Final Project Report

A Comprehensive Assessment of Aviary Laying-Hen Housing System for Egg Production in the Midwest

Submitted to

Midwest Poultry Research Program

By

Hongwei Xin[1,2,*], Morgan Hayes[1], Maro Ibarburu[2], Suzanne Millman[3], Rebecca Parsons[3], Byron Brehm-Stecher[4], Hyun Jung Kim[4], Hong Li[5]

[1] Department of Agricultural and Biosystems Engineering, Iowa State University

[2] Egg Industry Center, Ames, Iowa

[3] Department of Veterinary Diagnostic & Production Animal Medicine, College of Veterinary Medicine, Iowa State University

[4] Department of Food Science and Human Nutrition, Iowa State University

[5] Department of Animal and Food Sciences, University of Delaware, Newark, DE

*Corresponding author: Dr. Hongwei Xin
3204 NSRIC
Department of Agricultural and Biosystems Engineering
Iowa State University
Ames, IA 50011-3310
Phone: 515-294-4240; email: hxin@iastate.edu

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Executive Summary

Aviary hen housing system is one of the alternative egg production systems that are being used by some U.S. egg producers. The motivation for adopting such a housing system is to improve bird welfare by allowing the hens to exercise natural behaviors, such as foraging, dust-bathing, and perching. However, research-based information on the overall performance and thus sustainability of the system is meager under U.S. production conditions. The goal of this field study is to comprehensively evaluate the performance of the housing system under Midwest production conditions with regards to animal welfare, environmental impact (both indoor environment and air emissions to the atmosphere), bioenergetics (for design and operation of heating, cooling and ventilation system), energy use, production economic efficiency, and microbiological quality. The specific objectives of the study are as follows:

1) Continuous measurement of gaseous (NH_3, CO_2, N_2O, CH_4) and particulate matter (PM_{10} and $PM_{2.5}$) concentrations (indoor exposure for birds and human) and emissions (to the atmosphere);
2) Continuous measurement of the metabolic rate or total heat production of the hens which is partitioned into sensible heat and moisture production at the house level;
3) Electricity use for lighting, building ventilation, manure-drying, and total operation; and fuel use for supplemental heating;
4) Hen production performance (feed use, water use, hen-day and hen-house egg production, cage weight, feed conversion, percentage of floor eggs, mortality);
5) Economic analysis of production costs and cash returns.
6) Hen behaviors (litter use) and welfare (feather score, keel/wings injuries); and
7) Development and evaluation of a novel quadruplex multiplex PCR (mPCR) for rapid detection and characterization of *Salmonella* isolates from layer hen environments

Two aviary hen houses in a double-wide building located in Iowa were used in this field study. Each house measured 550 ft x 60 ft with a capacity of 50,000 hens (Hy-Line Brown) and had a production cycle of 17 to about 80 weeks of age (new flock started near the end of April 2010 in one – House 3 and the middle of September 2010 in the other – House 2). Each house was divided into twenty-five 20-ft sections along the length direction. The houses had open litter floor (8 ft x 20 ft per section for the center aisles and 4 ft x 20 ft per section for the outer aisles), nest boxes, and perches. 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 row 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, feeding, and drinking area from top to bottom. Each house had 20 exhaust fans, all on one sidewall, including twelve 4-ft, four 3-ft, and four 2-ft fans. Ceiling box air inlets were used. Compact fluorescent lighting was used.

The following observations were made from the 15-month monitoring study:

1) Average daily emissions rates of ammonia (NH_3), carbon dioxide (CO_2) and methane (CH_4) for the aviary hen houses were 0.15, 78, and 0.10 g/bird/day. These values are higher than reported literature emission values for manure-belt hen houses, but lower than reported literature values for high-rise hen houses. Particulate matter (PM10 and PM2.5) emissions of the aviary houses were higher than reported literature values for layer barns, with mean daily emissions of 105 and 8 mg/bird/day for PM10 and PM2.5, respectively. The indoor PM concentrations are closely related to hen's diurnal activities.
2) Total heat production rate of the hens and house-level latent heat production rate for the aviary housing system averaged 6.15 and 1.85 W/kg. These values are comparable to the values found with conventional housing systems.
3) The aviary barns do use some supplemental heat (22 gallons LP for one house – House 2 and106 gallons for the other house – House 3 with higher set-point temperature); however its primary usage was not in the coldest months but instead was used in the spring when there was a great fluctuation in the ambient temperature. The fluctuating temperature led to over-ventilation of the barns which in turn called for supplemental heating. Barn set-point temperature impacts LP use. The electric energy use in these barns is driven mainly by the ventilation fans, but in winter the blowers for manure drying are in fact the primary power consumer. The amount of time these blowers run should be evaluated.
4) The aviary houses had 25 fewer eggs per hen housed during the production period of 18-80 week as compared to the Hy-Line brown layer guidelines. Cumulative mortality was 10.2% as compared to the 4.2% suggested in the guideline. Feed conversion was somewhat poorer at 3.59 lb/doz. eggs as compared to the guideline of 3.31 lb/doz.
5) The production cost for the aviary system was about 60% higher than for the conventional system. The higher cost mainly results from the higher housing and equipment costs relative to the larger space per bird housed in the aviary system. Hence it is critical to evaluate if/how the space per bird can be reduced without affecting the hen's well-being. Poorer feed conversion, related to the hen genetics, also contributes to the higher production cost. Eggs in the aviary houses also had higher percentage of checks which may be improved by adjusting the diets or by equipment design/operation. The projected payback period for the aviary system may range from >40 years to 3 years, depending on feed cost and egg price.
6) Some welfare assessment parameters such as keel injuries changed over time within the same group of hens, and further research is needed to determine risk factors for correction. Litter was a valuable resource for these hens that, on average accessed the litter area more than once daily.
7) The mPCR assay approach provides an accurate and rapid method for quickly identifying *Salmonella* spp. among suspect isolates recovered from poultry production environments. Incorporation of this mPCR in an FDA/NPIP-based isolation workflow may speed the acquisition of actionable data on the presence of *Salmonella*, differentiate between generic *Salmonella*, *Salmonella* subspecies I, *S*. Typhimurium and *S*. Enteritidis, and eliminate wasteful downstream testing of false-positive non-*Salmonella* isolates.

INTRODUCTION

Sectors of the U.S. egg operations are facing the challenge of being forced to switch from conventional cage housing system to cage-free housing system, while others may consider the alternative housing systems for product diversity or in anticipation of imminent regulations. One of the alternative hen housing systems being constructed is the so-called aviary system, where birds have access to open litter-floor (dustbathing and exercise) area, nest boxes, and perches. However, data on the system performance are limited, especially under the Midwest production conditions, concerning animal welfare, indoor environment for both the birds and workers (e.g., gaseous and dust levels), resource use efficiency, microbiological quality and environmental impact (i.e., air emissions to the atmosphere). This knowledge gap could hamper the producer’s decision making when considering the alternative housing system. Filling this knowledge gap is hence the rationale and significance of the study reported here.

FDA and National Poultry Improvement Program (NPIP) methods for isolation of *Salmonella* from environmental samples rely on selective enrichment and plating steps to screen for target cells against high levels of background microflora. Although these media are highly selective, some non-target organisms may still grow and yield false-positive reactions. These isolates must be tested further through biochemical testing, serotyping or generic PCR, resulting in added expense and delays in obtaining actionable data.

Our ultimate goal is to identify and promote housing system(s) and management practices that will lead to improved animal welfare, working condition for the workers, hen production performance, safe and quality products, environmental soundness, efficient use of natural resources, and economic viability for both the producers and the consumers. Hence, in this study we will systematically assess two 50,000-hen aviary layer houses in Iowa by performing the following measurements and analysis over a one-year period (one full production cycle):

1. Continuous measurement of gaseous (NH_3, CO_2, N_2O, CH_4) and particulate matter (PM_{10} and $PM_{2.5}$) concentrations (indoor exposure for birds and human) and emissions (to the atmosphere);
2. Continuous measurement of the metabolic rate or total heat production of the hens which is partitioned into sensible heat and moisture production at the house level;
3. Electricity use for lighting, building ventilation, manure-drying, and total operation; and fuel use for supplemental heating;
4. Hen production performance (feed use, water use, hen-day and hen-house egg production, cage weight, feed conversion, percentage of floor eggs, mortality);
5. Economic analysis of production costs and cash returns.
6. Hen behaviors (litter use) and welfare (feather score, keel/wings injuries); and
7. Development and evaluation of a novel quadruplex multiplex PCR (mPCR) for rapid detection and characterization of *Salmonella* isolates from layer hen environments

MATERIALS AND METHODS

Two aviary hen houses in a double-wide building located in Iowa were used in this field study. Each house measured 550 ft x 60 ft with a capacity of 50,000 hens (Hy-Line Brown) and had a production cycle of 17 to ~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). A cross-sectional schematic of the houses is shown in figure 1. Each house was divided into twenty-five 20-ft sections along the length direction. The houses had open litter floor (8 ft x 20 ft per section for the center aisles and 4 ft x 20 ft per section for the outer aisles), nest boxes, and perches. 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 row 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, feeding, and drinking area from top to bottom. Each house had 20 exhaust fans, all on one sidewall (fig. 2), including twelve 4-ft, four 3-ft, and four 2-ft fans. Ceiling box air inlets were used. Compact fluorescent lighting was used.

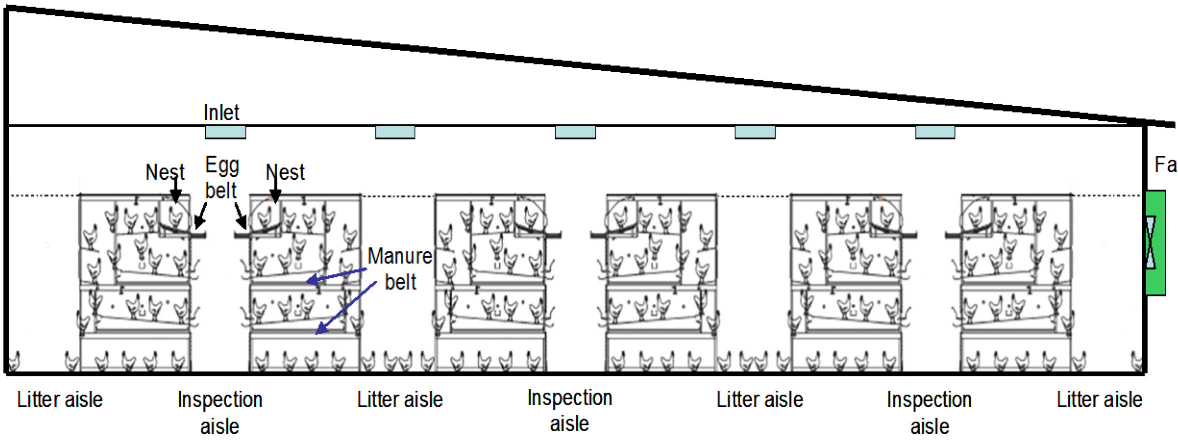


Figure 1. Cross-sectional view of the aviary hen house (one side of the double houses) to be monitored in this study.

