



Ammonia and Carbon Dioxide Concentrations in a Layer House

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ABSTRACT: Higher concentrations of ammonia (NH₃) and carbon dioxide (CO₂) in animal barns can negatively affect production and health of animals and workers. This paper focuses on measurements of summer concentrations of ammonia (NH₃) and carbon dioxide (CO₂) in a naturally ventilated laying henhouse located at an egg production facility in Bursa region, western Turkey. Also, indoor and ambient environmental conditions such as temperature and relative humidity were measured simultaneously with pollutant gas concentrations. The average NH₃ concentrations during summer of 2013 was 8.05 ppm for exhaust and 5.42 ppm for inlet while average CO₂ concentration was 732 ppm for exhaust and 625 ppm for inlet throughout summer. The overall minimum, average and maximum values and humidity were obtained as 16.8°C, 24.72°C, and 34.71°C for indoor temperature and 33.64%, 63.71%, and 86.18% for relative humidity. The lowest exhaust concentrations for NH₃ and CO₂ were 6.98 ppm and 609 ppm, respectively. They were measured in early morning at the maximum diurnal ventilation rate in July 2013 and August 2013. The highest concentrations were 10.58 ppm for NH₃ and 904 ppm for CO₂ recorded in the afternoon when the ventilation rate was the lowest in June 2013. (**Key Words:** Ammonia, Carbon Dioxide, Concentration, Diurnal Pattern, Laying Hens Houses)

INTRODUCTION

In the Turkish egg production sector, there are about 85 million laying hens with an annual production of 15 million eggs (about 1 million kg) produced in 2012 (TUIK, 2013) and 61 billion kg produced annually worldwide (FAO, 2011). Currently, laying hen husbandry with a cage system is the most common method of commercial egg production in Turkey, in parallel with the trend worldwide.

The indoor air quality in laying hen houses is crucially important to the hens' egg production as well as emitting less pollutant gas and providing a healthier environment for workers. Pollutant gas concentrations, indoor environmental conditions such as, temperature, relative humidity, light intensity and airflow are major characteristics of indoor air quality in laying hen houses. Ammonia (NH₃) is dominant pollutant gas in poultry houses. Furthermore, NH₃ plays an essential role in the atmosphere with contribution to the nitrogen cycle as well as in indoor air quality (Arogo et al.,

2006). Also, high concentrations of NH₃ (e.g. >20 ppm) may cause respiratory diseases (e.g., coughing, upper respiratory tract bleeding, excessive secretions, and lung bleeding or inflammation) (Smith, 1998; Dong et al., 2009).

Ammonia in laying hen houses emitted mainly from manure, whereas CO₂ formation commonly comes from the bird's respiration. The magnitude of NH₃ concentration in buildings mainly depends on husbandry systems (cage, on litter or alternative systems), capacity of house, density (in cage or on unit floor area) and feed content. The NH₃ concentration increases in cases of higher density and feed with higher protein.

There are a few studies to determine NH₃ concentrations in animal barns in Turkey. In these studies, NH₃ concentration was measured in broiler houses (Atilgan et al., 2010; Simsek et al., 2013), dairy barns (Simsek et al., 2012) and laying hen houses (Kocaman et al., 2006). On the contrary, many of studies have been conducted to quantify NH₃ concentrations in laying hen houses in Europe and in the US.

Gao et al. (2013) estimated NH₃ concentration and emissions in a laying hen house in China. The emissions factor for laying hen houses was found as 164

