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# Ammonia, Greenhouse Gas, and Particulate Matter Concentrations and Emissions of Aviary Layer Houses in the Midwestern USA

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## Abstract

There has been an increased interest in alternative housing for laying hens in certain parts of the world, including the United States. Associated with the movement are many questions to be addressed concerning sustainability of such systems. This study continually quantifies concentrations and emissions of ammonia (NH<sub>3</sub>), carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and particulate matters (PM<sub>10</sub> and PM<sub>2.5</sub>) for two side-by-side aviary barns each housing 50,000 Hy-Line brown laying hens, located in the Midwestern US. The gaseous concentrations were continually monitored using a photoacoustic multi-gas analyzer, while the PM concentrations were measured with tapered element oscillating microbalances (TEOMs). Barn ventilation rate was determined through monitoring the operation time of ventilation fans that had been calibrated in-situ. Nineteen consecutive months of monitored data (June 2010 – Dec 2011) are analyzed and presented. Daily indoor NH<sub>3</sub>, CO<sub>2</sub>, CH<sub>4</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> concentrations (mean ±SD) were 8.7 (±8.4) ppm, 1,636 (±1,022) ppm, 10.0 (±6.8) ppm, 2.3 (±1.6) mg/m<sup>3</sup>, and 0.25 (±0.26) mg/m<sup>3</sup>, respectively. The aerial emissions are expressed as quantities per hen, per animal unit (AU, 500 kg body weight), and per kg of egg output. Daily emission rates were 0.15 (±0.08) NH<sub>3</sub>, 75 (±15) CO<sub>2</sub>, 0.09 (±0.08) CH<sub>4</sub>, 0.11 (±0.04) PM<sub>10</sub>, and 0.008 (±0.006) PM<sub>2.5</sub> g/bird. The results are compared to reported emission values for conventional (high-rise and manure-belt) US laying-hen housing systems. Data from this study provide baseline concentration and emission values from the aviary housing system in the Midwestern US.

## Keywords

Aviary, Air Quality, Aerial Emissions, Concentrations, Laying Hen

## Disciplines

Bioresource and Agricultural Engineering

## Comments

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## **Ammonia, Greenhouse Gas, and Particulate Matter Concentrations and Emissions of Aviary Layer Houses in the Midwestern USA**

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**Abstract.** There has been an increased interest in alternative housing for laying hens in certain parts of the world, including the United States. Associated with the movement are many questions to be addressed concerning sustainability of such systems. This study continually quantifies concentrations and emissions of ammonia (NH<sub>3</sub>), carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and particulate matters (PM<sub>10</sub> and PM<sub>2.5</sub>) for two side-by-side aviary barns each housing 50,000 Hy-Line brown laying hens, located in the Midwestern US. The gaseous concentrations were continually monitored using a photoacoustic multi-gas analyzer, while the PM concentrations were measured with tapered element oscillating microbalances (TEOMs). Barn ventilation rate was determined through monitoring the operation time of ventilation fans that had been calibrated in-situ. Nineteen consecutive months of monitored data (June 2010 – Dec 2011) are analyzed and presented. Daily indoor NH<sub>3</sub>, CO<sub>2</sub>, CH<sub>4</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> concentrations (mean ±SD) were 8.7 (±8.4) ppm, 1,636 (±1,022) ppm, 10.0 (±6.8) ppm, 2.3 (±1.6) mg/m<sup>3</sup>, and 0.25 (±0.26) mg/m<sup>3</sup>, respectively. The aerial emissions are expressed as quantities per hen, per animal unit (AU, 500 kg body weight), and per kg of egg output. Daily emission rates were 0.15 (±0.08) NH<sub>3</sub>, 75 (±15) CO<sub>2</sub>, 0.09 (±0.08) CH<sub>4</sub>, 0.11 (±0.04) PM<sub>10</sub>, and 0.008 (±0.006) PM<sub>2.5</sub> g/bird. The results are compared to reported emission values for conventional (high-rise and manure-belt) US laying-hen housing systems. Data from this study provide baseline concentration and emission values from the aviary housing system in the Midwestern US.