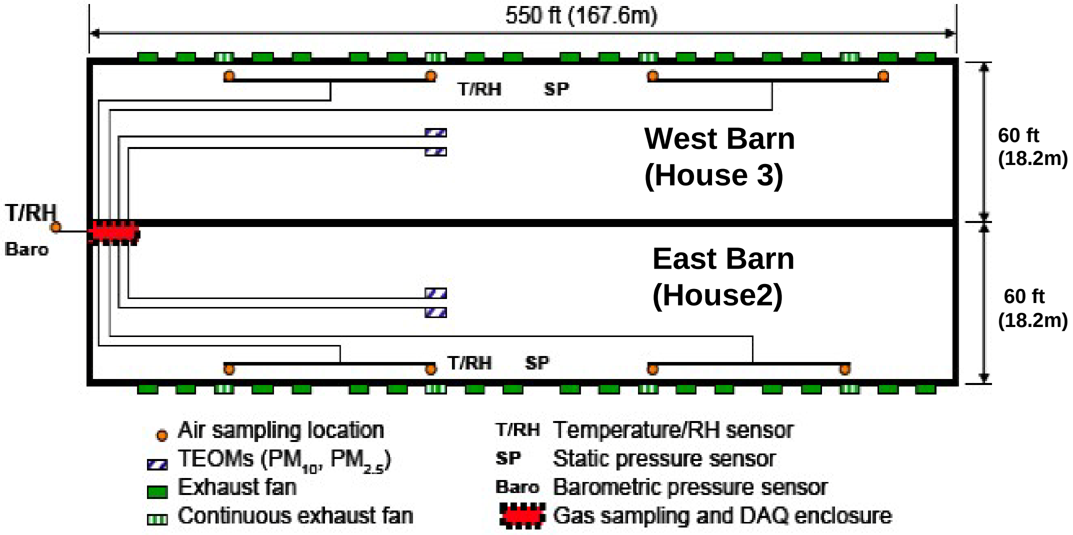


Figure 2. Schematic representation of the aviary hen houses and placement of sampling locations.

Objective 1. *Continuous measurement of gaseous (NH_3, CO_2, N_2O, CH_4) and particulate matter (PM_{10} and $PM_{2.5}$) concentrations (indoor exposure for birds and human) and emissions)*

Concentrations of ammonia (NH_3) and greenhouse gases (GHG) (CO_2, N_2O, CH_4) 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). Oxygen concentration was measured with a paramagnetic gas analyzer (755A, Rosemount Analytical, California). Two locations (near two continuous ventilation fans) were combined into one composite sample, hence there were two composite sampling lines per barn (fig. 2). FEP Teflon tubing (3/8-inch o.d. and ¼-inch i.d.) was used for the air sampling lines to avoid ammonia absorption to the sampling lines. Each sampling port was equipped with a dust filter to keep large particulates from plugging the sample tubing or damaging the gas analyzer. 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 (fig. 3). To ensure measurement of the real concentration values, considering the response time of the analyzer, each location were 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. In addition, every 2 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_{10} (inhalable dust) and $PM_{2.5}$ (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) (fig. 3). 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 being reported every 30 seconds. The pair of TEOMs were placed near sidewall fan 7 (minimum ventilation fan) in both barns. Temperature (type-T thermocouple, Cole-Parmer, Illinois), relative humidity (HMW60, Vaisala, Massachusetts), and static pressure (264, Serta, Massachusetts) were measured from the middle of the barns at 1-second intervals and reported as 30 second averages.

Instead of using a mobile air emission monitoring lab (trailer), all sampling lines, data acquisition and instrumentation for this study were kept in enclosures in the south end of the eastern barn (barn 2). The enclosure was supplied with fresh air from the attic to provide a positive pressure system in an effort to minimize dust.

Figure 3. Gaseous and particulate matter (PM) concentration monitoring system (*L- R: positive-pressure gas sampling system or P-P GSS, gas analyzers, and Tapered Element Oscillation Microbalance or TEOM PM monitors***).**

The building ventilations rate (VR) was determined based on *in situ* calibrated fan curves with fan assessment numeration systems (FANS) sized 36 inch, 48 inch, and 54 inch. Individual fan curves were established for each stage (1-8) including operational ranges of the variable speed control of the lower stages. The runtime of fans was recorded continuously with inductive current switches. Magnetic proximity sensors (MP1007, ZF Electronics, Wisconsin) were used to measure the fan speed (rpm) of the variable speed fans. Fan runtime and speed along with the corresponding building static pressure were recorded every second. Using the calibrated curves for each stage with the above data an overall building VR was calculated. All data were collected in a data acquisition system (DAQ, Compact Fieldpoint, National Instruments, Texas). All samples taken at 1 second intervals were averaged to 30-second values and reported to the on-site PC.

With the measured gaseous or PM concentrations and building VR, emission rate (ER) of the gas or PM from the barn to the atmosphere can be calculated as follows:

$$[ER_G]_t = \sum_{e=1}^{2}[Q_e]_t\left([G]_e - \frac{\rho_e}{\rho_i}[G]_i\right)\times 10^{-6}\times\frac{w_m}{V_m}\times\frac{T_{std}}{T_a}\times\frac{P_a}{P_{std}} \quad [1]$$

$$[ER_{PM}]_t = \sum_{e=1}^{2}[Q_e]_t\left([PM]_e - \frac{\rho_e}{\rho_i}[PM]_i\right)\times 10^{-6}\times\frac{T_{std}}{T_a}\times\frac{P_a}{P_{std}} \quad [2]$$

where $[ER_G]_t$ = Gaseous emission rate of the house at sample time t (g house^{-1} t^{-1})
$[ER_{PM}]_t$ = PM emission rate of the house (g house^{-1} t^{-1})
$[Q_e]_t$ = Average building VR under field temperature and barometric pressure at sample time t (m^3 house^{-1} t^{-1})
$[G]_I$ = Gaseous concentration of incoming air (ppm$_v$)
$[G]_e$ = Gaseous concentration of the exhaust air (ppm$_v$)
$[PM]_I$, = PM concentration of incoming ventilation air (ug m^{-3})
$[PM]_e$ = PM concentration of exhaust ventilation air (ug m^{-3})
w_m = molar weight of air pollutants, g mole^{-1}
V_m = molar volume of NH_3 gas at standard temperature (0°C) and pressure (1 atmosphere) (STP), 0.022414 m^3 mole^{-1}
T_{std} = standard temperature, 273.15 K
T_a = absolute house temperature, (°C+273.15) K
P_{std} = standard barometric pressure, 101.325 kPa
P_a = atmospheric barometric pressure for the site elevation, kPa
ρ_i, ρ_e = air density of incoming and exhaust air, kg dry air m^{-3} moist air

Objective 2. *Continuous measurement of the metabolic rate of the hens and heat and moisture production at the house level*

The metabolic rate or total heat production (THP) of the hens will be determined using the indirect animal calorimetry technique. Namely, THP of the birds can be related to their oxygen (O_2) consumption and carbon dioxide (CO_2) production, of the following form (Brouwer, 1965):

$$THP = 16.18\ O_2 + 5.02\ CO_2 \quad [3]$$

where THP = total heat production rate of the animal, W
O_2 = oxygen consumption rate, mL s^{-1}
CO_2 = carbon dioxide production rate, mL s^{-1}

The O_2 consumption rate and CO_2 production rate will be determined from the data of O_2 and CO_2 concentrations for both incoming and exhaust air and the building VR. To obtain the O2 concentrations of incoming and exhaust air, a paramagnetic O_2 analyzer (model 750A, Rosemount Analytical, CA) will be used.

Moisture production rate (MP) at the house level, including latent heat of the birds and moisture evaporation from the manure or spilled water (if any), will be calculated by the following mass-balance equation:

$$MP = \rho\ Q\ (W_e - W_o) \quad [4]$$

where MP = moisture production rate, kg s^{-1}

W_e, W_o = humidity ratio of exhaust and outside air, respectively, g g^{-1}
Q = building ventilation rate, $m^3 s^{-1}$
ρ = air density, g m^{-3}.

Sensible heat production (SHP) at the house level will then be calculated as the difference between THP of the hens and latent heat production of the barn, of the form,

$$SHP = THP - MP \cdot h_{fg} \cdot 1000 \qquad [5]$$

where h_{fg} = latent heat of vaporization for water, J/g
1000 = conversion of MP from kg s^{-1} to g s^{-1}

Objective 3. *Electricity use for lighting, building ventilation, manure-drying, and total operation; and fuel use for supplemental heating*

Electricity use for lighting, barn ventilation, manure-drying, and total operation was monitored. Since the aviary houses are equipped with supplemental heating (LP fuel), the fuel use per house was also monitored using a temperature compensated gas meter with a pulse output.

Objective 4. *Hen production performance (feed use, water use, hen-day and hen-house egg production, cage weight, feed conversion, percentage of floor eggs, mortality)*

The weekly data on hen production performance for each of the monitored houses, including feed and water consumption, hen-day egg production, case egg weight, feed conversion ratio, and bird mortality were collected from the cooperating producer.

Objective 5. *Economic analysis of production costs and cash returns*

The economic analysis utilizes a budgeting approach to estimate production costs for the two production systems considered. The first analysis estimates the production cost of the aviary house for the period between 18 and 80 weeks of age. It also estimates the pay-back price needed for the house and equipment in 8 years. The second analysis compares the cost of production of the aviary system for brown birds with the cost of production of conventional high-rise houses for white birds for the period between 21 and 69 weeks of age. The conventional system dataset was obtained from a recently completed field study conducted by some of the authors of this report (USDA-CIG Project Report by Xin et al., 2011). Unfortunately the dataset we had for the conventional system ends at 69 weeks of age and we were unable to compare the production systems for the full period.

Objective 6. *Hen behaviors (aggression, cannibalism, dustbathing) and welfare (feather score, tibia strength, keel/wings and feet injuries)*

Welfare Assessment. Ten sentinel pens per house were selected for the welfare assessment observations. A modified Welfare Quality Assessment Protocol was performed at peak-, mid- and end-of-lay for each of the 10 sections. Ten hens were selected from each of the sections for individual scoring (n=100). Clinical scoring of bird health (plumage, parasites, injuries and disease) and fearful behavior (avoidance distance testing [ADT] with the middle tier hens) were performed. Keel scores (normal/no deformity or deformity) plumage scores (score range of 0-2; 0=no to slight wear, 1=moderate wear and 2=bare spots >5cm) and avoidance distance testing (distance at which a person can approach before a hen withdraws) were quantified.

Litter Use. Cameras were mounted in a section of one of the houses to capture video images of the lowest cage tier from which the hens accessed the litter. Cameras were rotated biweekly amongst the sentinel sections. Frequencies of hens leaping to and from the litter area were determined using 10-minute continuous sampling from 12:30 to 20:30 for two days during the recording period.

