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EFFECTS OF POULTRY BUILDING DESIGN ON INDOOR AIR QUALITY IN HUMID CLIMATES

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ABSTRACT

In this study, six poultry buildings, consisting of four layer hen houses and two broiler houses located in Manisa Province in Turkey, were examined to find out the effects of planning systems on indoor environmental conditions where the age of litter for broiler ranged from 4-18 weeks and the age of commercial layer hens ranged from 22-43 weeks. Air quality parameters, as concentrations of ammonia, carbon dioxide and methane were measured by using multi-gas monitor. Other parameters, as temperature/relative humidity and particulate matter were measured by using respectively, psychrometric sensors and multi-function meter. These measurements were obtained as four replicates for each building in winter, early spring, and summer. The measured data were evaluated via repeated measures analysis of variance (rANOVA). According to the research results, measured indoor temperature values tend to rise in Californian cage type buildings in all seasons (max. 27.65 °C in winter and max. 41.85 °C in summer). The highest relative humidity values were measured in deep litter type buildings (max. 76.27 % in winter and max. 80.44 % in summer). Particulate matter levels had high values in Californian cage type buildings in summer (Avg. 1.09 mg/m^3) and in deep litter type buildings in winter (Avg. 3.16 mg/m^3). Concentrations of NH_3 and CH_4 had high levels in Californian cage type (34.68 ppm NH_3 and 15.14 ppm CH_4 max. values) and deep litter type (49.54 ppm NH_3 and 19.32 ppm CH_4 max. values) buildings in winter. NH_3 and CH_4 have a tendency to rise in all types of buildings in summer. CO_2 had the highest levels in Californian cage type (max. 1805.57 ppm) and deep litter type (max. 8906.33 ppm) buildings in all seasons. Concentrations of CO_2 had lower levels in summer than in winter in all types of poultry buildings. Statistical analysis showed that the design of poultry buildings determined indoor environmental conditions. Also, hot and humid local climate has the effects on indoor air quality.

Keywords: ammonia, broiler, carbon dioxide, laying hen, methane, particulate matter.

INTRODUCTION

The fundamental objective when planning animal housing is to provide optimal environmental conditions, such as temperature, relative humidity, particulate matter, microorganisms, and gaseous concentrations required by the animals, depending on the type of stockbreeding, and thereby to improve the quantity and quality of production (Koelkebeck, 2013).

The thermal comfort zone is 15°C to 25°C for both types of hens (Hulzebosch, 2006). Temperatures higher than 32°C are associated with reduced feed consumption and growth of hens. High temperature, combined with high relative humidity, causes hens to experience stress (Mashaly *et al*., 2004). Therefore, relative humidity should not exceed 70% within the appropriate temperature range. It is quite important to provide uniform air flow within the building throughout the year, in order to maintain the temperature within optimum limits, to prevent condensation of moisture, and to disperse hazardous gas, dust, particulate matter, and other disease agents from the indoor environment before reaching levels detrimental to hens. (Olgun, 2013). Pathogens and microorganisms are directly associated with chronic and allergic diseases in humans and animals. Occupational health studies implicate dust, microorganisms, and endotoxins in the prevalence of respiratory diseases among agricultural workers based in animal confinement buildings (Fabbri *et al*., 2014).

Cage systems are widely used in the farming of laying hens, and since cage systems are arranged in three dimensions, meeting the required temperature, relative humidity, and clean air becomes a challenge. Therefore, issues such as ventilation, housing cleanliness, and waste management are even more apparent in cage systems. Deep-litter systems are used in rearing broiler hens. Manure and other wastes are allowed to accumulate on the floor during the growing season. The subsequent fermentation of these wastes can negatively affect the quality of indoor air, especially if ventilation systems are inadequate. For these reasons, different measures may be necessary in different planning systems to control the levels of temperature, relative humidity, and gaseous and particulate matter (Olgun, 2013).