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mg·hen⁻¹·year⁻¹ in this study. Groot Koerkamp et al. (1998) and Nicholson et al. (2004) measured NH₃ emissions from different manure handling systems in four European countries and UK, respectively. They measured NH₃ concentrations as 8.3 ppm in England, 29.6 ppm in the Netherlands, and 25.2 ppm in Denmark. Fabbri et al. (2007) reported NH₃ and greenhouse gases (GHG) concentrations and emissions from two different laying hen houses in Italy. The average NH₃ concentration in summer months was about 2 ppm in their study. Wang-Li et al. (2013) monitored two tunnel-ventilated high-rise layer houses in North Carolina, USA to determine NH₃ concentrations and emissions. They found that NH₃ concentrations were 23 ppm for laying hen houses. Lin et al. (2012) addressed NH₃ and other pollutant gas concentrations and emissions from high-rise laying hen houses in California, USA. The NH₃ emission from Californian laying hen houses was calculated 0.95 g·d⁻¹·bird⁻¹ during two years measurement. Kilic et al. (2011) estimated using nitrogen balance method NH₃ concentration in US high-rise laying hen houses. NH₃ emissions was calculated as 0.16 kg·birds⁻¹·year from laying hens house in Kilic et al. (2011).

The aim of this study were to quantify NH₃ and CO₂ concentrations gases and determine effects of indoor environmental conditions on pollutant gas concentrations during summer seasons for a naturally ventilated laying hens house located in Bursa, west Turkey.

MATERIALS AND METHOD

House characteristics

A cage layer farm in Bursa, western Turkey, was selected in this study to monitor NH₃, and CO₂ concentrations and emissions. Selection of the farm was based on its production scale and management practices being representative of the current and growing trend of egg production facilities in Bursa region. The farm had a total of two naturally ventilated houses.

The monitored house had a dimension of 39×12 m (L×W) with a north-south orientation. The monitored house contained five cage rows and each cage row had three tiers, with a total holding capacity of approximate 12,000 laying hens (Figure 1). Each house had 10 air inlet openings (0.5×2.1 m each) spaced at 1.6 m intervals along each east and west sidewalls. There was an opening on ridge throughout length of building.

Fresh air enters the building through both sets of sidewall openings and exits the building through the ridge opening (Figure 1). Operation of the ventilation windows and ridge vents was based on the target house temperature, which was 25°C in summer and was adjusted manually.

The leghorn hens were fed with commercial standard diets three times a day at 06:00, 12:00, 18:00, and 24:00 h and had free access to drinking water. Feces dropped to the manure belt beneath the cages and were scraped out to a manure collection channel at the end of each cage row. The removed manure was taken from the manure collection channel to a trailer outside the house.

The cage density was five birds per cage. Bird performance data (feed consumption, bird age, and egg production) were taken from farm records during the experiment.

Egg, feed and manure samples from each cage rows were collected. Their physical and chemical properties, including dry matter and total nitrogen contents, were analyzed in a certified analytical lab (TUBITAK, BUTAL) in Bursa.

Pollutant gas concentration and environmental conditions measurement

In this study, NH₃ and CO₂ concentrations and indoor environmental conditions such as temperature, and relative humidity was measured for five consecutive days in first, medium and last week of each month in summer of 2013. The laying hen age during the summer measurement period was 56 weeks. A multi-gas analyzer (MultiRAE IR Lite,

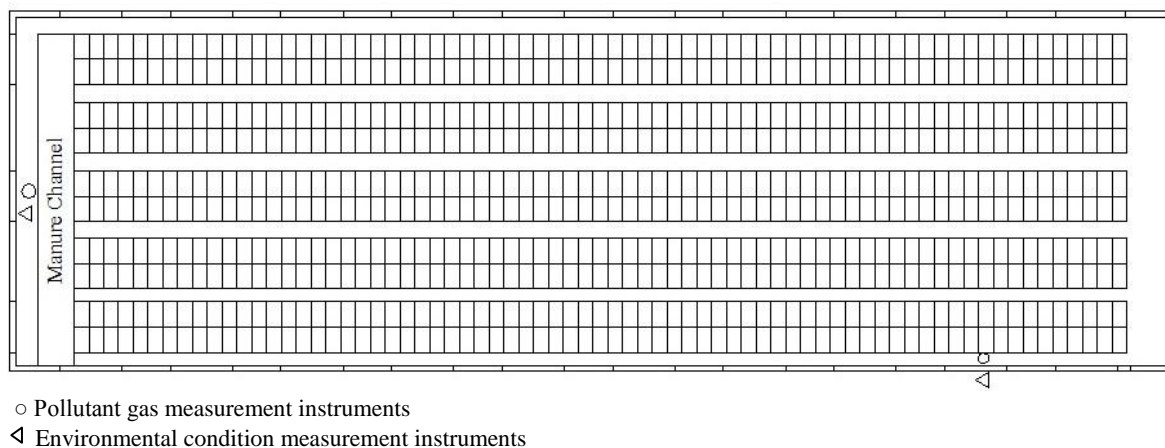


Figure 1. Measurement locations in monitored laying hen house.