**Keywords.** *Aviary, Air Quality, Aerial Emissions, Concentrations, Laying Hen*

## Introduction

In the past decade there has been increased pressure to move from traditional laying hen cage houses with both high rise and belt manure systems to cage-free and enriched cage housing. With this pressure there are many questions about the performance of these alternative systems. There is very little information on the emissions from these alternative systems, particularly as they are operated in the U.S. This study was conducted in aviary barns with the Natura 60 (Big Dutchman, Holland, MI) design, from which we collected baseline data on concentrations and emissions for particulate matter with aerodynamic diameter of 10 or 2.5  $\mu\text{m}$  ( $\text{PM}_{10}$  and  $\text{PM}_{2.5}$ ); greenhouse gasses (GHG)- carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ); and ammonia ( $\text{NH}_3$ ). Studies have been conducted to quantify aerial emissions for conventional laying-hen housing in the US and conventional and alternative housing in Europe. The study by Liang et al. (2003) showed  $\text{NH}_3$  emission rates of 0.05 to 0.1 g/bird-day for conventional manure belt hen houses and 0.95 g/bird-day for high-rise hen houses. European studies showed  $\text{NH}_3$  emission rates from cage-free barns of 0.27 and 0.85 g/bird-day (Groot Koerkamp et al, 1998, Muller et al., 2003). The European reported values for ammonia emissions at the higher end are comparable to high-rise housing. Reported values for  $\text{CO}_2$  from belt houses are 70 to 85 g/bird-day (Liang et al., 2003, Nesar et al., 1997). For  $\text{CH}_4$  literature suggests all housing systems emitting between 0.08 and 0.13 g/bird-day (Groot Koerkamp and Uenk ., 1997; Monteny et al., 2001; Fabbri et al., 2007; Wathes et al., 1997). Literature on conventional laying-hen housing reports  $\text{PM}_{2.5}$  emissions of 0.0036 to 0.014 g/bird-day; and for  $\text{PM}_{10}$  the reported literature emission values range from 0.019 to 0.048 g/bird-day (Li et al., 2011). Cage-free systems in Europe were reported to have  $\text{PM}_{10}$  emissions 2 to 3 times greater than conventional houses (Takai et al., 1998).

The objectives of this study were to quantify average daily gaseous and particulate matter concentrations and emission rates from aviary houses in the Midwestern US. As well, daily house temperatures, relative humidity (RH), and ventilation rates (VR) needed to be determined.

## Materials and Methods

The study was conducted in two barns at one site in Iowa over 19 months in an effort to capture flocks from placement to the end of production. Each house measured 167.6 m x 19.8 m with a capacity of 50,000 hens (Hy-Line Brown) and a production cycle of 17 to about 80 weeks of age (new flock started the fourth week of April 2010 in barn 3 and the second week of September 2010 in barn 2). To minimize floor eggs and improve manure management, the hens were trained to be off the floor and return to the aviary colonies at night and remained in the colonies until the next morning. Each colony had three tiers and manure belt with a manure-drying air duct was placed underneath the lower two cage tiers. The three tiers were divided into nest, perch, wire floor, feeding, and drinking areas. Each house had 20 exhaust fans, all on one sidewall (fig. 1), including twelve 1.2 m, four 0.9 m, and four 0.5 m fans. Ceiling box air inlets were used. Compact fluorescent lighting was used.