Bicudo *et al*. (2002) indicated that gas emissions from laying hen houses vary according to seasonal and climatic conditions, feeding practices, and housing type, of which the most important pollutants are NH_3, CO_2 and CH_4. Additionally, H_2S, particulate matter, and dust adversely affect the quality of indoor air. NH_3 should not exceed 10 ppm in poultry buildings (Wathes *et al*., 2002). Methane (CH_4) is released by the anaerobic decomposition of animal waste (Wathes *et al*., 1998).

This study examines the presence and the degree of the effects of different internal planning systems on concentrations of CH_4, NH_3, and CO_2 gases and variations in temperature, relative humidity, and particulate matter levels in both broiler and laying hen houses.

MATERIALS AND METHODS

Manisa is a humid climatic region of Turkey, and poultry breeding is wide spread throughout the province. There are minimal variations in the capacity, animal breed, age, body weight, and feeding regime of poultry operations throughout the province. Thus, laying and broiler rearing poultry buildings examined in the study are primarily differentiated by their different management systems.

Climatic data for the Manisa Province show that the coldest and warmest months are January (mean 6.7°C) and July (mean 28.1°C) respectively. Precipitation is lowest during summer and highest during winter. The annual daytime average temperature is 16.9°C and the average relative humidity is 70%.

Research materials and measurements: The summary of a research plan is given according to the work order in Table 1. The poultry buildings were selected as close as possible to each other, to ensure that external climatic conditions were consistent. Temperature, relative humidity, particulate matter, ammonia (NH_3), carbon dioxide (CO_2), and methane (CH_4) levels were measured for 24 hours, with four replications during a period of 5 days in three seasons: winter, early spring, and summer. Data were gathered from six (6) laying hen and broiler hen buildings with *Californian cage*, *battery cage*, and *deep litter* type internal planning systems, which are widely used in egg and broiler poultry farming. Data were recorded every 10 minutes and transferred to a computer. Tables 2 and 3 summarize the structural characteristics and planning systems, and also specify the breeding types, flock size, and age of the birds in the poultry buildings examined in this study.

A temperature/relative humidity sensor (DO 2003 HVAC Datalogger) was used to measure temperature and relative humidity. A multi-gas monitor (Industrial Scientific IBRID MX6) was used to measure the concentrations of air pollutants (with NH_3, CO_2, and CH_4 gas sensors). Particulate matter was measured using a multi-function meter (PDR-1200 Thermo Fisher Scientific). Care was taken to clean and calibrate the devices before and after the measurements. The measurements were taken over a short period of 5 days in order to avoid potential malfunctions of the operating systems of the devices caused by the temperature, humidity, and particulate matter in the buildings.

Calculations of ventilation rates: In each building, measurements were made in a vertical cross-section at six locations, which were representative of the location of the animals and the exhaust of the ventilation system. A seventh location was sited outside the building so as to record the ambient conditions. The CO_2 mass balance method was used to estimate the ventilation rates of each building (Phillips *et al*., 1998).

The calculations of ventilation rates were based on the output of heat, moisture, or carbon dioxide from the birds within the buildings. Metabolic heat production into sensible and latent components was also necessary. Hourly total heat production (THP) and respiratory quotient (RQ) of the birds, as reported by Chepete and Xin (2004), were used to estimate the CO_2 production of the hens during day and night periods using the equations (Table 1).