Analyses for ADT and movement patterns were performed using a mixed model in SAS 9.2 (SAS Inst. Inc., Cary, NC). Movement to and from the litter were analyzed separately with respect to either time or pen. Clinical scoring parameters are reported as percentages of the flock.

Objective 7. *Development and evaluation of a novel quadruplex multiplex PCR (mPCR) for rapid detection and characterization of Salmonella isolates from layer hen environments*

We developed and evaluated a novel quadruplex multiplex PCR (mPCR) for rapid detection and characterization of *Salmonella* isolates from layer hen environments. The mPCR assay was designed for identification of generic *Salmonella*, *Salmonella* subspecies I, *S*. Typhimurium and *S*. Enteritidis and was evaluated against a panel of *Salmonella* type strains and environmental isolates from layer hen housing environments. An additional set of environmental isolates that yielded false positive reactions on XLT-4 or BGN agars, but were ultimately found not to be *Salmonella* based on serology were also evaluated. The identities of all strains used were determined independently via full-length 16S rDNA sequencing.

Bacterial strains: Seventy one isolates from hen housing environments were evaluated with the mPCR. These were obtained using the NPIP method for isolation (Figure 1) and consisted of both *Salmonella* and non-*Salmonella* strains yielding typical positive or negative results on BGN or XLT-4 and later identified via 16S gene sequencing. An additional 17 non-*Salmonella* environmental isolates which yielded apparent *Salmonella* positives on XLT-4 and/or BGN agars, yet were identified as non-*Salmonella* via serology and 16S gene sequencing were obtained from industrial sources or from Iowa State's Veterinary Diagnostic Laboratory. Eighty five well-characterized type strains of *Salmonella* were also used in this study.

Genomic DNA extraction: Genomic DNA was extracted using the DNAeasy Tissue Kit (Qiagen, Valencia, CA) and a total of 25 ng were used in each PCR reaction.

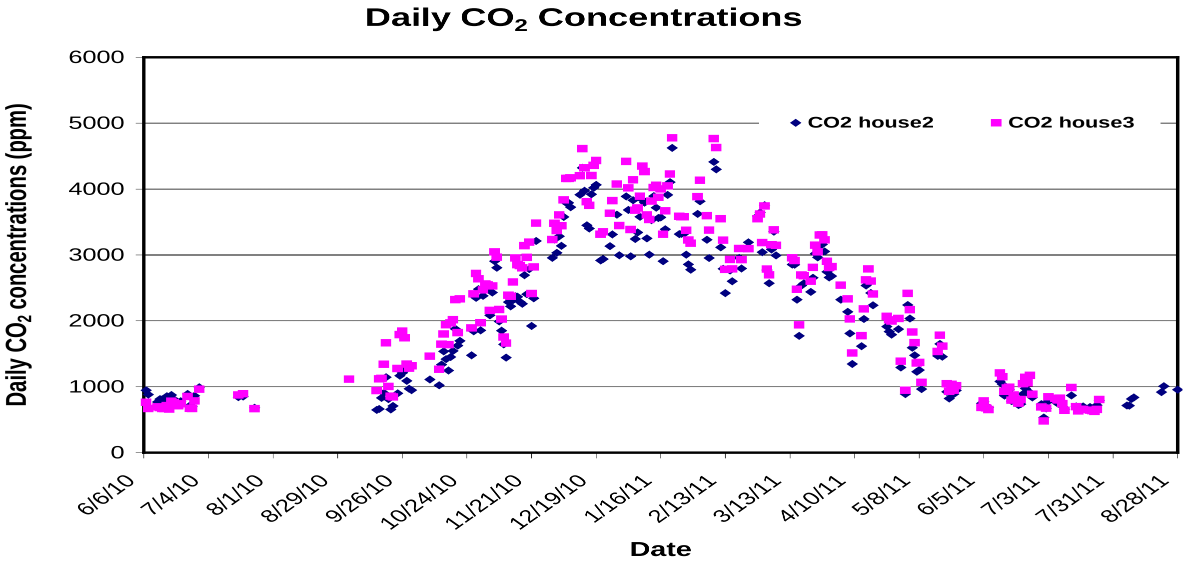
16S rRNA gene sequencing: The 16S rRNA gene was amplified using the following primers: (F) 5'-AGAGTTTGATCCTGGCTCAG-3'; (R) 5'-GGTTACCTTGTTACGACT-3'; the forward primer was used for cycle sequencing and data were analyzed using the Ribosomal Database Project resource (http://rdp.cme.msu.edu/).

Multiplex PCR for identification of Salmonella: Multiplex PCRs were performed with primer sets specific for generic *Salmonella*, *Salmonella* subspecies I, *S*. Typhimurium and *S*. Enteritidis. As a means for further speeding detection of *Salmonella*, we also developed an approach for extraction of DNA directly from colonies on BGN and XLT-4 (colony PCR).

RESULTS AND DISCUSSION

Gaseous and Particulate Matter (PM) Concentrations and Emissions

Daily indoor concentrations are of concern for both human and bird exposure. This site never exceeded the OSHA 8-hour time-weighted-average (TWA) exposure limit of 10,000 ppm for carbon dioxide (CO_2), and only one day was the ammonia (NH_3) concentration was above the OSHA 8-hr TWA of 50 ppm in house 2 (fig. 4). Overall average concentrations over the 15 months were 10.8, 2147, 0.29, and 7.6 ppm for ammonia, carbon dioxide, nitrous oxide (N_2O), and methane (CH_4), respectively.



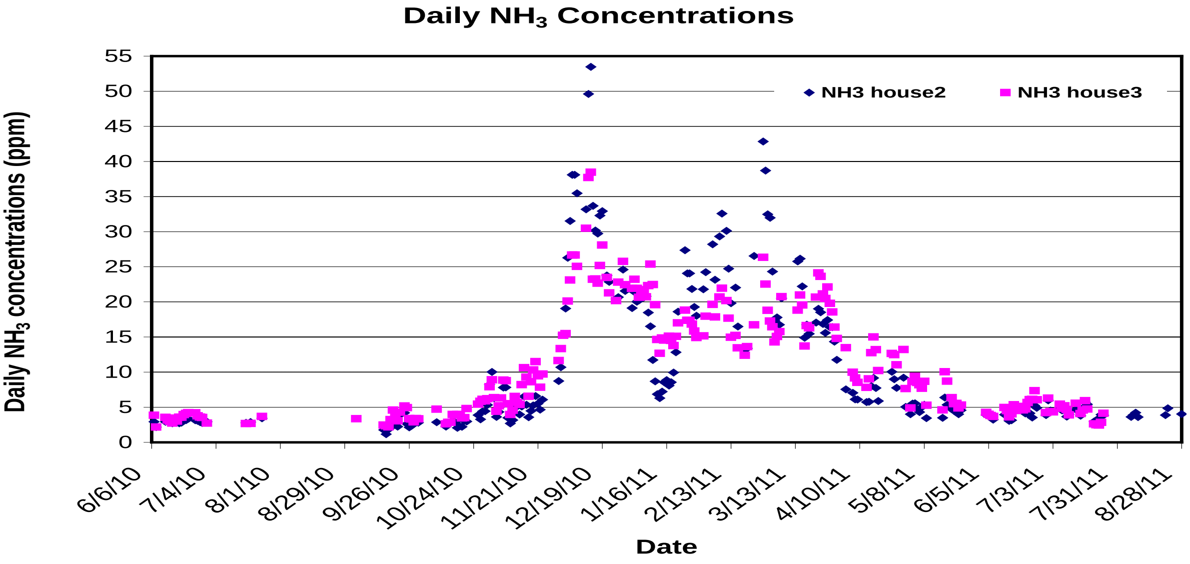


Figure 4. Mean daily gaseous concentrations for carbon dioxide and ammonia. Note that a new flock was placed in house 2 the second week of September 2010 and the flock in house 3 was removed the first week of August 2011.

Both houses 2 and 3 held fairly constant temperatures over the winter months (fig. 5). House 2 had a set point that was 3-5°F lower than House 3. House 2 had the set point increased in mid-February, while the set point in house 3 stepped up in December and again in mid-February.

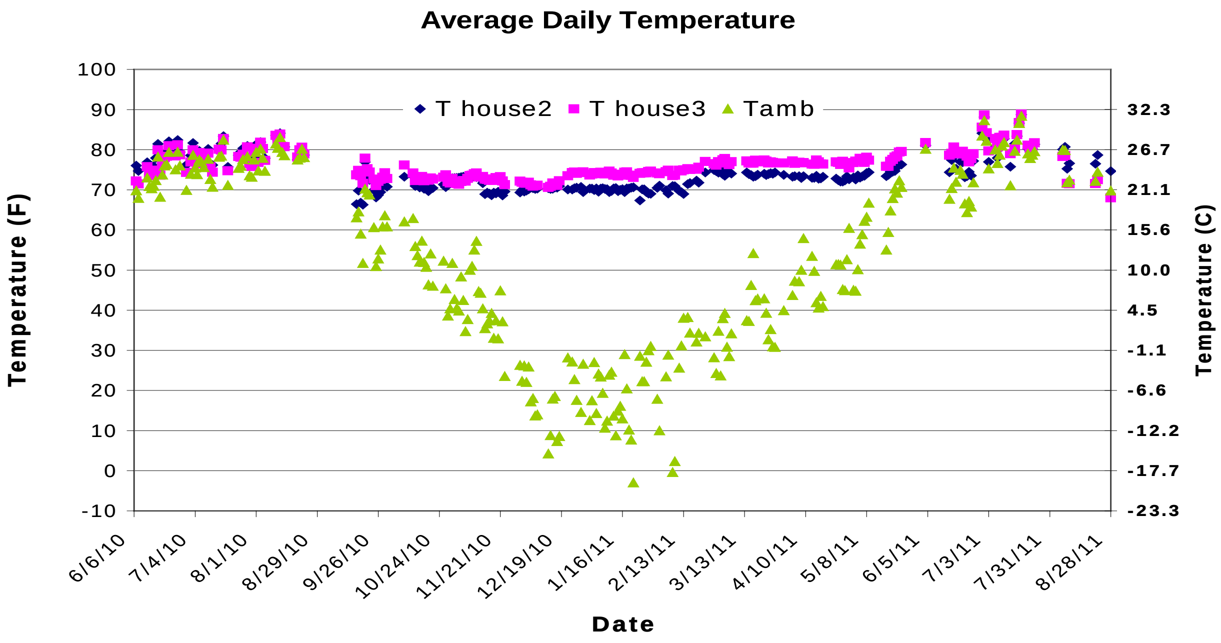
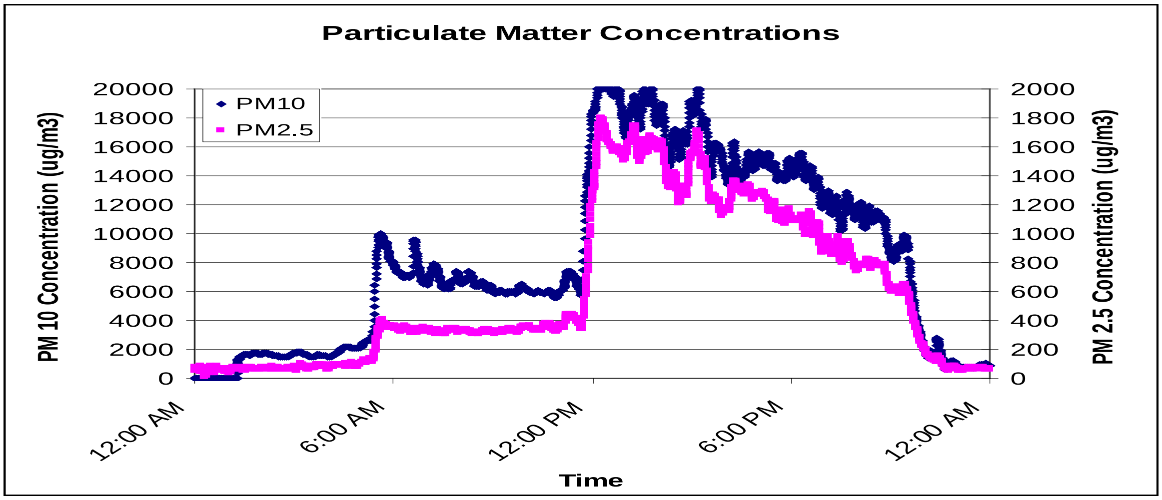


Figure 5. Mean daily temperature for houses 2 and 3 as well as the ambient.