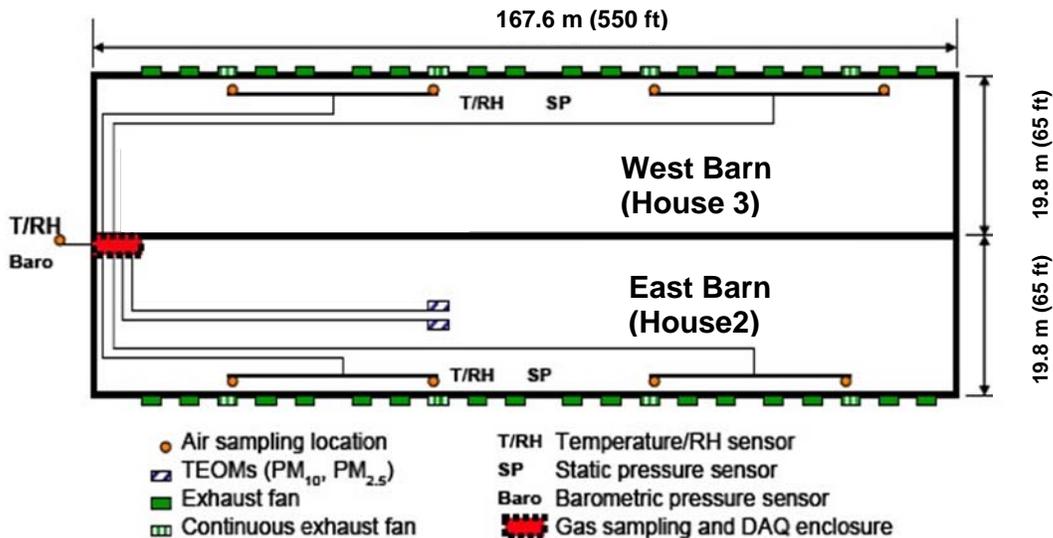


Figure 1. Schematic representation of the aviary laying hen houses and air sampling locations.

Concentrations of NH<sub>3</sub> and GHG (CO<sub>2</sub> and CH<sub>4</sub>) at four locations in each house were measured continually with a fast-response and high-precision photoacoustic multi-gas analyzer (model 1412, Innova AirTech Instruments, Denmark). Two locations (near two continuous ventilation fans) were combined into one composite sample, hence two composite sampling lines were used from the four continuously running ventilation fans per barn (fig. 1). Since one gas analyzer was used to measure multiple locations in two barns, the air samples from all locations were taken sequentially using an automatically controlled (positive-pressure) gas sampling system. To ensure measurement of the real concentration values, considering the response time of the analyzer, each location was sampled for 6 minutes, with the first 5.5 min for stabilization and the last 0.5 minute readings for measurement. This sequential measurement yielded 30-min data of gaseous concentrations. Sampling pumps were run for one minute prior to the location sampling, and turned off as soon as the sampling was finished. In addition, every two hours the outside air was drawn and analyzed. The less frequent sampling and analysis of the outside air is because its compositions remain much more stable than those of the indoor air.

Concentrations of PM<sub>10</sub> (inhalable dust) and PM<sub>2.5</sub> (respirable dust) inside the barns were measured continuously with real-time Tapered Element Oscillating Microbalances equipped with the respective PM head (TEOM, Model 1400a, Thermo Fisher Scientific Inc., Waltham, MA, USA). A 300-s integration time was used. A pair of TEOMs were run continuously for two days each week in each barn, with mass concentrations of both particle sizes reported every 30 s. The pair of TEOMs were placed near sidewall at minimum ventilation fan (fan 7) in both barns. Temperature (type-T thermocouple, Cole-Parmer, Illinois, USA), RH (HMW60, Vaisala, MA, USA), and building static pressure (264, Serta, MA, USA) were measured at the middle of the barns at 1-second intervals and reported as 30-second averages.

## Results and Discussion

In this study, the daily gaseous emission rates were taken on 358 days out of 546, giving a 66% data completeness. Issues with instrument calibration, instrument functioning, pump failures,

data recording, and power failures account for the days of missing data. The PM readings were taken for two consecutive days. A total of 56 days had both PM<sub>10</sub> and PM<sub>2.5</sub> for both houses. Both houses 2 and 3 held fairly constant temperatures over the winter months. House 2 had a setpoint that was 1.7°C to 2.8°C (3°F to 5°F) lower than house 3. The setpoint of house 2 was increased in February, while the setpoint of house 3 stepped up in December and again in February. The higher temperatures in house 3 corresponded to lower VR. RH in both houses was below 80% through most of the winter, but RH consistently above 70%. VR was generally between 0.6 and 11m<sup>3</sup>/hr-bird.

Daily indoor gaseous and particulate matter concentrations are of concern from the standpoint of both human and bird exposure. This site never exceeded the OSHA 8-hour time weighted average (TWA) exposure limit of 10,000 ppm for CO<sub>2</sub>. The average daily NH<sub>3</sub> concentrations exceeded 25 ppm on 24 days in house 2 and 11 days in house 3, and on one day NH<sub>3</sub> concentration in house 2 was above the OSHA 8-hour TWA exposure limit of 50 ppm (fig. 3). Overall average concentrations over the 19 months were 8.7, 1636, and 10.0 ppm for NH<sub>3</sub>, CO<sub>2</sub>, and CH<sub>4</sub>, respectively. The average PM<sub>10</sub> and PM<sub>2.5</sub> concentrations over the 19 months were 2.3 and 0.25 mg/m<sup>3</sup>. Although the TEOMs only ran two days per week, there were 8 days out of 153 monitored where PM<sub>10</sub> concentrations were above 5 mg/m<sup>3</sup>, the OSHA 8-hour TWA exposure limit during lighted hours. Figure 2 and 3 and table 1 summarize these concentration data.