Statistical analysis: As shown in Table 2 and Table 3, there are two different breeding types (commercial laying hen and broiler) and three different planning systems (battery cage, Californian cage and deep litter) in this research. The data obtained from laying hen buildings were evaluated by repeated analysis of variance (rANOVA) in factorial design. There are two levels (Battery cage (1) and Californian cage(2)) of the planning system factors, three levels (January (1), March (2), July (3)) of season factors, five levels (1, 2, 3, 4, 5) of day factors and twenty-four levels (01:00 a.m. from 00:00 p.m.) of hour factors in the experiment. Repeated measurements were carried out in the levels of season, day and hour factors. Data analysis were evaluated by using IBM SPSS STATISTICS (VERSION 22) software. DUNCAN’s multiple range test method was used in determining the different groups. The data obtained from broiler buildings were evaluated by repeated analysis of variance (rANOVA) in factorial design as in laying hen buildings. There are three levels (January (1), March (2), July (3)) of season factors, five levels (1, 2, 3, 4, 5) of day factors and twenty-four levels (01:00 a.m. from 00:00 p.m.) of hour factors in the experiment. Repeated measurements were carried out in the levels of season, day and hour factors. Data analysis were evaluated by using IBM SPSS STATISTICS (VERSION 22) software. DUNCAN’s multiple range test method was used in determining the different groups (Winer *et al*. 1991; Sokal and Rohlf, 1995; Raykov and Marcoulides, 2008). According the calculations, it was tried to determine whether or not the parameters varied significantly between the different planning systems. The evaluation accounted for the planning systems of the buildings, in addition to semi-diurnal and seasonal variability. The methods of data evaluation and comparison were also informed by similar studies in the literature (Fabbri *et al*., 2014; Wathes *et al*., 2002; Wathes *et al*., 1998; Hinz and Linke, 1998; Phillips *et al*., 1998; Chepete and Xin 2004; Lin *et al*., 2010).

RESULTS AND DISCUSSION

Ventilation rates: The ventilation rates are given in Table 4. The ventilation rates were within the comfort range of 0.3-4.3 m^3/h/bird in broiler houses and 0.1-4.8 m^3/h/bird in laying hen houses. The measurement of ventilation rates in all the poultry houses surveyed showed that the mean ventilation rates over 24 h were usually in agreement with the recommended minimum values of ventilation rates in winter, that is 0.18 m^3/h/kg, and 1.8 m^3/h/kg in summer in Anonymous (2003), Chepete and Xin (2004). The ventilation rate was higher in the deep litter system than the other planning types because of the differences in the waste management system in the deep litter type poultry buildings.

Temperature: The maximum, minimum, average, and standard deviation for temperature and relative humidity parameters measured during winter (January), early spring (March), and summer (July) were calculated for the six laying hen and broiler buildings, as summarized in Table 5. Climatic conditions in the research area showed hot and humid characteristics in spring and summer. For this reason, indoor temperature did not decrease significantly. The measurements in January showed that, the temperature levels did not fall below 10°C. Furthermore, continuous heating prevented the temperature from falling inside the buildings. In all of the poultry buildings, the ventilation control system was programmed relating bird weight to minimum ventilation rate. A target temperature was assigned as a function of the age of the birds for the breeding period. The ventilation rate increased if the temperature and relative humidity were higher than the target values. The ventilation rate in the building was established, operating a variable number of fans for a certain time. The operation of fans was timer controlled and air inlets were automatically controlled to maintain constant static pressure. Although the levels of temperature and relative humidity were controlled by ventilation system automation in buildings, especially in Californian cage systems, the ventilation system sometimes failed. However, even in winter, the data showed that the interior temperature tended to raise, especially in Californian cage type and deep litter system buildings (Table 5). As seen in Table 5, average temperatures in July (above 30°C) exceeded the comfort level (typically 10–25°C) for laying and broiler hens(Groot Koerkamp, 1994). In summer, outdoor temperature and relative humidity increased together, and consequently, the indoor temperature further increased. The indoor temperature sometimes increased more in the Californian cage type (building 3 and 4) and deep litter buildings (building 5 and 6), in which the ventilation systems were inadequate There was some evidence for insufficient management of ventilation, which would lead to a risk of heat stress in a hot and humid climate. This was especially true for the deep litter system, which prompted the consideration of the need for a cooling system. The data for March are similar to those for January (Table 5). All buildings showed comparatively low temperatures (especially minimum temperatures) in the mornings and higher temperatures later in the day.