The diurnal patterns in concentrations are also interesting to note. The particulate matter concentration increases as lights are turned on and increases again as birds are given access to the floors. A similar pattern is seen in carbon dioxide concentrations. However, ammonia and other gaseous concentrations tend to drop during the daylight hours due to higher ventilation rates (fig. 6). These trends are most obvious in winter conditions when ventilation is fairly consistent and close to minimum over the whole day.



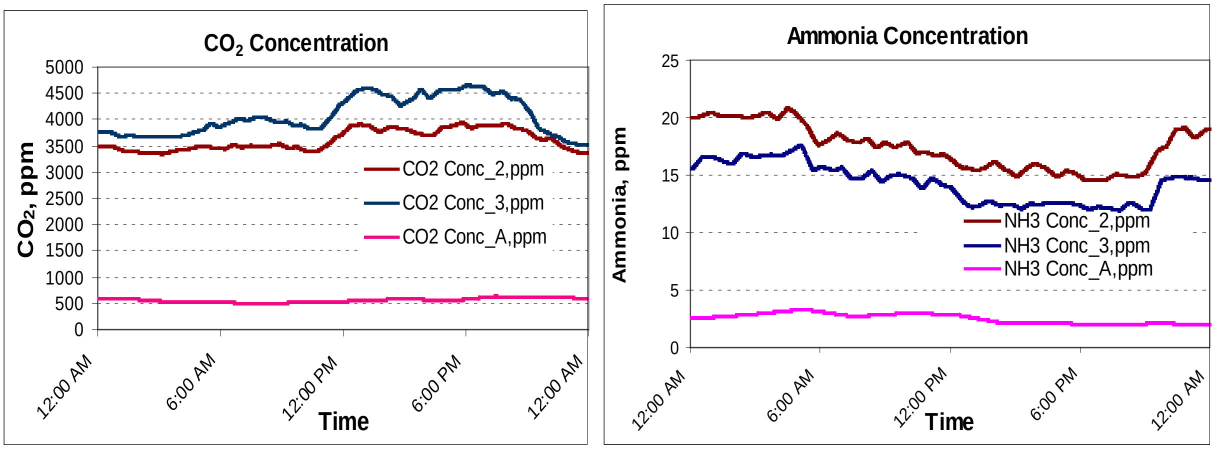
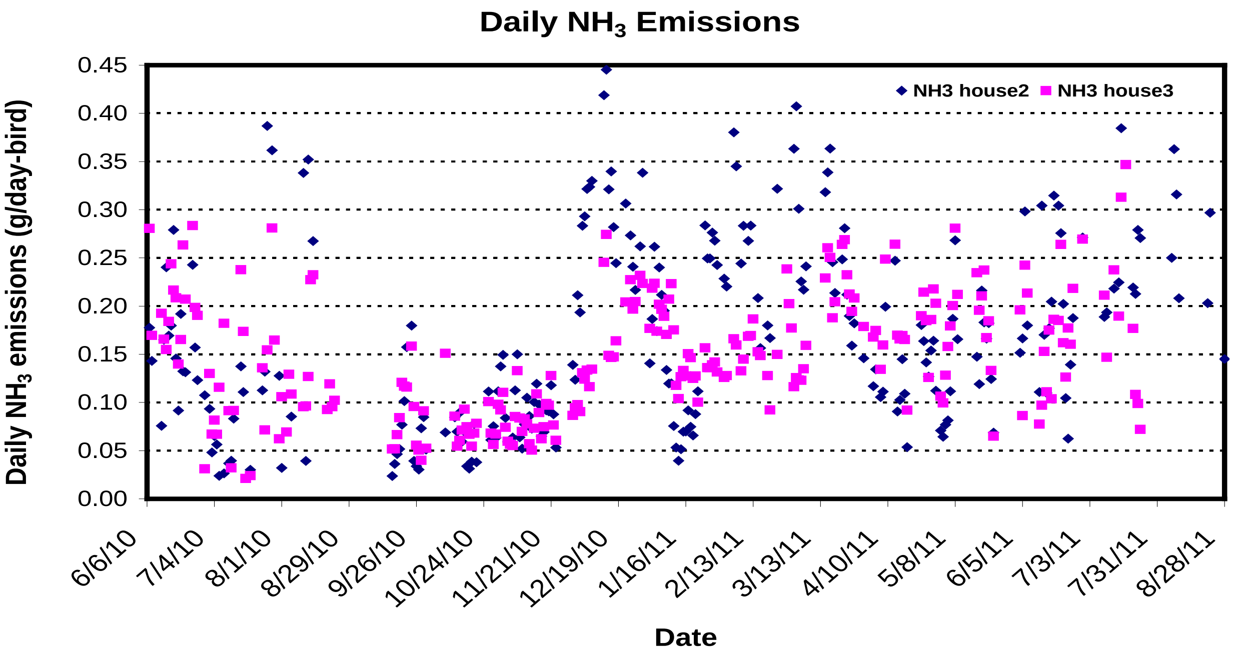
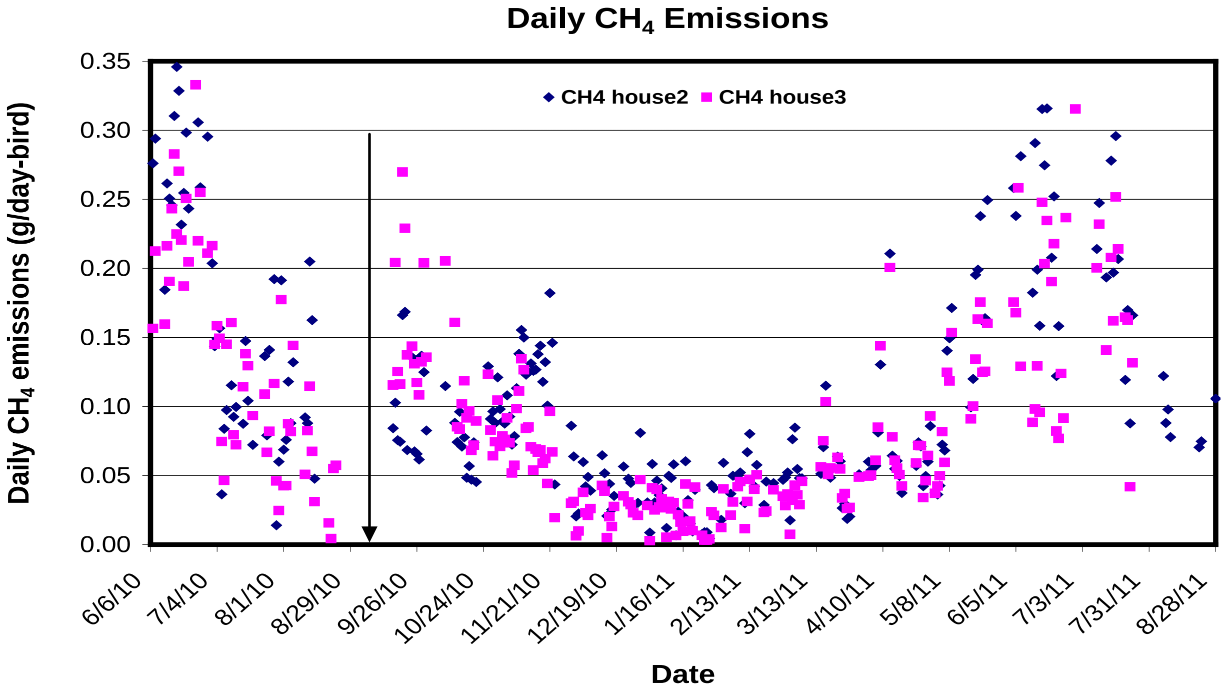


Figure 6. Typical winter diurnal patterns with an ambient temperature of -9.5°C (15°F) and ventilation rate of approximately 30,000 m^3/hr (17,657 CFM) (i.e. minimum ventilation). Lights came on at 5:45AM, birds given floor access at 11:45AM, and lights off and birds locked in at 9:45PM.

The gas and PM emissions were calculated from equations 1 and 2 and reported as a total house emission, per bird emission and per animal unit (AU, AU=500 kg or 1,100 lb.). Reported values are summarized as average daily emission rates and as cumulative emissions for the year. In this study, the daily emission rates were taken on 307 days out of 451, giving a 68% data completeness. Ammonia, methane and carbon dioxide emissions are presented on a gram per bird basis (fig. 7). The PM are graphed based on three average daily ambient temperature ranges: hot condition for days warmer than 26.7°C (80°F), mild condition for days with temperature of 7.2-26.7°C (45-80°F), and cold condition for days with temperatures below 7.2°C (45°F) (fig. 8).