Table 1. Average daily concentrations [mean (SD)] for the two aviary houses (2 and 3) and overall.

| House   | Gas, ppm  |                |            | PM, mg/m <sup>3</sup> |                   |
|---------|-----------|----------------|------------|-----------------------|-------------------|
|         | Ammonia   | Carbon Dioxide | Methane    | PM <sub>10</sub>      | PM <sub>2.5</sub> |
| 2       | 9.0 (9.4) | 1,853 (1,082)  | 10.1 (6.9) | 2.1 (1.4)             | 0.24 (0.24)       |
| 3       | 8.5 (7.4) | 1,418 (956)    | 9.9 (6.7)  | 2.5 (1.9)             | 0.27 (0.28)       |
| Overall | 8.7 (8.4) | 1,636 (1,022)  | 10.0 (6.8) | 2.3 (1.6)             | 0.25 (0.26)       |

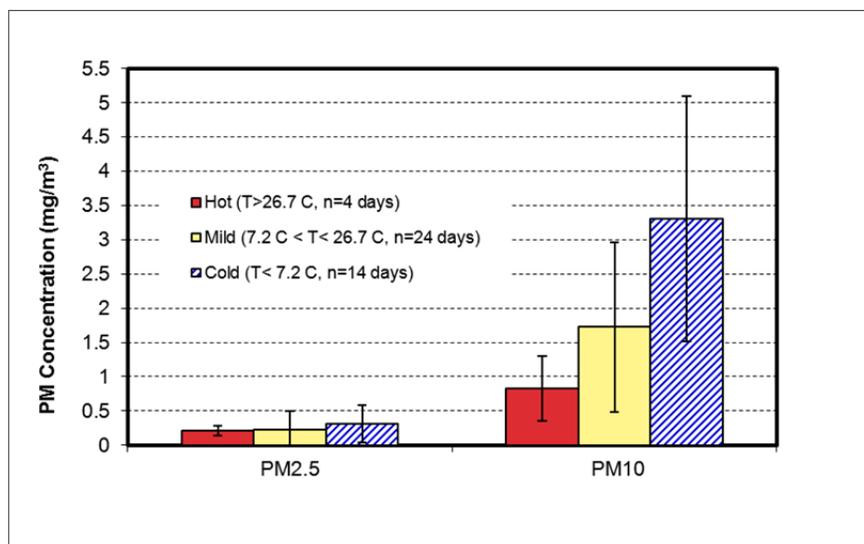


Figure 2. Particulate matter (PM) concentrations (mean and std dev) by ambient temperature