Table 5 shows that average relative humidity deviated from the comfort range of 57–77%, with maximum values exceeding 70% and minimum values of less than 60%. Thus, average relative humidity values were lower. Lower relative humidity has the effect of increasing dust concentrations in the environment, leading to respiratory diseases in animals and workers (Yahav *et al*. 2000). As shown in Table 5, decreased minimum relative humidity was observed in the Californian cage type buildings and deep litter type buildings.

Maximum relative humidity values were again higher in buildings Californian cage type buildings (77.36%) and deep litter type buildings (80.44 %). The increase in relative humidity along with temperature can lead to respiratory distress, fatigue, and decreased productivity in animals (Groot Koerkamp, 1994). Poultry feces accumulate in pits beneath the cages of Californian type buildings and on the floor in deep litter type buildings. Unless measures are taken to ensure regular cleaning and sufficient ventilation, the humidity and pollutant concentrations in the ambient air increase in conjunction with increasing temperature and associated evaporation from the waste pit and floors (Hinz and Linke, 1998). As a result, higher relative humidity, together with high temperature, has an even greater negative impact on animal welfare (Nimmermark and Gustafsson, 2005). Ambient air conditions are more favorable in battery-cage type buildings from which animal waste is regularly disposed without accumulating inside the buildings.

Particulate matter: Table 6 shows that deep litter systems have higher concentrations of airborne particular matter than the two other systems, and these high values (maximum 9.20-13.32 mg/m^3 and average 2.10-3.16 mg/m^3) are likely to occur due to inadequate ventilation systems and cleaning regimes. Particulate matter values are also higher in the Californian cage systems than in battery cage systems. The air in Californian cage and deep litter systems may have more pollutant matter since particulate matter and gases are emitted from large surfaces of waste and litter. Furthermore, high outdoor relative humidity effectively reduces concentrations of indoor particulate matter, especially in summer periods. Concentrations of particulate matter tend to increase in association with lower relative humidity levels in January and March (Table 6).

As Table 6 indicates, the deep litter systems showed high concentrations of particulate matter in all seasons, followed by the Californian cage systems. Morrison *et al*. (1993) reported a size range of 0.1-1.0 mg/m^3 as respirable for hens; Takai *et al*. (1998) reported the size range of 0.42-1.14 mg/m^3 as respirable for hens. The lowest value of particulate matter was measured in battery cage systems. The semi-diurnal variations observed in particulate matter concentrations were non-significant, whereas the different building types showed significant differences in concentrations of particulate matter (P<0.05 and P<0.01).

Concentrations of NH_3, CH_4 and CO_2: Table 7 gives the maximum, minimum, and average values of NH_3, CH_4, and CO_2 gases measured in the poultry buildings. Table 8 also gives maximum, minimum, and average values for concentrations of NH_3, CH_4, CO_2 and particulate matter, at day and night released within the poultry buildings.

Table 1. The research plan and methodology of study.

Work Plan	Method
Selecting Poultry Buildings	Minimum variations of capacity, breeding type, age, body weight and feeding regime of poultry operations have been considered. Four layer hen houses and two broiler houses were selected.
Measurements	DO 2003 HVAC Datalogger
Temperature	DO 2003 HVAC Datalogger
Relative Humidity	Industrial Scientific IBRID MX6 with NH_3, CH_4, CO_2 sensors
NH_3, CH_4, CO_2	PDR-1200 Thermo Fisher Scientific
Particulate Matter	
Calculation of Animal Heat Production	Hourly total heat production *(THP)* and Respiratory quotient *(RQ)* $THP = 16.18 O_2 + 5.02 CO_2$ $RQ = \frac{CO_2}{O_2}$ *THP* = Total heat production rate of the hen, *W/kg* O_2 = Oxygen consumption rate, *mL/s/kg* - *Chepete and Xin (2004)* CO_2 = Carbon dioxide production rate, *mL/s/kg* *RQ* = Respiratory quotient which is the ratio of CO_2 to O_2
Calculation of Ventilation Rate	CO_2 mass balance method Ventilation rate *(V)* - *Li et. al (2004)* $CO_2 = \frac{THP}{16.18/RQ + 5.02}$ $V = \frac{CO_2 \times 10^6}{[CO_2]_e - [CO_2]_i}, m^3/h/kg$
Statistical Analysis of Data	Repeated Measures Analysis of Variance - (rANOVA) - *Winer et al. (1991)* SPSS Software (IBM-Version 22) - *Sokal and Rohlf (1995)*
Evaluation and interpretation of results	- *Raykov and Marcoulides (2008)*