Table 1. Egg production parameters monitored in laying hen house

Month	Number of hens	Body weight (kg)	Age of hen (week)	Mortality (bird)	Egg production (viol-day ⁻¹)	Daily feed intake (g-bird ⁻¹)
June	11,142	1.92	56	3,5	287	152
July	11,038	1.95	61	6,4	221	154
August	10,512	1.97	65	3,1	241	155

RAE systems, San Jose, CA, USA) with electrochemical and NDIR sensors was used for pollutant gas concentrations. Two multi-gas analyzers were located at the inlet and exhaust openings and measured pollutant gas concentrations at 5 min intervals. Indoor and outdoor air temperatures, relative humidity (RH) and air velocity in monitored house were measured at 5 min intervals throughout the experiment using portable temperature/RH/air velocity meter with hot-wire probe (Model 435-2, Testo, Germany). Outdoor temperature/RH/air velocity data was taken from a meteorology station near the monitored layer house. The distance between the house and station is approximately 14 km.

Airflow rates calculation

Calculation of airflow rates in naturally ventilated facilities is highly difficult during the summer season. Therefore we used an indirect method to calculate airflow rate. The house ventilation rate was calculated using a CO₂ balance method based on CO₂ production of laying hens given below (Albright, 2000).

$$Q = \frac{V_{CO_2} \times 10^6}{C_{e,CO_2} - C_{i,CO_2}} \times \rho_{CO_2}$$

Where; V_{CO₂} is CO₂ generation rate of the hen house (m³·h⁻¹·house⁻¹), C_e, CO₂ and C_i, CO₂ are exhaust and inlet CO₂ concentrations of the hen house at 20°C (mg·m⁻³), and ρ_{CO₂} is CO₂ density (1.977 kg·m⁻³ at 20°C).

Data analysis

The data obtained from the monitored laying hen house was statically analyzed using JMP 7. The general linear model was used to determine significance of differences among pollutant gas concentrations and also regression analyze was done to reveal relationship between environmental indoor conditions and pollutant gas concentrations.

RESULT AND DISCUSSION

Egg production parameters

The number of hens, average body weight, bird age, mortality, egg production and daily feed intake parameters

in egg production during the study period are summarized in Table 1. Feed intake increased with hen age from 56 to 65 weeks. The lowest feed intake was found in June 2013. The highest mortality occurred in July 2013 due to environmental conditions. In the study period, egg production was affected by mortality.

Feed, egg and manure samples were analyzed weekly during each month in the summer of 2013. The results are listed in Table 2.

Ambient and indoor environmental conditions

The descriptive statistics of indoor and ambient air temperature, relative humidity, air velocity and airflow rate are given in Table 3. The indoor temperature varied from 16.80°C to 34.71°C while relative humidity ranged between 34.60% and 86.18%. The indoor temperature and relative humidity in August 2013 were significantly higher than other months in summer. The air velocity and airflow rates varied from 0.04 to 0.54 m·s⁻¹ and from 8 to 37 m³·s⁻¹·house⁻¹, respectively. The maximum airflow rate was obtained in July and August 2013.

The diurnal variation was observed on indoor environmental conditions during study period (Figure 2). The average daytime and night time indoor air temperatures (T), relative humidity (RH) and velocity (V) were 26°C and 22°C, 59% and 69%, 0.20 and 0.18 m·s⁻¹ respectively. Also, the differences between daytime and nighttime variables were statistically significant for T, RH (p<0.01) and V (p<0.05).

