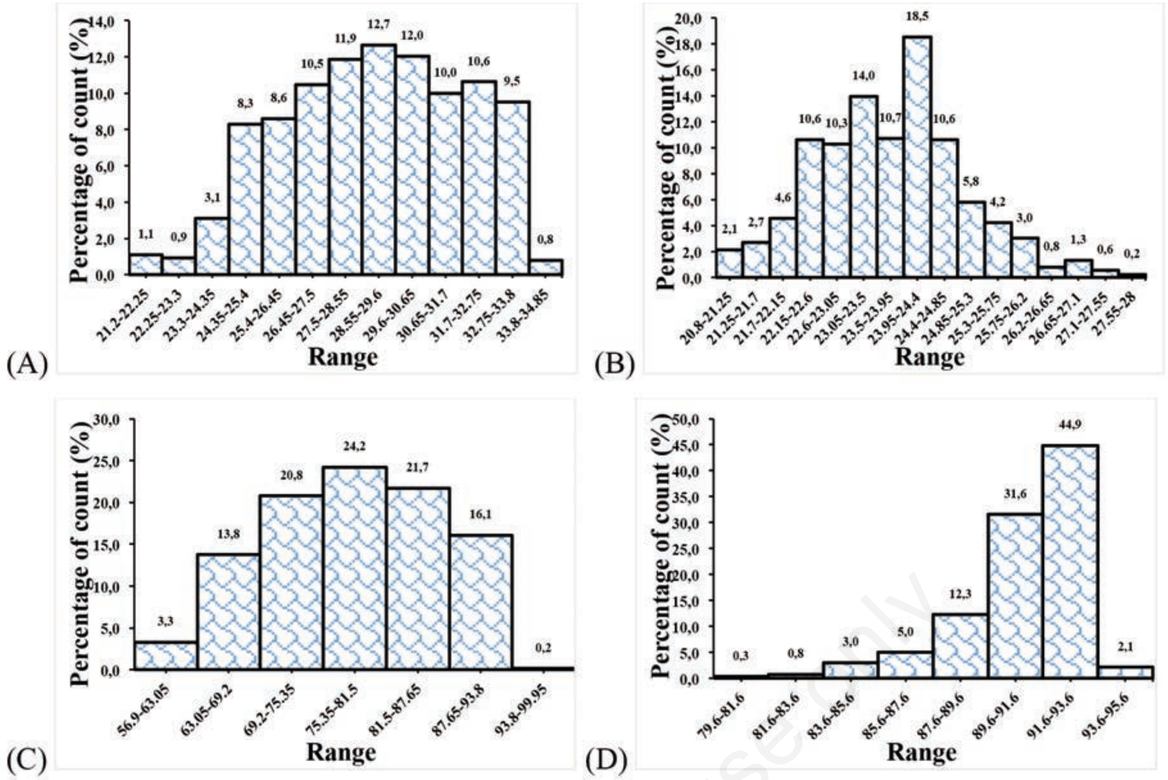

Figure 4. Chart showing data spread of microclimate parameters (**A**) daytime temperature, (**B**) nighttime temperature, (**C**) daytime relative humidity, and (**D**) nighttime relative humidity in the battery cage system.