As seen in Table 7, concentrations of NH_3 tend to increase in all buildings during summer, which is attributed to high outdoor relative humidity and temperature. However, further increase in relative humidity in the Californian and deep litter type buildings has the effect of amplifying NH_3 concentration, which presents a health risk to both animals and workers at concentrations greater than 20 ppm. The use of heating systems during winter and early spring conditions raises the internal temperature and relative humidity, leading to increased NH_3 concentrations. During these periods the fermentation of animal waste and the release of pollutant gasses lead to increased concentration of NH_3 in the air, especially in Californian cage (layer) and deep litter type (broiler) buildings. As a result of a more effective waste management strategy in the battery-cage type buildings, NH_3 concentrations were lower than those in the Californian and deep litter type buildings (Liang at al., 2005). Daily removal of manure on manure belts has been found to considerably reduce the NH3 concentration (von Wachenfelt *et al*., 2002). In experiments, ammonia emissions from laying hens showed an increase with air temperature (Groot Koerkamp *et al*., 1995). Ammonia emission is also considered to increase with the water content of the litter (Groot Koerkamp *et al*., 1999). In experiments with broilers, increased levels of relative air humidity resulted in increased litter moisture and caking, as well as increased ammonia levels (Weaver and Meijerhof, 1991). However, all building types showed high levels of NH_3 during periods of maximum temperature. Appropriate and effective use of the ventilation system solves this problem in the battery cage-type buildings. However, the fermentation of feces, urine, and other wastes seems continuous in the buildings with Californian type and deep litter planning systems. Nevertheless, in those buildings, increased ventilation or air speed has a negative effect on the animals. Ultimately, this situation is regarded as a drawback of the Californian cage and deep litter systems, as wastes accumulate and remain on the floor for long periods of time.

Measured CH_4 concentrations are given in Table 7. All buildings showed significant increases in daily and hourly CH_4 concentrations during summer periods of increased relative humidity. CH_4 concentrations were significantly higher in the deep litter (20.33 ppm) and Californian cage systems (16.28 ppm) than in the battery-cage systems (11.47 ppm). The Californian system permits the accumulation of poultry waste in pits beneath the cages. Subsequent fermentation results in higher concentrations of NH_3 and CH_4 released into the ambient air, compared to those measured for the battery-cage type systems. Similarly, in winter and early spring seasons, CH_4 levels were higher in the deep litter and Californian systems. In the battery-cage systems, CH_4 concentrations were higher in summer than in winter and early spring. The fattening period had a significant effect on CH4 concentration. Differences were mainly caused by the course of the outside temperature during the fattening period. Maximum concentration occurred during summer, when outside temperature reached maximum values up to 38 °C (Haeussermann *et al.*, 2006). As shown in Table 7, CO_2 concentrations generally tend to increase during winter for all types of poultry buildings, a tendency which is attributed to reduced ventilation during the cold season. CO_2 levels were higher in deep litter systems than battery-cage type and Californian cage type buildings in all three periods. CO_2 levels may be maintained within desired levels via effective and adequate ventilation.

Table 2. Characteristics of laying hen buildings.