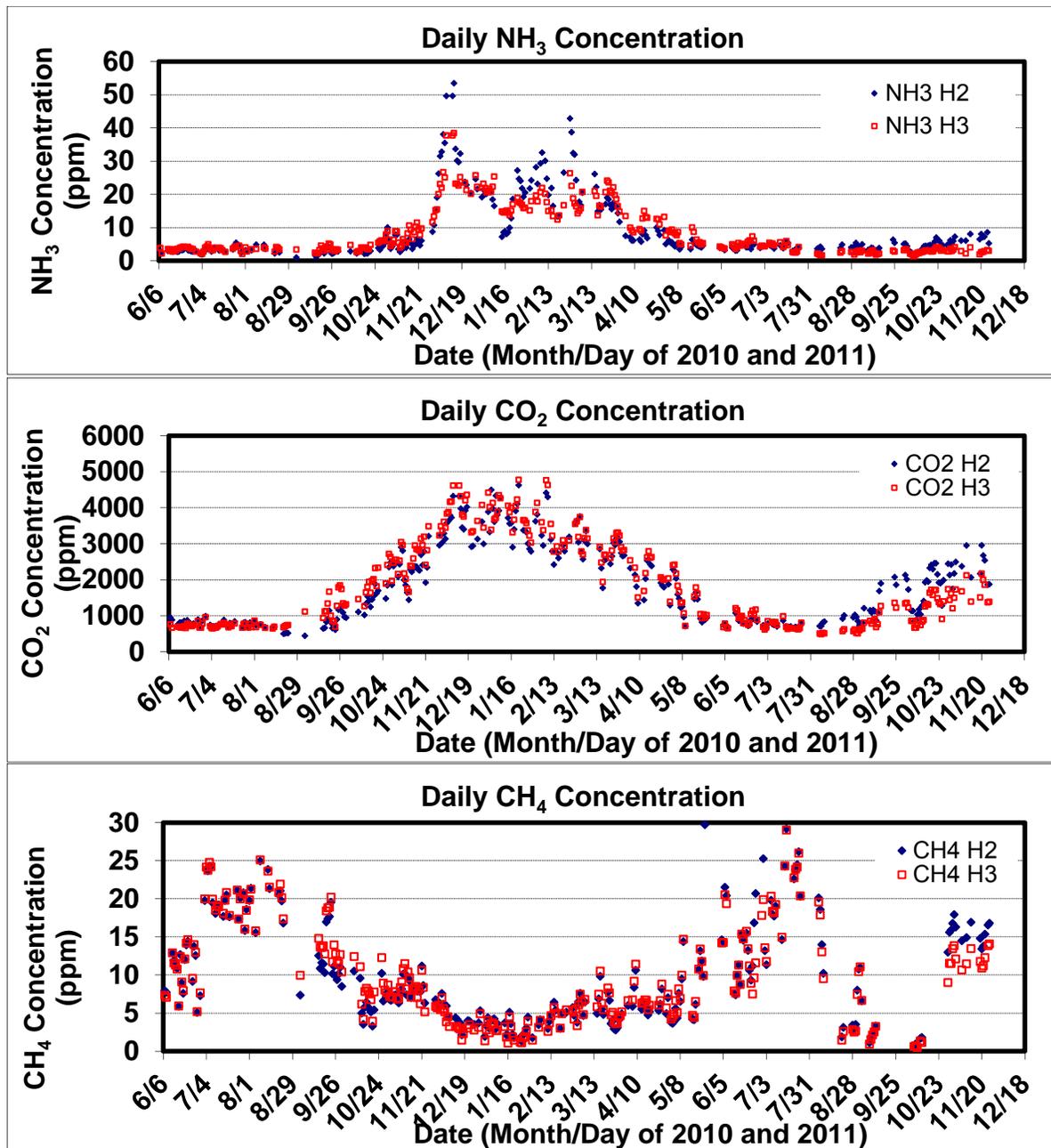


Figure 3. Average daily concentrations of ammonia (NH<sub>3</sub>), carbon dioxide (CO<sub>2</sub>), and methane (CH<sub>4</sub>) in the two aviary hen houses monitored.

The gas and PM emissions reported as emissions per house, per bird, per animal unit (AU, AU=500 kg live body mass), and per kg egg produced. Reported values are summarized as average daily emission rates. Ammonia, carbon dioxide, and methane emissions are presented on a gram per bird basis based on three average daily ambient temperature ranges: hot condition includes days with ambient temperatures greater than 26.7°C (80°F), mild conditions (ambient temperature of 7.2°C -26.7°C or 45°F -80°F), and cold conditions (ambient temperature below 7.2°C or 45°F). (fig. 4). The particulate matter emissions are graphed based on the same temperature ranges (fig.5).