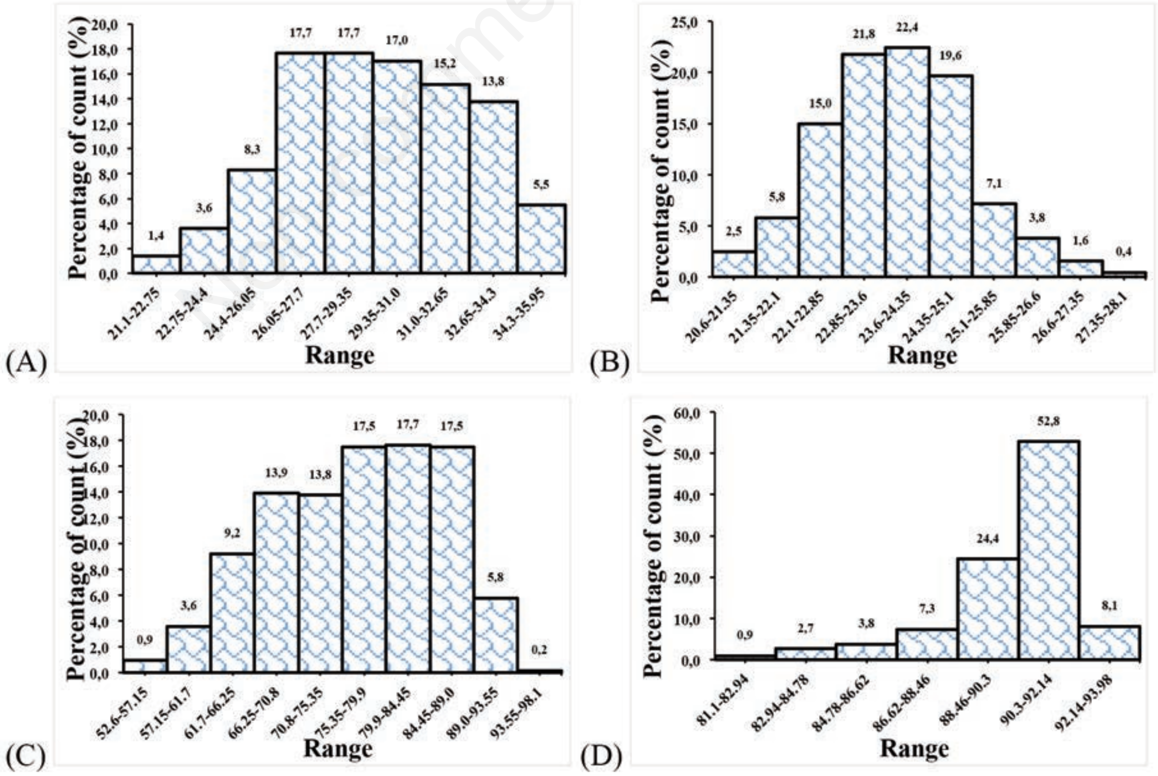

Figure 5. Chart showing data spread of microclimate parameters (**A**) daytime temperature, (**B**) nighttime temperature, (**C**) daytime relative humidity, and (B) nighttime relative humidity in the deep litter system.

within the optimum environmental temperatures of 12-24°C, 24-30°C, and above 30°C, respectively (Bhadauria *et al*., 2014). Whereas during the night, the ranges 18-24°C, 24-30°C, and above 30°C were 67.41%, 32.59%, and 0%, respectively. The RH spread indicates that during the day in the DL, 41.41% and 58.59% of the data were within the poultry optimum RH of <75% and >75%, respectively (Nayak *et al*., 2015), whereas during the night, the RH above 75% was 100%.

Conclusions

Daytime, nighttime, rainy, and dry season temperature and RH distributions in the BC and DL systems were analyzed. A temperature range of 29-23°C and a RH range of 93-75% existed within the systems. Approximately, a 1.2°C temperature difference was recorded between the poultry house and the ambient environment during the day- and nighttime.

The temperature and RH distributions within the BC and DL systems were heterogeneous. Because the deep litter birds can move freely, they can sense comfort zones within the system which may lead to overcrowding among birds. In the case of laying birds in battery cages where movement is restricted, ensuring homogenous distribution is paramount.

Approximately 5% and 67-73% of the daytime and nighttime temperature data, respectively, were within the optimum environmental temperature of 18-24°C; 37-41% of the daytime RH was within the optimum environment RH. Natural ventilation is not sufficient to ensure homogenous distribution and optimum environmental conditions within the systems.

In the future, studies on the effect of ventilation on temperature, RH distributions, and energy demand in poultry environments are recommended.

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