Features	Building 1	Building 2	Building 3	Building 4
Capacity	9000	9050	9450	9600
Planning system	4-floor Battery	3-floor Battery	3-floor Californian	3-floor Californian
Age of bird, weeks	22-43	22-41	22-43	22-40
Flock size	8700±200	8900±150	8700±200	9000±100
Dimensions				
Floor area, m^2	615.00	550.00	517.50	750.00
Side wall height, m	3.15	3.30	2.85	2.60
Ridge height, m	5.10	4.80	5.10	4.25
Length, m	50.00	50.00	45.00	60.00
Width, m	12.30	11.00	11.50	12.50
Ventilation				
Air inlet openings	Window	Window	Window	Window
Air outlet openings	Mechanical-fan (6 units)	Mechanical-fan (6 units)	Mechanical-fan(8 units)	Mechanical-fan (8 units)
Barn cleaning	Daily	Daily	Daily	Daily
Structural elements				
Wall	Solid brick (20 cm) Interior-exterior plastered,whitewashed	Solid brick (20 cm) Interior-exterior plastered,whitewashed	Solid brick (20 cm) Interior-exterior plastered,whitewashed	Solid brick (20 cm) Interior-exterior plastered,whitewashed
Roof	Plywood (1 cm) Styrofoam (2 cm) Corrugated sheet	Wood veneer (2.5 cm) Glasswool (2 cm) Tile	Plywood (1 cm) Styrofoam (2 cm) Corrugated sheet	Wood veneer (2.5 cm) Glasswool (2 cm) Tile

Table 3. Characteristics of broiler buildings.

Features	Building 5	Building 6
Capacity	3000	3100
Planning system	Deep litter	Deep litter
Age of bird, weeks	4-12	4-18
Flock size	2850±100	2900±100
Dimensions		
Floor area, m^2	600.00	621.00
Side wall height, m	2.85	2.75
Ridge height, m	4.15	4.10
Length, m	45.00	45.00
Width, m	13.50	13.80
Ventilation		
Air inlet openings	Window	Window
Air outlet openings	Mechanical-fan (6 units)	Mechanical-fan (6 units)
Barn cleaning	Every 3 months	Every 3 months
Structural elements		
Wall	Solid brick (20 cm) Interior-exterior plastered, whitewashed	Solid brick (20 cm) Interior-exterior plastered, whitewashed
Roof	Plywood (1 cm) Styrofoam (2 cm) Corrugated sheet	Plywood (1 cm) Styrofoam (2 cm) Corrugated sheet

Table 4. Ventilation rates of poultry buildings (calculated from CO_2 balance method).

Buildings	Ventilation rate, m^3/h – *in winter*		Ventilation rate, m^3/h – *in summer*	
	Total ventilation, m^3/h	**$m^3/h/birds$**	**Total ventilation, m^3/h**	**$m^3/h/birds$**
Battery cage Building 1	30976	3.52	81190	8.10
Battery cage Building 2	39498	4.54	84301	8.43
Californian cage Building 3	45090	5.01*	81693	8.17*
Californian cage Building 4	45088	5.00	88811	8.22
Deep litter Building 5	17790	5.93*	25345	10.11**
Deep litter Building 6	15510	5.17	28563	9.20

* $P<0.05$, ** $P<0.01$

Table 5. Temperature and relative humidity values in poultry buildings.

Planning system	Months measured	Critical values					
		Temperature, °C			*Relative humidity, %*		
		Max.	*Min.*	*Avg.±S.E.*	*Max.*	*Min.*	*Avg.±S.E.*
Battery cage Building 1	*January*	24.05	16.48	21.36±0.03**	72.32	51.10	57.76±0.06
	March	23.28	17.09	18.19±0.03	71.28	50.41	56.88±0.04
	July	40.28	28.21	30.52±0.02	75.12	44.09	62.66±0.05
Battery cage Building 2	*January*	24.20	18.63	22.12±0.03	76.36	45.66	67.25±0.08
	March	22.63	18.93	19.14±0.02	73.21	45.02	66.29±0.07
	July	41.44	29.32	34.85±0.02*	74.39	44.72	62.40±0.07**
Californian cage Building 3	*January*	27.65	21.14	26.25±0.02	73.70	52.42	65.28±0.07
	March	28.50	22.28	21.19±0.02	71.54	45.45	59.58±0.07
	July	41.85	28.05	35.25±0.02**	72.73	48.05	61.28±0.06
Californian cage Building 4	*January*	27.21	20.96	23.41±0.03	77.36	57.28	68.57±0.09
	March	25.63	23.01	22.50±0.03	76.28	46.16	67.50±0.08
	July	41.10	30.25*	35.10±0.03	73.14	42.02	68.34±0.07*
Deep litter Building 5	*January*	24.14	18.25	22.74±0.02	76.27	50.21	70.47±0.10
	March	24.58	17.63	21.25±0.02	78.67	44.57	71.62±0.13