Daily CH$_4$ Emissions
CH4 house2
CH4 house3
Daily CH$_4$ emissions (g/day-bird)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
6/6/10
7/4/10
8/1/10
8/29/10
9/26/10
10/24/10
11/21/10
12/19/10
1/16/11
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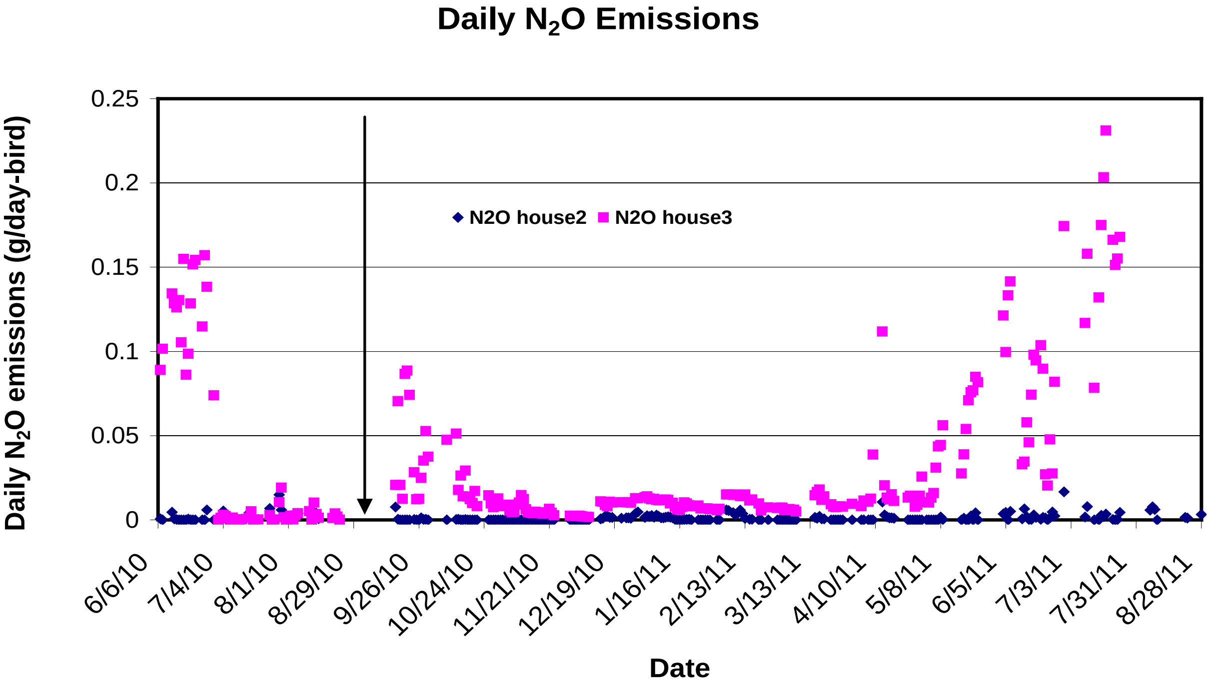
8/28/11
Date


Daily N$_2$O Emissions
N2O house2
N2O house3
Daily N$_2$O emissions (g/day-bird)
0.25
0.2
0.15
0.1
0.05
0
6/6/10
7/4/10
8/1/10
8/29/10
9/26/10
10/24/10
11/21/10
12/19/10
1/16/11
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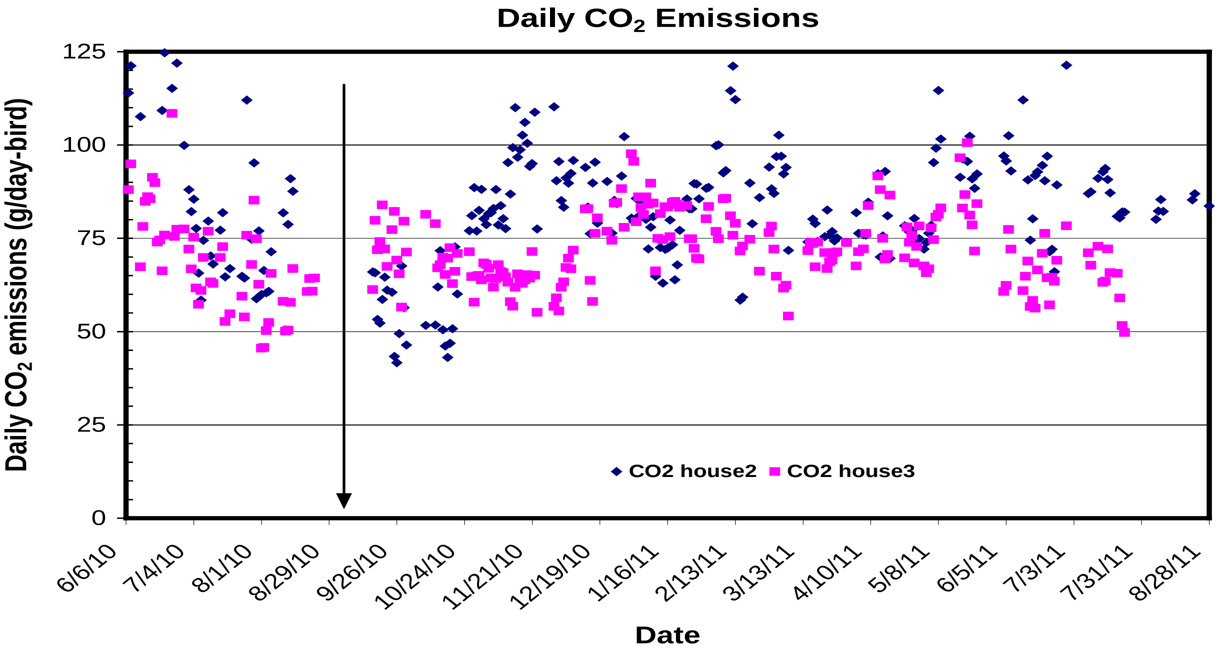

Figure 7. Mean daily gaseous emissions for ammonia, methane, nitrous oxide, and carbon dioxide. Note that a new flock was placed in house 2 the second week of September 2010 and the flock in house 3 was removed the first week of August 2011.

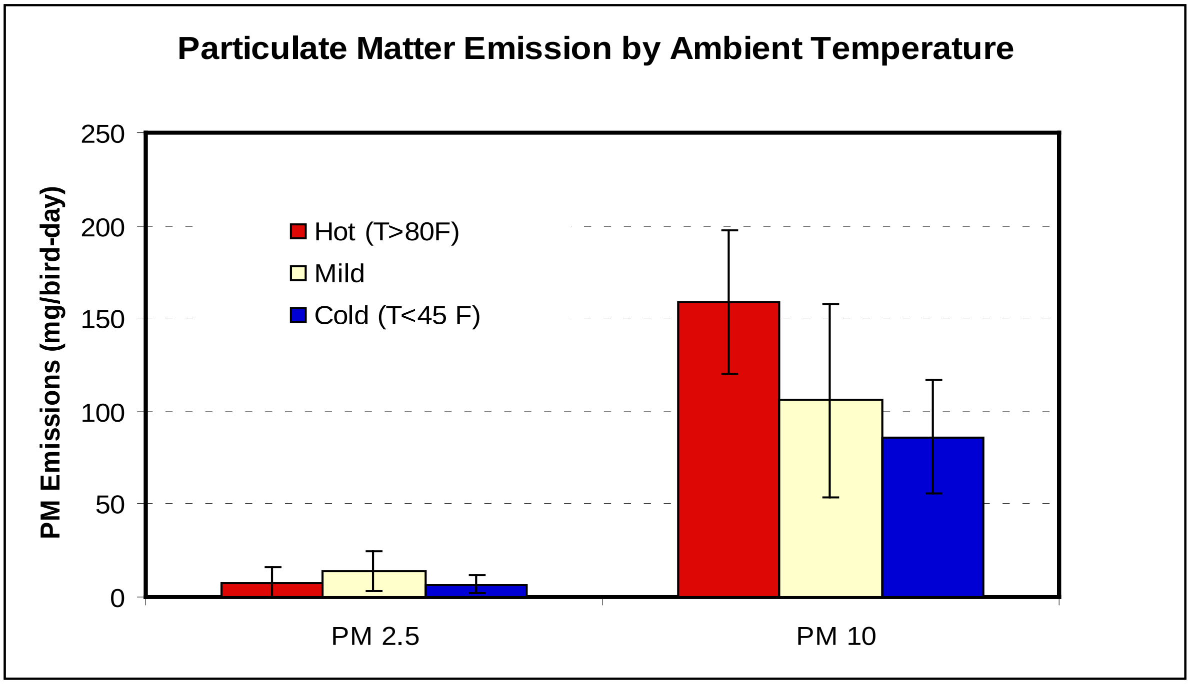

Figure 8. Daily particulate matter emissions (mean ± standard deviation) for different seasons, with hot condition including temperatures warmer than 80°F (26.7°C), mild including the range from 45-80°F (7.2-26.7°F), and cold including temperature below 45°F (7.2°C).

A summary of the average daily emission rates and cumulative emissions for the year are reported in Tables 1 and 2. The gaseous emissions for this study tended to be slightly higher in House 2 than in House 3, while PM emissions followed the opposite trend, i.e., higher in House 3 than House 2. Some manure samples were taken between March 2011 and August 2011 that indicated manure moisture content was higher in House 2 than in House 3. This might have been the cause of the variability between the houses.

Table 1. Average daily gaseous and particulate matter emission rates of Hy-Line brown laying hens in aviary houses (mean and std dev). The average weight of hens was 1.76 and 1.78 kg in houses 2 and 3, respectively. The average population was 48,250 and 47,600 hens for houses 2 and 3, respectively.

		Average Daily Emission Rate				
House	Unit	Ammonia	Carbon Dioxide	Methane	PM 10	PM 2.5
2	kg	7.9 (5.0)	4,035 (1,144)	5.0 (6.2)	3.9 (1.9)	0.24 (0.19)
	g/bird	0.17 (0.1)	86 (22)	0.11 (0.12)	0.08 (0.04)	0.005 (0.004)
	g/AU	48 (28)	24,430 (6250)	31 (34)	24 (11)	1.4 (1.1)
3	kg	6.8 (2.9)	3,393 (505)	4.1 (3.3)	6.2 (1.9)	0.48 (0.38)
	g/bird	0.14 (0.07)	70 (12)	0.09 (0.07)	0.13 (0.04)	0.011 (0.008)
	g/AU	39 (20)	19,660 (3,370)	25 (20)	35 (11)	2.8 (2.2)

Table 2. One-year cumulative emissions of Hy-Line brown laying hens in aviary houses. The average weight of hens was 1.76 and 1.78 kg in houses 2 and 3 respectively. The average population was 48,250 and 47,600 hens for houses 2 and 3, respectively.

		One-Year Cumulative Emissions				
House	Unit	Ammonia	Carbon Dioxide	Methane	PM 10	PM 2.5
2	kg	2831	1450750	1307	1425	88
	g/bird	58	30295	27	31	2
	kg/AU	16	8606	8	9	0.6
3	kg	2464	1250163	1130	2262	175
	g/bird	52	26436	24	46	4
	kg/AU	15	7426	7	13	1.1

Overall, the values in these tables are in line with expectations. Previous Midwestern studies showed manure-belt house ammonia emission rates between 0.05 and 0.1 g/bird-day but high-rise house ammonia emission rate of about 0.9 g/bird-day (Liang et al., 2005). Ammonia emissions for this aviary system average 0.15 g/bird-day, being higher than those for manure-belt systems but significantly lower than those for high-rise systems. For carbon dioxide the average emission rate of 78 g/bird-day is in line with reported values from belt systems (70 - 85 g/bird-day). For methane, literature suggests a belt system emitting between 0.07 and 0.18 g/bird-day. Our data fall inside this range. Overall this system has emission rates that relate well to a conventional belt house, with the exception of ammonia being higher. The major difference in this system lies in the PM emissions. Literature for conventional laying-hen housing reports PM2.5 emissions of 0.002 to 0.014 g/bird-day (Li et al., 2011), while this study reveals 0.008 g/bird-day. For PM10 the reported literature ranges from 0.008 to

0.051g/bird-day, while this study averages 0.105 g/bird-day. The emissions from our study are higher than those reported in literature, especially for PM10; however this system does have a littered floor area. Overall, this higher PM concentration and emission rate is not unexpected, but may be a concern.