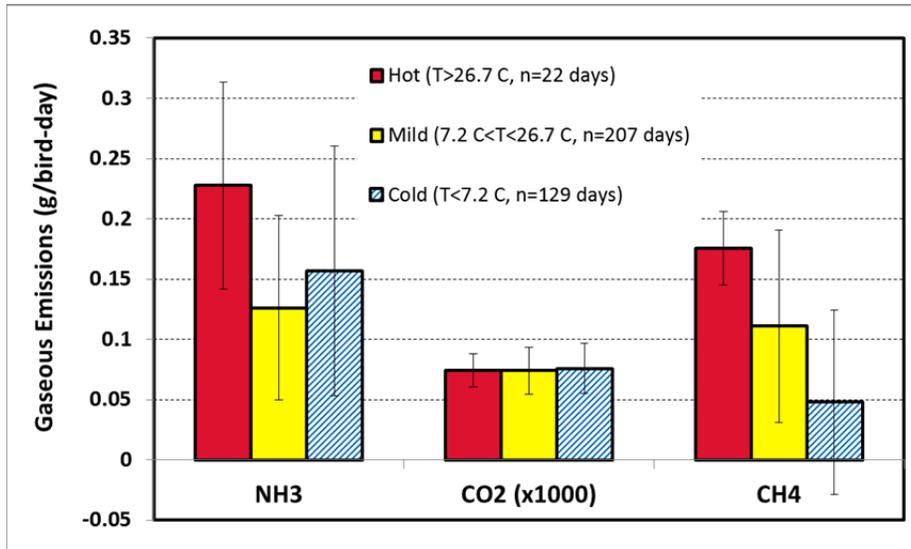


Figure 4. Daily emission rates of ammonia (NH<sub>3</sub>), carbon dioxide (CO<sub>2</sub>), and methane (CH<sub>4</sub>) (mean and std dev) by ambient temperature. Please note, to accommodate scales, CO<sub>2</sub> emissions must be multiplied by 1,000 to gain the actual emission rate.

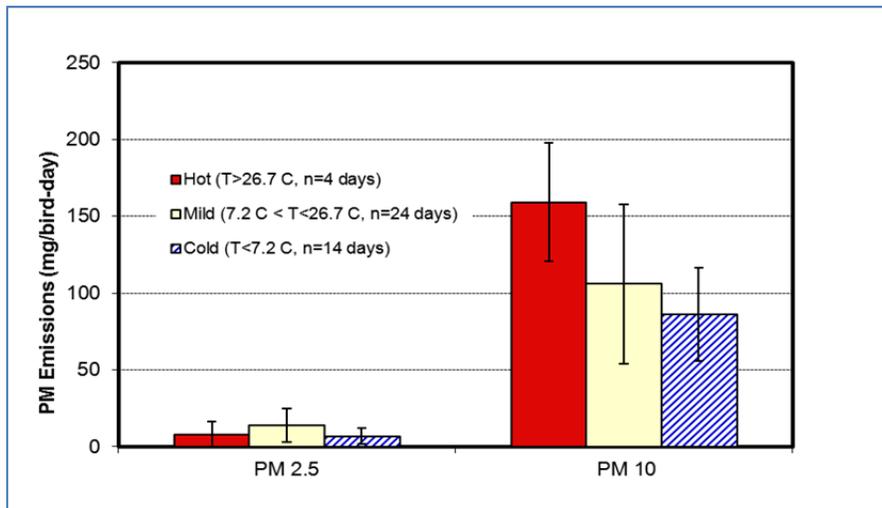


Figure 5. Daily particulate matter emissions (mean and std dev) by ambient temperature.

Overall, the results on gaseous emissions observed from this study were within expectations. European studies suggest aviary ammonia concentrations are higher than belt houses (Hörnig et al., 2001). Liang et al. (2003) reported manure-belt hen house in the Midwestern US had NH<sub>3</sub> concentrations ranging from 1 to 7 ppm, while high-rise houses had concentrations ranging from 9 to 108 ppm at the exhaust (note: the bird-level NH<sub>3</sub> concentrations were substantially lower). With average NH<sub>3</sub> concentrations of 9 ppm, the aviary houses tended to have somewhat higher NH<sub>3</sub> concentrations than manure-belt houses, which agreed with European findings. With some of the high winter concentrations, it is important to remember to use face masks with ammonia filters. The study by Liang et al. (2003) also showed NH<sub>3</sub> emission rates of 0.05 to 0.1 g/bird-day (depending on the manure removal interval) for belt houses and 0.95 g/bird-day for high-

rise houses. Ammonia emissions for the aviary houses averaged 0.15 g/bird-day, which is higher than the belt system but significantly lower than the high-rise system. Two European studies demonstrated the range in NH<sub>3</sub> emission rates for cage-free barns as 0.27 to 0.85 g/bird-day (Groot Koerkamp et al, 1998; Muller et al., 2003). The emissions observed from this study were quite a bit lower. Many of the cage-free barns in Europe do not have a method of locking birds in the tiered structure, which may affect litter amount and quality. For CO<sub>2</sub> the average emission rate of 75 g/bird-day is in line with reported values from belt systems (70 to 85 g/bird-day) (Liang et al., 2003; Nesar et al., 1997). For CH<sub>4</sub> literature suggests a belt system emitting between 0.08 and 0.13 g/bird-day (Groot Koerkamp and Uenk, 1997; Monteny et al., 2001; Fabbri et al, 2007; Wathes et al., 1997). The value of 0.09 g/bird-day from the current study did fall inside this range. Overall this aviary system has emission rates that relate well to a traditional belt house, with the exception of NH<sub>3</sub> emission being slightly higher.