	July	39.47	24.10	34.39±0.02**	80.44	45.23	75.56±0.12**
Deep litter Building 6	*January*	24.63	18.19	19.67±0.03	74.15	54.47	69.32±0.16
	March	22.89	19.14	19.24±0.02	75.85	42.41	71.40±0.17
	July	39.14	27.36	32.11±0.01*	80.14	38.83	76.47±0.13

S.E. : Standard Error * $P<0.05$, ** $P<0.01$

Table 6. Particulate matter concentrations in poultry buildings

Planning system	***Months Measured***	***Particulate matter, mg/m³***		
		Max.	***Min.***	***Avg.±S.E.***
Battery cage Building 1	*January*	0.41**	0.01	0.04±0.0002
	March	0.22*	0.00	0.06±0.0002
	July	0.12	0.01	0.03±0.0001
Battery cage Building 2	*January*	0.52*	0.01	0.04±0.0002
	March	0.28	0.00	0.04±0.0001
	July	0.15	0.00	0.02±0.0001
Californian cage Building 3	*January*	2.32	0.04	0.09±0.0003
	March	2.30	0.03	0.09±0.0001
	July	2.25	0.03	1.08±0.0002*
Californian cage Building 4	*January*	2.30	0.03	1.05±0.0003
	March	2.28	0.03	1.05±0.0001*
	July	2.23	0.03	1.09±0.0002
Deep litter Building 5	*January*	12.31	0.06	3.16±0.0002**
	March	13.27	0.06	3.12±0.0002
	July	9.20	0.04	2.10±0.0002
Deep litter Building 6	*January*	13.32	0.06	3.14±0.0002
	March	12.32	0.05	3.16±0.0003**
	July	10.30	0.03	2.12±0.0002

S.E.: Standard Error * $P<0.05$, ** $P<0.01$

Table 7. Maximum, minimum and average values for concentrations of ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2) released within the poultry buildings

Planning System	**Months**	**Critical values**								
		NH₃, ppm			***CH₄, ppm***			***CO₂, ppm***		
		Max.	***Min.***	***Avg.±SE***	***Max.***	***Min.***	***Avg.±SE***	***Max.***	***Min.***	***Avg.±SE***
B. cage Building 1	*January*	25.18	3.47	8.47±0.03	7.21	5.10	6.36±0.04	1190.70	150.20	951.14±1.56
	March	33.34	6.02	8.63±0.04	7.93	5.42	6.52±0.04	957.50	111.25	537.18±1.53
	July	48.55	10.33	17.56±0.05*	11.47	6.65	8.96±0.04*	775.75	68.09	396.22±1.53
B. cage Building 2	*January*	29.06	3.17	12.33±0.03	8.43	5.65	6.94±0.04	1617.10	550.68	1153.47±1.58**
	March	38.88	8.14	10.21±0.03	7.47	5.63	6.71±0.04	1544.43	509.57	806.77±1.63
	July	60.77	13.07	22.24±0.03**	14.17	6.33	10.82±0.03**	958.96	93.74	457.17±1.59
C. cage Building 3	*January*	27.09	8.58	14.47±0.03	13.54	6.42	9.49±0.03	1613.40	567.55	1289.44±1.50*
	March	39.11	8.76	18.14±0.02	14.14	6.77	11.76±0.03**	1503.70	461.24	848.69±2.13
	July	51.79	13.73	22.09±0.02	14.18	7.63	11.82±0.03	956.63	100.60	468.16±2.11
C. cage Building 4	*January*	34.68	9.04	15.93±0.002**	15.14	8.43	10.73±0.03	1805.57	584.30	1346.43±3.30
	March	45.06	10.13	19.62±0.03	15.33	6.74	12.09±0.02	1621.40	490.44	970.34±3.29
	July	68.81	25.29	24.47±0.03	16.28	9.93	15.91±0.03	992.60	108.22	479.99±3.40
Deep litter Building 5	*January*	43.57	8.51	18.09±0.05	16.47	7.44	12.14±0.05	8906.33	502.1	2057.07±7.33*
	March	55.36	10.25	26.41±0.05	16.25	9.22	14.20±0.05*	4029.77	301.11	1650.93±7.34
	July	82.25	12.09	43.07±0.05*	18.14	10.41	15.02±0.05	1806.04	264.79	960.28±7.35
Deep litter Building 6	*January*	49.54	8.84	20.74±0.05	19.32	9.95	10.44±0.04	8807.88	411.66	1350.71±7.23
	March	60.42	13.17	26.06±0.04	19.96	11.77	15.29±0.04	4649.07	388.69	1073.23±7.24
	July	85.10	17.14	48.86±0.04	20.33	12.48	18.87±0.04	1996.11	293.54	981.95±7.23