Total Heat Production of the Hens and House-Level Moisture Production

Total heat production (THP) of hens in this system was calculated using indirect calorimetry, which required accurate measurements of oxygen and carbon dioxide concentrations. Due to the extra instrumentation, data completeness for THP was 58%. Because latent heat production (LHP) is not dependent on the oxygen analyzer, it had data completeness of 68%. The THP LHP values throughout the monitoring period are shown in figure 9. The daily diurnal THP pattern follows the similar pattern to the carbon dioxide diurnal concentration in that it steps up as lights come on and steps up again when birds are given access to the littered floor area (fig. 10). Overall, the average daily THP is 6.8 (±1.9) and 5.6 (±1.2) W/kg [mean (±std dev)] for Houses 2 and 3, respectively; and the LHP is 2.0 (±0.7) and 1.7(±0.5) W/kg for Houses 2 and 3, respectively. Overall these values match or are slightly lower than other reported values. In conventional housing THP values range from 6.1 to 6.6 W/kg, and LHP values range from 2.8 to 3.5 W/kg (Chepete et al., 2004; Green et al., 2009). These brown birds are between 15 and 20% heavier than those (white leghorn) hens reported in literature, and THP in W/kg is expected to decrease with increasing body mass.

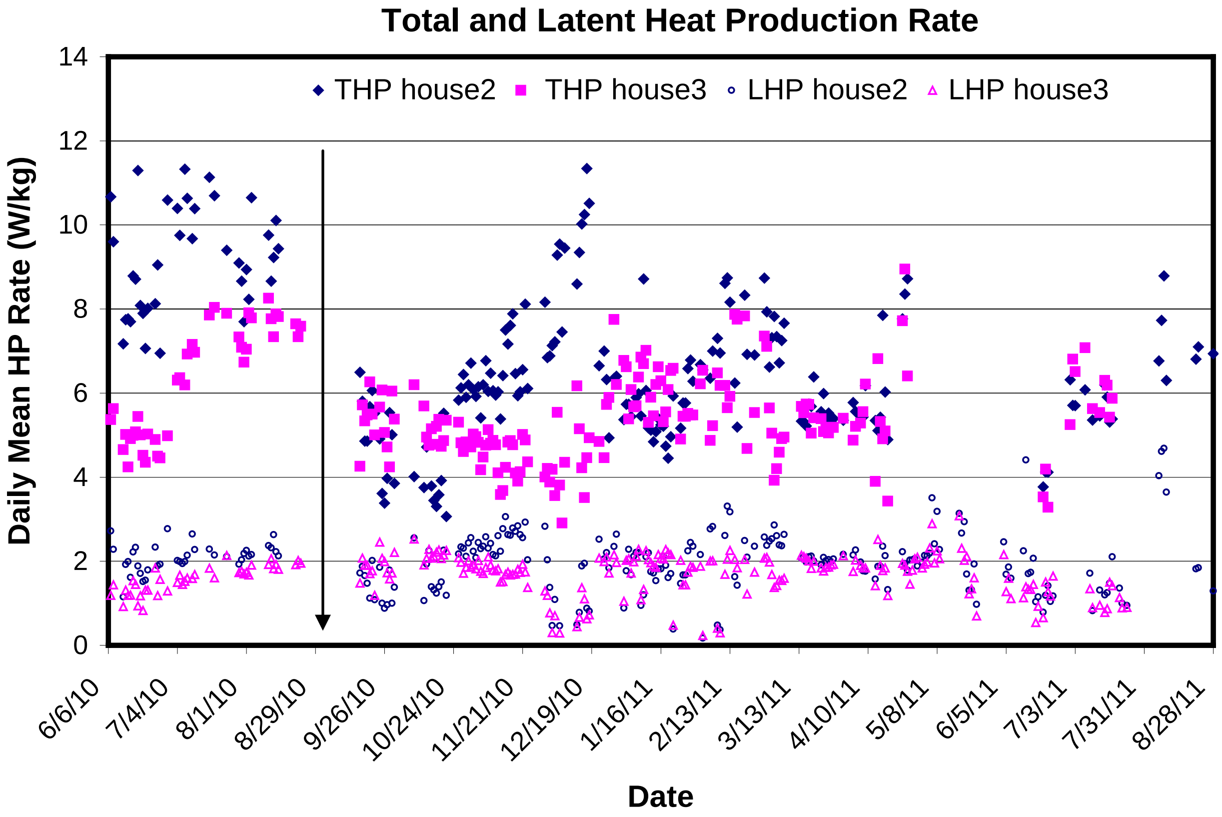

Figure 9. The average daily total production rate (THP) of Hy-Line brown hens and house-level latent heat production (LHP) in the aviary hen houses. A new flock was placed in House 2 the 2nd week of September 2010 and the flock in House 3 was removed the 1st week of August 2011.

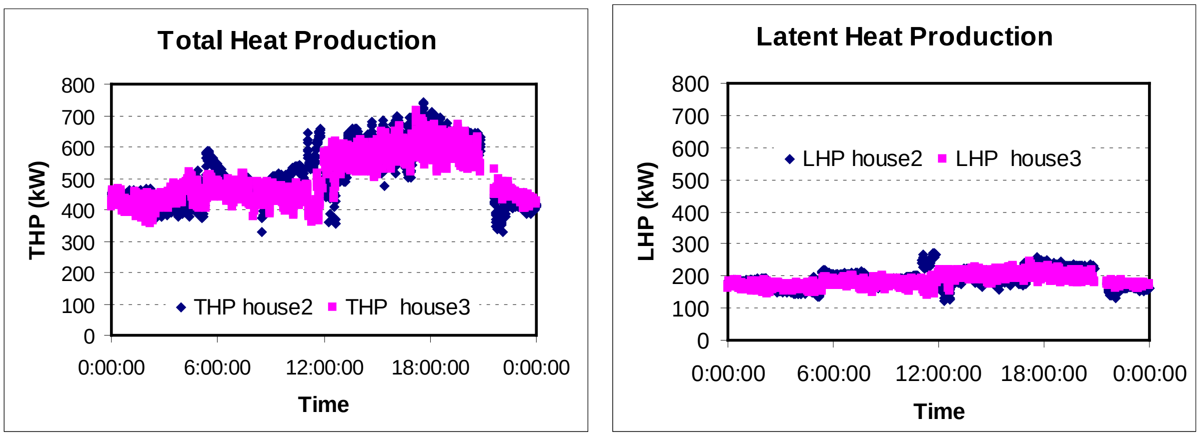

Figure 10. A typical diurnal pattern of hen total heat production (THP) and house-level latent heat production (LHP) in the aviary hen houses. Lights came on at 5:45AM, the birds were given floor access at 11:45AM, lights went off and birds were locked in at 9:45PM.

Electricity and Fuel Usage

Houses 2 and 3 had different winter temperature set-point with House 2 set at 72°F and House 3 at 77°F. This resulted in different propane usage by the barns. House 2 used 800 cubic feet (22.2 gallons), while house 3 used 3,800 cubic feet (105.6 gallons) of propane fuel over the monitoring period. This difference shows how much the fuel usage increases with increasing set-point temperature in these aviary hen houses that have lower stocking densities. Of the 800 cubic feet (22.2 gal) used in House 2, 300 cubic feet (8.3 gal) was used over 3 winter days, while the remaining 500 cubic feet (13.9 gal) were used in the spring (April and May) during night hours. The same propane usage trend was seen in House 3 where 700 cubic feet (19.4 gal) was used in 4 winter days, and the remaining 3100 cubic feet (86.1 gal) was used in the spring. The electricity usage was partitioned into power usage for lighting, ventilation, and blowers used to dry manure on the belts. Minimum ventilation only requires approximately 20 kWh each day while maximum ventilation draws 875 kWh each day. The manure-drying blowers (3 per barn, 7.5 HP per blower) draw 350 kWh each day when running continuously. The lighting with CFL bulbs draws approximately 25 kWh each day.

Production Performance

The graphs in figure 11 show production data for a full cycle for House 3 and through 66 weeks of age for House 2. There are some trends to note. The dip in egg production in House 2 around 60 weeks of age occurred during mid to late July when seasonally high temperature was encountered. There was also a drop in feed conversion and feed consumption at this same point. This trend is harder to see in House 3 as this was the last two weeks of the production for House 3. There was a higher mortality rate in House 3 early in the flock as well as a slightly lower peak percent hen-day egg production. This flock was placed in April and reached peak production in mid to late June when the average daily house temperature was 26.1°C (79°F).