The major difference between the aviary system and manure-belt or high-rise systems lies in the PM emissions. Literature on conventional laying-hen housing reports PM<sub>2.5</sub> emissions of 0.0036 to 0.014 g/bird-day (Li et al., 2011), while the current study with aviary housing averages 0.008 g/bird-day. For PM<sub>10</sub> the reported literature emission values range from 0.019 to 0.048 g/bird-day (Li et al., 2011), while this study averages 0.105 g/bird-day. The emissions from our study were higher than those reported in literature; however this system did have a litter floor area. A European study reports on a group of cage-free barns having a PM<sub>10</sub> emission rate of 0.05 g/bird-day, however the most extreme site in the study has an emission rate of 0.07 g/bird-day (Takai et al., 1998). While the average in the European study was above the range of conventional housing emissions, it is well below the value found in the current study. Li et al. (2011) noted that data from conventional barns in Europe including the Takai et al. (1998) study were lower than similar studies in the US. Management of the litter (e.g., moisture content) and environmental conditions (house RH and ventilation) presumably contributed to the difference in the PM<sub>10</sub> emissions.

Table 2. Daily emission rates [mean (std dev)] for the aviary hen houses (2 and 3) and overall values. The average body weight of the hens was 1.76 and 1.78 kg in houses 2 and 3, respectively, and the average population was 48,250 and 47,600 hens, respectively.

|         |            | Gases and Particulate Matter |                |             |                  |                   |
|---------|------------|------------------------------|----------------|-------------|------------------|-------------------|
| House   | Unit       | Ammonia                      | Carbon Dioxide | Methane     | PM <sub>10</sub> | PM <sub>2.5</sub> |
| Overall | kg/house-d | 7.1 (4.8)                    | 3,421 (1035)   | 4.8 (7.0)   | 5.1 (1.9)        | 0.36 (0.29)       |
|         | g/bird-d   | 0.15 (0.08)                  | 75 (15)        | 0.09 (0.08) | 0.11 (0.04)      | 0.008 (0.006)     |
|         | g/AU-d     | 41 (23)                      | 21,307 (4,262) | 25 (21)     | 29.5 (11)        | 2.1 (1.7)         |
|         | g/kg egg   | 3.3 (2.1)                    | 1,626 (618)    | 2.3 (3.4)   | 2.5 (0.9)        | 0.16 (0.13)       |

## Conclusion

Air emissions (NH<sub>3</sub>, CO<sub>2</sub>, CH<sub>4</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub>) from two aviary hen houses in Iowa were continuously monitored for 19 consecutive months, covering 2 flocks from 17 to 80 weeks of age. The following observations and conclusions were made:

- Daily indoor NH<sub>3</sub>, CO<sub>2</sub>, CH<sub>4</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> concentrations (mean ±SD) were 8.7 (±8.4) ppm, 1,636 (±1,022) ppm, 10.0 (±6.8) ppm, 2.3 (±1.6) mg/m<sup>3</sup>, and 0.25 (±0.26) mg/m<sup>3</sup>, respectively. NH<sub>3</sub>, CO<sub>2</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> concentrations were highest at coldest ambient conditions, although CH<sub>4</sub> increased with ambient temperatures.
- Daily NH<sub>3</sub>, CO<sub>2</sub>, CH<sub>4</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> emissions (mean ±SD) were 0.15 (±0.08), 75 (±15), 0.09 (±0.08), 0.11 (±0.04), and 0.008 (±0.006) g/bird, respectively. NH<sub>3</sub> and CO<sub>2</sub> emissions were rather independent of ambient temperatures. CH<sub>4</sub> emissions increased with increasing ambient temperature. PM<sub>10</sub> and PM<sub>2.5</sub> generally decreased with increasing ambient temperatures.
- Annual NH<sub>3</sub>, CO<sub>2</sub>, CH<sub>4</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> emissions were 55 g/bird, 28.4 kg/bird, 26 g/bird, 39 g/bird, and 3 g/bird, respectively.

Overall this aviary system has emission rates that relate well to a conventional belt house, with the exception of ammonia being slightly higher. The ammonia emissions were lower than those reported for European layer houses, however.

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