S .E. : Standard Error * $P<0.05$, ** $P<0.01$

Table 8. Day and night – maximum, minimum ,average and standard errorvalues for concentrations of ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2) and particulate matter (PM) released within the poultry buildings.

Planning type	Day/night	Parameters	NH_3, ppm	CH_4 ppm	CO_2 ppm	PM mg/m^3
Battery cage	Day	*Average*	1.12**	84.27**	502.82**	0.07**
		Maximum	6.62	682.57	741.20	0.62
		Minimum	0.22	51.40	180.17	0.01
		S.E.	0.05	50.23	70.10	0.03
	Night	*Average*	2.46	120.17*	510.27*	0.05
		Maximum	8.01	655.33	802.13	0.33
		Minimum	0.41	50.11	408.25	0.01
		S.E.	0.02	80.10	68.60	0.03
Californian cage	Day	*Average*	2.54*	90.14*	702.24**	0.08
		Maximum	8.41	752.36	1200.54	0.85
		Minimum	0.85	60.24	190.29	0.03
		S.E.	0.07	50.21	2.53	0.05
	Night	*Average*	5.03*	140.57*	914.47*	0.05
		Maximum	12.6	800.26	1401.22	0.51
		Minimum	1.47	62.30	74.10	0.03
		S.E.	0.03	1.40	2.01	0.05
Deep litter	Day	*Average*	6.82*	4.25	802.12**	0.32
		Maximum	18.72	9.1	1587.20	2.10**
		Minimum	1.02	0.58	41.23	0.05
		S.E.	0.08	1.85	280.11	0.18**
	Night	*Average*	8.20*	9.82**	942.13*	0.21**
		Maximum	19.14	20.40	1702.41	0.81
		Minimum	2.85	2.47	51.02	0.01
		S.E.	0.03	2.14	297.47	0.10

S .E. : Standard Error * $P<0.05$, ** $P<0.01$

Conclusion: It is concluded that different planning systems affect indoor air quality of poultry buildings. Variations in floor arrangement, ventilation and waste management systems have significant effects on the concentrations of NH_3, CH_4, CO_2, temperature, relative humidity, and particulate matter in the three types of poultry buildings ($P<0.05$ and $P<0.01$).

1. NH_3 and CH_4 showed significant semi-diurnal variations in Californian types and were higher in summer than the other systems.
2. Battery cages had the lowest particulate matter, whereas the deep litter system had the highest particulate matter.
3. A hot and humid local climate and the type of waste management system also increased the relative humidity. Higher relative humidity also led to high NH_3 levels.
4. The results indicate that the battery cage system is more appropriate type for providing the required air quality for birds.

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