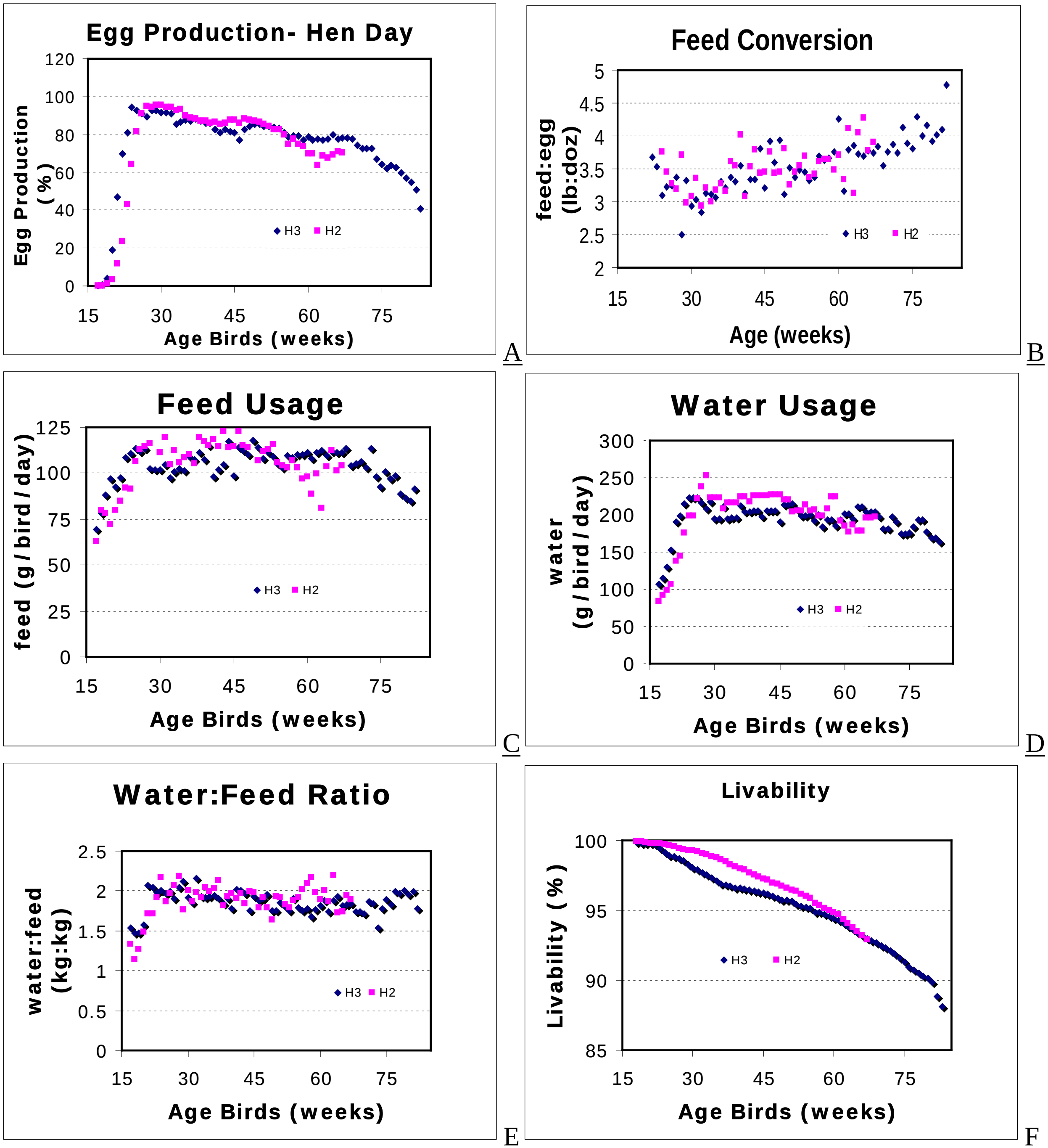

Figure 11. Weekly production data for a full flock in House 3 and through 66 weeks for House 2. a) Hen-day egg production (%), b) Feed conversion in pounds of feed per dozen eggs, c) Daily feed usage in grams per bird, d) Daily water usage in grams per bird, e) Water to feed ratio, and f) percent of live birds relative to the initial number of hens placed.

Table 3. One-cycle (18-80 weeks) average production parameters of Hy-Line brown laying hens in the aviary houses

		House2		House 3	
		Avg	*SD*	Avg	*SD*
Population	**No. of hens**	47782	*1465*	47499	*1348*
Body Weight	**kg**	1.83	*0.12*	1.80	*0.09*
Body Weight	**lb**	4.02	*0.27*	3.96	*0.20*
Feed	**g/bird/day**	106	*12*	105	*8*
Water	**g/bird/day**	199	*30*	196	*19*
Egg Case Weight	**lb**	49.5	*6.9*	49.5	*2.9*
Water:Feed Ratio		1.88	*0.19*	1.86	*0.14*
Weekly Mortality	**%**	0.15	*0.08*	0.16	*0.08*
Egg Production	**hen day%**	72.7	*22.5*	76.2	*18.2*
Egg Production	**hen housed%**	70.0	*22.4*	72.8	*18.0*
Feed Conversion	**lb:lb**	2.16	*0.27*	2.12	*0.21*
Feed Conversion	**lb:doz**	3.66	*0.43*	3.53	*0.37*

Production Economics

Table 4 shows the dietary compositions and prices of ingredients for hens housed in the aviary system and hens housed in a typical conventional system. The ingredient prices are standardized using the respective average ingredient prices over the 2007-2011 time period. Ingredient use is the actual amount utilized during the study period for the two respective diets. The prices of corn, soybean meal, flaxseed meal, dry distillers grains with solubles (DDGS), meat and bone meal, fat and salt are the 2007-2011 average prices for Minneapolis, Chicago and Kansas City as published in the Feedstuffs newspaper. Dehydrated corn germ was priced at 112 percent of the DDGS price. Ecocal was priced at 8 cents/cwt and micronutrients priced at $1,000 per ton. Ecocal and dehydrated corn germ prices were acquired through personal communication with industry personnel. Limestone prices were obtained from USDA AMS reports. Soybean oil price was assumed to be equal to the animal fat price and dicalcium phosphate price was estimated based on the units of calcium and phosphorus per ton.

The feed cost per ton was estimated to be $249.58 for the aviary house and $220.27 for the conventional house (table 4). These diets were fed for a full cycle of hen’s egg production. The diets used in both systems were very different, which led to the difference in the final cost per ton of feed. The aviary house feed contained higher levels of soybean meal, soybean oil, dicalcium phosphate and micro-ingredients; while the conventional house feed contained higher levels of meat and bone meal and fat, but it used a higher percentage of corn and corn-derived products that are less expensive.

Table 4. Feed compositions, ingredient prices, and feed cost per metric ton for hens in both the aviary housing and conventional housing systems.

	Inclusion rate		Price	Feed value ($/ton of feed)	
Ingredient	Aviary	Conventional	($/metric ton)	Aviary	Conventional
Corn	53.66%	58.89%	180.07	96.63	106.05
Soybean Meal	26.30%	17.31%	342.18	89.99	59.23
Limestone	10.45%	9.02%	60.00	6.27	5.41
Fat	0.52%	1.12%	627.90	3.25	7.05
Flaxseed meal	3.75%		239.96	9.00	0.00
Soy Oil	2.33%		627.90	14.64	0.00
Dicalcium Phosphate	1.69%		256.41	4.33	0.00
Salt	0.38%	0.34%	51.44	0.19	0.17
DDGS		3.33%	155.81	0.00	5.19
EcoCal		2.05%	176.21	0.00	3.62
Corn Germ Dehy		4.15%	174.51	0.00	7.24
Meat & Bone Meal		3.33%	347.31	0.00	11.58
Micro-ingredients	0.92%	0.45%	1101.32	10.15	4.95
Transport and milling ($/ton)				13	13
Total				**247.45**	**223.50**

The egg price for the conventional system was determined using the 2007-2011 Urner Barry prices minus a discount (37 cents for the period between January 2007 to March 2009, 40 cents for the period after April 2009). Unfortunately data were not available on the cage-free eggs prices paid to producers. Therefore, the cost of production in the aviary house was compared with the retail price of cage-free brown eggs reported in the USDA AMS Weekly Retail Shell Egg and Egg Products Feature Activity. The pullet cost was estimated based on the feed cost as “1.65+12*feed price” for the white layers in the conventional house and “1.65+12.9*feed price” for the brown layers in the aviary house, although this difference can be larger if pullets for the aviary laying-hen house are also grown with twice the space per bird (as was the case with the laying hens).

The manure value was estimated in the conventional house study based on the nitrogen and phosphorus content and we assumed that the manure value is the same for both systems (the aviary house and the conventional house). This assumption might not be accurate but would not have tangible effect on the final economic results.

Estimation of Costs

The economic projection of returns and costs was based on an aviary house of 50,000 hens and then compared with the costs of a conventional high-rise house of 100,000 hens. The 2007-2011 average cost of building a high-rise layer house was assumed to be $12/bird and the 2007-2011 average cost of building an aviary layer house was assumed to be $44/bird. It was assumed that an employee can take care of two aviary houses or two conventional houses. It was also assumed that one supervisor is needed for every 2 employees. Therefore we assumed it would take twice as much labor per bird to take care of an aviary house than a conventional house. It was further assumed that the health related management and overhead costs per hen housed are the same for both systems (41.7 cents/bird). The following costs were assumed to be twice as high ($2.7/bird vs. $1.35/bird) for the aviary because of the higher space per bird: utilities, repairs and maintenance, supplies and small equipment, and miscellaneous.

Estimation of the Aviary House Costs of Production (between 18 and 80 weeks old)

Table 5 shows the production and economic results for both aviary flocks. There were some production performance differences between the two flocks, but they were also started in different seasons, with one flock (House 2) placed in September and the other (House 3) placed in April. Hens in House 2 produced 12.3 less eggs per hen housed, but their eggs averaged 1.3 grams heavier. Hens in House 2 consumed 8.6 kg less feed per hen housed, resulting in 270 grams less feed consumption per dozen eggs produced. These hens resulted in a lower cost of 4.4 cents/dozen than hens in House 3.

The average of both flocks resulted in 314.9 eggs and 40.1 kg of feed consumed per hen housed. The feed conversion was 1.53 kg of feed per dozen eggs produced or 2.00 kg or pound of feed per kg or pound of eggs produced because the average weight (egg weight =63.6 g). Feed cost represented 40.5% of the total costs while housing and equipment represented 28.3% of the total costs. The larger space per bird used in the aviary houses dramatically increases the housing and equipment costs as compared to conventional houses (where feed costs generally account for 60-56% of the total costs), therefore the shares of the total cost by different components change dramatically as well. These costs are estimated using a 20-year depreciation time for the building and 10-year depreciation time for the equipment with 10% interest rate on the investment. There seems to be some higher risk involved in investing in this new technology because the investment is made toward a higher-cost production system; therefore producers venturing in these new systems would need a shorter payback period for the facilities in order to take the risk. For example, if a producer can get an 8-year contract and they want to have their facilities paid off by the time the contract expires they would need an egg price of $1.02 cents per dozen, but this is the average price of all eggs produced (including small and checks) and it is for not graded or processed in any way. Therefore it should be compared with the $0.74 per dozen received by producers for conventional white eggs. As a result, the $1.02/dozen means that a 38% premium in the price relative to the conventional white eggs is needed for the producers to pay off the cost of the facilities in an 8-year period. The 2007-2011 average retail price for large brown cage-free eggs was $2.78; therefore the needed price ($1.02/doz) for all-size nest run eggs under these conditions represents 36.8% of the retail price for large brown cage-free eggs. However, at the time of this writing, there was no published info on egg prices paid to aviary egg producers which would have allowed us to better compare the costs of production with the received price and project the payback time.

Table 5. Aviary houses results per hen housed (between 18 and 80 weeks old)

	Units	**House 2**	**House 3**	**Both Houses**
Feed consumed	kg	35.78	44.36	40.07
Eggs produced	eggs	308.67	321.02	314.85
Egg mass	kg	19.83	20.21	20.02
Egg Weight	grams	64.24	62.97	63.60
Feed conversion	ton/ton	1.80	2.19	2.00
Feed conversion	kg/dozen	1.39	1.66	1.53
Feed Cost	$	8.85	10.98	9.92
Pullet cost	$	3.10	3.10	3.10
Housing & Equipment	$	6.93	6.93	6.93
Labor	$	0.75	0.75	0.75
Utilities	$	2.53	2.53	2.53
Other cost	$	1.25	1.25	1.25
Total Cost	$	23.41	25.53	24.47
Cost per Kg of eggs	$/kg of eggs	1.18	1.26	1.22
Cost per dozen	$/dozen	0.910	0.954	0.932

To examine the effects of egg price and feed cost on payback period, a sensitivity analysis was performed and the results are shown in table 6.