Ammonia and carbon dioxide concentrations

The descriptive statistics of measured gas

Table 2. The chemical characteristics of feed, egg and manure samples during study

Sample	Month	Sample n	Parameters		
			DM (%)	TN (%)	pH
Egg	Jun-13	21	23.50	1.77	7.46
	Jul-13	21	22.10	1.79	7.12
	Aug-13	21	19.20	1.89	7.19
Feed	Jun-13	21	90.30	2.80	6.55
	Jul-13	21	91.95	2.68	6.41
	Aug-13	21	90.90	14.9	6.51
Manure	Jun-13	21	29.90	1.31	8.13
	Jul-13	21	42.45	1.36	8.01
	Aug-13	21	22.80	8.8	8.80

DM, dry matter; TN, total nitrogen.

Table 3. The descriptive statistics of indoor and outdoor environmental conditions

Month	Parameter	June 2013		July 2013		August 2013	
		Ambient	Indoor	Ambient	Indoor	Ambient	Indoor
T (°C)	Min	12.2	16.8	12.9	17.7	14.6	18.34
	Avg	21.5	24.46	21.94	22.95	24.43	26.74
	Max	31.2	33.22	30.5	27.65	35.3	34.71
	SD	4.33	4.35	3.8	3.38	4.94	5.67
RH (%)	Min	18.3	34.6	35.7	47.24	19.3	33.64
	Avg	63.28	64.39	65.33	65.25	55.96	61.47
	Max	92.8	83.8	96.1	76.98	87	86.18
	SD	17.43	11.41	15.47	8.91	17.4	14.36
Velocity (m·s ⁻¹)	Min	0.3	0.05	0.6	0.05	0.4	0.04
	Avg	2.25	0.2	3.28	0.12	2.8	0.21
	Max	5.8	0.54	6.9	0.31	7.7	0.45
	SD	1.31	0.09	1.8	0.06	1.89	0.07
Airflow rates (m ³ ·s ⁻¹ ·house ⁻¹)	Min	-	8.0	-	9.0	-	7.1
	Avg	-	14.5	-	17.9	-	16.5
	Max	-	35.6	-	37.2	-	37.2
	SD	-	4.6	-	7.7	-	6.8

T, temperature; Min, minimum; Avg, average; Max, maximum; SD, standard deviation; RH, relative humidity.

concentrations during the summer 2013 are presented in Table 4. The average exhaust or inlet NH₃ and CO₂ concentrations were defined as the average of the hourly

mean concentrations measured at inlet and exhaust levels. When the inlet concentration measurement location was in front of the inlet on the side wall, pollutant gas

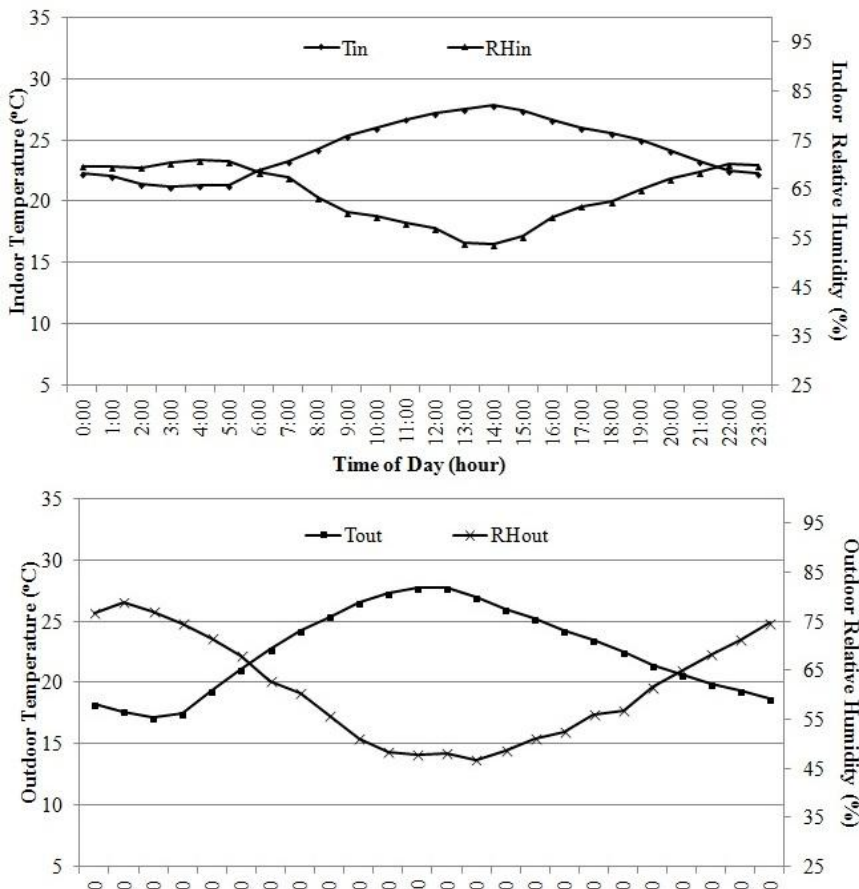


Figure 2. Diurnal variation in indoor and outdoor environmental conditions during study period.

Table 4. The descriptive statistics of NH₃ and CO₂ concentrations

Month	Type	NH ₃ concentration (ppm)					CO ₂ concentration (ppm)				
		Min	Avg	Max	Real	SD	Min	Avg	Max	Real	SD
June 2013	Inlet	5.53 ^a	6.55 ^a	8.67 ^a	7.02 ^a	2.20	533 ^a	665 ^a	824	671 ^a	45
	Exhaust	9.80	9.88 ^a	10.58 ^a	10.20	1.59	670 ^a	778 ^a	904 ^a	785 ^a	44
July 2013	Inlet	5.34 ^a	5.58 ^b	6.51 ^b	5.89 ^b	1.95	510 ^b	580 ^c	681	582 ^c	128
	Exhaust	7.11	7.16 ^b	7.42 ^b	10.19	3.71	609 ^b	673 ^c	764 ^c	679 ^c	101
August 2013	Inlet	4.00 ^b	4.15 ^c	4.84 ^c	4.42 ^c	1.95	552 ^a	631 ^b	753	641 ^b	59
	Exhaust	6.98	7.11 ^b	7.49 ^b	7.31	2.14	636 ^b	745 ^b	860 ^b	754 ^b	60

Min, minimum; Avg, average; Max, maximum; SD, standard deviation.

^{a-c} Means in a column with different superscripts significantly differ (p<0.0001).

concentrations were higher than ambient air surrounding the house because it was most likely affected by the emissions from the hen house itself. Pollutant gas concentrations at this inlet location varied from 4.00 to 8.67 ppm for NH₃ and from 510 to 824 ppm for CO₂.

Pollutant gas concentrations were generally higher in exhaust than that of inlet concentrations. The average NH₃ and CO₂ concentrations were calculated using hourly mean data. The minimum, average, maximum and standard deviation values of pollutant gas exhaust concentrations were measured as 6.98, 8.05, 10.58, and 2.48 ppm for NH₃,

609, 732, 904, and 69 ppm for CO₂ throughout study, respectively. The maximum NH₃ and CO₂ exhaust concentrations were observed on June 2013 while minimum exhaust concentrations were measured on August 2013 for NH₃ and July 2013 for CO₂.

According to average hourly pollutant gas concentrations (Figure 3), inlet concentrations for NH₃ and CO₂ illustrated no clear diurnal variations. However, exhaust concentrations for NH₃ and CO₂ showed a clear diurnal pattern depending on bird activity, ambient temperature and house airflow rate. The average NH₃ and

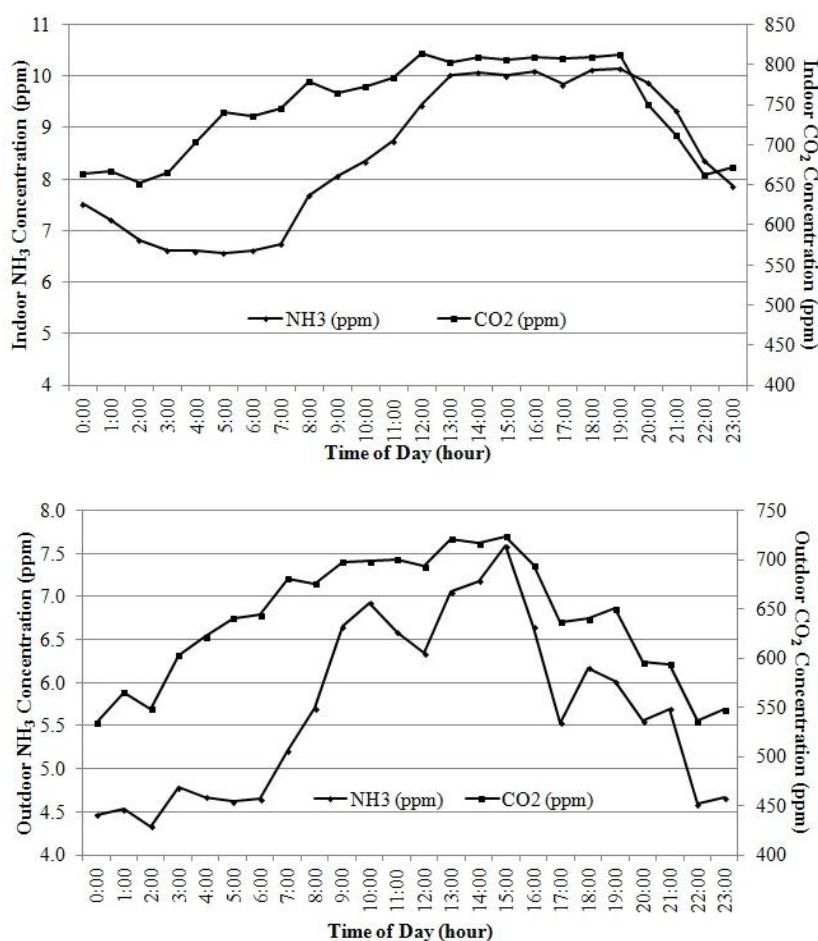


Figure 3. Diurnal variation in exhaust and inlet NH₃ and CO₂ concentrations during study period.

CO₂ exhaust concentrations in day time were 9.03 and 790 ppm, respectively. Consequently, the average NH₃ concentration was lowest in early morning (2.42 ppm) while average CO₂ exhaust concentration was lowest in early noon (467 ppm). The maximum exhaust concentrations for NH₃ and CO₂ were measured after noon. Since the inside and exhaust NH₃ and CO₂ concentrations are substantially affected by house airflow rates and the airflow rate varies with ambient temperature, this interaction among environmental conditions created diurnal patterns of NH₃ and CO₂ concentrations.

The magnitude of ammonia concentration in laying hen houses is more important comparing with other animal houses, e.g., dairy and swine (Koerkamp et al., 1998). In a study in the USA, NH₃ concentrations varied between 2 and 10 ppm in broiler houses under summer conditions, (Redwine 2003). Cheng et al. (2011) measured NH₃ concentration in layer houses with a cage system and their results for NH₃ concentration ranged from 0.5 to 12.5 ppm. These concentration values for NH₃ were comparable to the results of this study. The layer houses with a manure belt and high rise (HR) cage systems in North Carolina, USA were monitored continuously during two years. The results of Wang-Li (2013) stated that the 2-year mean NH₃ concentrations (23 ppm) at the exhaust fans in the HR houses were higher than results of this study, while the results (3 ppm) of a study from China (Zhu et al., 2011) were similar.

NH₃ concentrations affect workers' health as well as laying hens in house. Different countries worldwide have some regulations to protect workers' health in animal barns. These regulations set limits for a time-weighted average (TWA) over 8 h and a short exposure threshold limits. According to Turkish regulations on workers' health, the exposure limit of NH₃ was established as 20 ppm for short-term exposure and 50 ppm for TWA over 8 h (Kilic, 2013). Indicative Occupational Exposure Limit values by European Union (Directive 2009/161/EU) are similar to the Turkish limits (Anonymous, 2009). Additionally, NH₃ exposure limit for animals in barns in Sweden is 10 ppm (Anonymous, 2010).

The average summer CO₂ concentration was measured as 732 ppm in this study. This value is similar to some European studies while it is lower than some studies in USA. Dobeic and Pintaric, (2011) measured average CO₂ concentrations was 758 ppm in exhaust air in monitored seven layer hen houses in Slovenia. The average summer ammonia concentration was found 1,012 ppm in four laying hen houses with manure belt in Iowa in USA (Liang et al., 2005; Green et al., 2009).

CO₂ is one of the GHG involved in global warming. In this study, average CO₂ concentration per 1,000 bird was measured 66.54 ppm for the Bursa region. According to data obtained from the Turkish Statistical Institute (TUIK, 2013), the number of laying hens in Bursa region and Turkey for 2012 year was 4.2 million and 84.6 million, respectively. When the effect of a laying hen house on global warming is estimated using this study results, the contribution of CO₂ concentration produced in laying hen houses to atmospheric CO₂ concentrations is approximately 280,000 ppm regional wide and 5.6 million ppm national wide. However, under Turkey's conditions, more studies are required to more accurately estimate the CO₂ contribution to global warming.

Relationship of pollutant gases concentration and environmental conditions

Regression models were developed for NH₃ and CO₂ concentrations using the data obtained from this study (Eq 1 and Eq 2). The indoor air temperature (T), indoor air velocity (V) and indoor relative humidity were considered as independent variables. The regression analyze was used to develop these models. The descriptive statistics of these models were given in Table 5.

$$C_{\text{NH}_3} = -5.89 + 53.31V + 0.37T + 0.063RH \quad \text{Eq (1)}$$

$$C_{\text{CO}_2} = 1,024 - 1,306V + 1.49T - 3.74RH \quad \text{Eq (2)}$$

Only indoor air temperature among all variables had a significant effect on pollutant gas concentrations in the laying hen house. This study revealed that increased T was

Table 5. Statistics of relationship between pollutant gas concentrations and indoor environmental conditions

Term	NH ₃			CO ₂		
	SD	t ratio	Prob> t	SD	t ratio	Prob> t
Air velocity	56.7505	0.94	0.3483	2,145.581	-0.61	0.543
T	0.059207	6.25	<0.0001	2.238442	0.66	0.5074
RH	0.024976	2.51	0.0126	0.94429	-3.96	<0.0001
R ²		0.21			0.13	
RMSE		2.9			109.98	
Means of response		8.98			783	
Observation number		3,504			3,504	

SD, standard deviation; T, temperature; RH, relative humidity; RMSE, root mean square error.

associated with higher NH_3 and CO_2 concentrations (Table 5). The source of pollutant gas in laying hen houses can explain this finding in the model. NH_3 concentrations are mostly emitted from manure and urine on the manure belt. Indoor air temperature and pH have been reported as two of the most important factors that influence NH_3 volatilization from manure (Sommer et al., 1991; Arogo et al., 2006).

The producers in Bursa region can use these equations to estimate concentration level of NH_3 and CO_2 in their laying hen houses. They firstly need to measure indoor environmental conditions, such as temperature, relative humidity, and air velocity. They can easily estimate concentration level of NH_3 and CO_2 in their house via only these parameters in the equations and decide whether NH_3 and CO_2 concentration in their laying hen house exceed exposure limits for bird and workers' health. Therefore, producers can determine and implement the most reliable mitigation strategy to reduce these gases concentrations in their conditions. Also, the measurement of indoor environmental conditions is less expensive than air quality measurements in animal barns. When producers use these equations, they can easily determine NH_3 and CO_2 concentrations using this less expensive method.

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