Table 6. Payback period (year) for the aviary system as affected by feed cost and egg price.

		Nest run egg price (cents/dozen)						
		85	**95**	**105**	**115**	**125**	**135**	**145**
Feed cost ($/tonne)	**200**	14	9	6	5	4	4	3
	225	22	10	7	6	5	4	3
	250	> 40	13	8	6	5	4	4
	275	> 40	19	10	7	5	4	4
	300	> 40	> 40	12	8	6	5	4
	325	> 40	> 40	17	9	7	5	4
	350	> 40	> 40	31	11	8	6	5

Note: The interest amount over the complete value of the investment is higher than the revenue-cash costs. Therefore the producer needs a down payment to be able to cover the interest costs and pay the facility in the long run.

Comparison of Production Performance and Costs between the Aviary Hen Houses and Conventional Hen Houses (between hen ages of 21 and 69 weeks)

This section compares the production performance of the conventional and the aviary house systems. These two studies were run in facilities owned by different companies and they differed in many important aspects such as feed composition and bird genetics. Therefore they could not be analyzed as well as a totally controlled experiment. Nevertheless, it made an interesting comparison because one was representative of a typical conventional production system in the Midwest while the other represented one of the many cage-free alternative production systems. There are many factors other than the house itself that affect this performance such as the genetic strain and the feed formulations used. The aviary house produces cage-free eggs that are sold in the market with a large price premium. Therefore they should be considered as two different products rather than just two different houses.

Hen-day egg production was not much different between the two systems (fig. 12), but the mortality rate was 2.25 times higher for the aviary system (fig. 13) resulting in a lower number of eggs produced per hen housed.

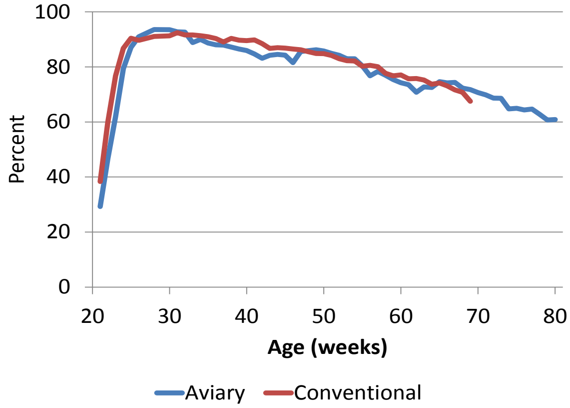

Figure 12. Hen-day production of the aviary and conventional hen houses.

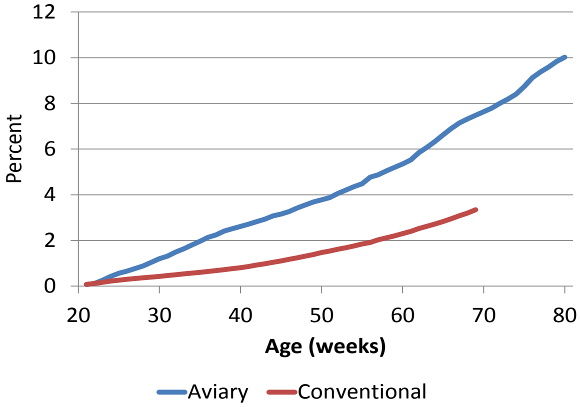

Figure 13. Cumulative mortality of the aviary and conventional hen houses.

Feed conversion (FC) of the conventional system was better than that of the aviary (figs. 14 &15), averaging 1.92 vs. 2.09 kg feed/kg egg (or 1.40 vs. 1.59 kg feed/doz. eggs). The better FC for the conventional houses with white-egg birds was in part attributable to the higher body weight of the brown birds used in the aviary.

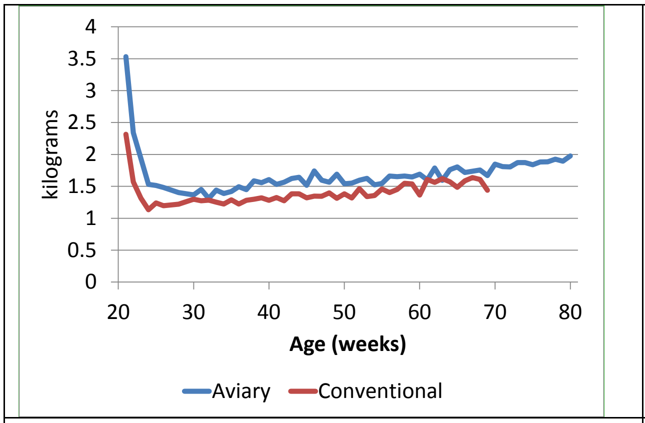

Figure 14. Feed conversion (kg feed/doz eggs) of the aviary and conventional hen houses.

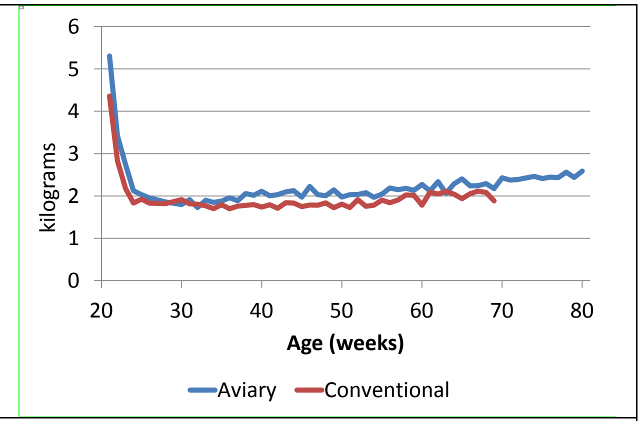

Figure 15. Feed conversion (kg feed:kg egg) of the aviary and conventional hen houses.

The aviary system eggs were larger (fig. 16) which was attributable to the brown bird strains used in the system vs. the white-egg hens in the conventional system.

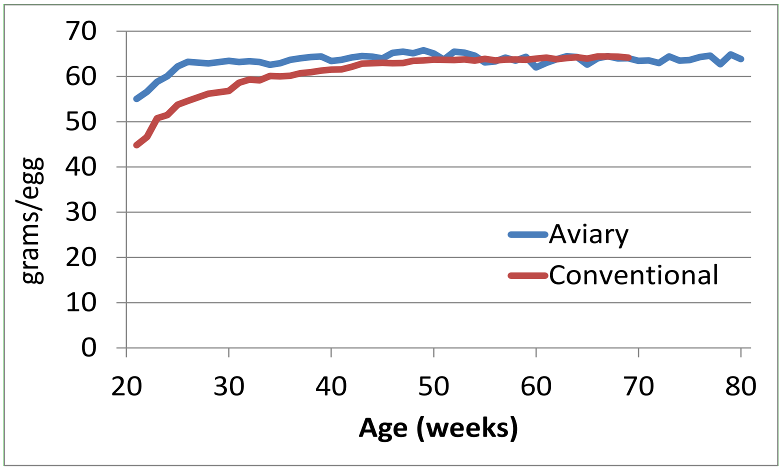

Figure 16. Egg weight (g/egg) of the aviary (brown hen) and conventional (white hen) houses.

Table 7 shows the production performance per hen-housed of the conventional and the aviary houses from 21 to 69 weeks of age. The brown layers in the aviary house consumed 9.9% more feed and produced 3.5% less eggs than the white layers in the conventional house. But the brown eggs were 4.5% heavier, leading to a 0.8% higher egg mass output by the brown layers in the aviary house. The white layers in the conventional house were more efficient in feed use in that they consumed 13.9% less feed per dozen eggs and 9.1% less feed per kg eggs produced. Housing and equipment costs are almost 4 times higher for the aviary house because of the much higher space per bird; all other costs such as labor and utilities are also considerably higher for the aviary house; and feed cost was 21.7% higher in the aviary system. As a result, the cost per hen housed was 54.4% higher for the aviary which in turn leads to a 59.9% higher cost per dozen eggs produced because of the lower egg production per hen housed.

Table 7. Production performance and costs per hen-housed of the conventional and the aviary houses for layers between 20 and 69 weeks old

	Units	Conventional	Aviary	Difference	% of conv.
Mortality	%	3.15	7.21	4.06	228.9
Water	liters	59.12	68.03	8.91	115.1
Water/Feed	ton/ton	1.82	1.90	0.09	104.7
Feed consumed	kg	32.49	35.71	3.23	109.9
Eggs produced	eggs	278.55	268.87	-9.68	96.5
Egg mass	kg	16.91	17.05	0.14	100.8
Feed conversion	ton/ton	1.92	2.09	0.17	109.1
Feed conversion	kg/dozen	1.40	1.59	0.19	113.9
Feed Cost	$	7.26	8.84	1.58	121.7
Pullet cost	$	2.87	3.10	0.23	108.1
Housing & Equipment	$	1.50	5.50	4.00	366.7
Labor	$	0.30	0.59	0.30	200.0
Utilities	$	1.00	2.01	1.00	200.0
Other cost	$	0.70	1.00	0.30	142.9
Total Cost	$	13.62	21.03	7.41	154.4
Cost per Kg	$/kg of eggs	0.81	1.23	0.43	153.1
Cost per dozen	$/dozen	0.59	0.94	0.35	159.9
Feed price	$/ton	223.50	247.45	23.95	110.7
Egg weight	grams	60.71	63.43	2.72	104.5

A problem that a cage-free system such as the aviary will face is that not all the egg sizes and qualities receive a premium in the market. For example eggs with defects such as checks and leakers will have very little value regardless of the production system. It is also difficult to get a cage-free premium for small and medium size eggs. Therefore the price premium received by good quality and larger size eggs such as “large”, “extra-large” and “jumbo”, which represent approximately 85% of the total eggs produced, must be responsible for compensating for the higher costs of producing all the eggs in the system. The aviary system produced about 50% more check eggs than the conventional house but they had a higher proportion of “large”, “extra-large” and “jumbo” eggs because of the brown birds strain. If we consider that they get the same price for “small,, “medium” and “check” eggs, then the price premium needed in the “large”, “extra-large” and “jumbo” should be approximately 78% of the conventional white eggs price to achieve the same profit level.

Welfare Assessment

ADT did not differ between visits (29.56cm ± 10.8; p=0.95). Overall the hens were relatively healthy and presented with few injuries or pathology: toe damage was present in 0-1% of the hens, comb pecking in 3-7% of the flock, respiratory infection 3-6% of the flock, foot pad dermatitis in 3-7% of the flock and there was no evidence of parasites. Keel deformities were relatively rare, but did increase slightly in prevalence over time (fig. 17). All hens had no to slight wear early in the lay cycle, but just over 50% of hens had at least one bare spot >5cm late in the lay cycle (fig. 18), most of which were on the neck.

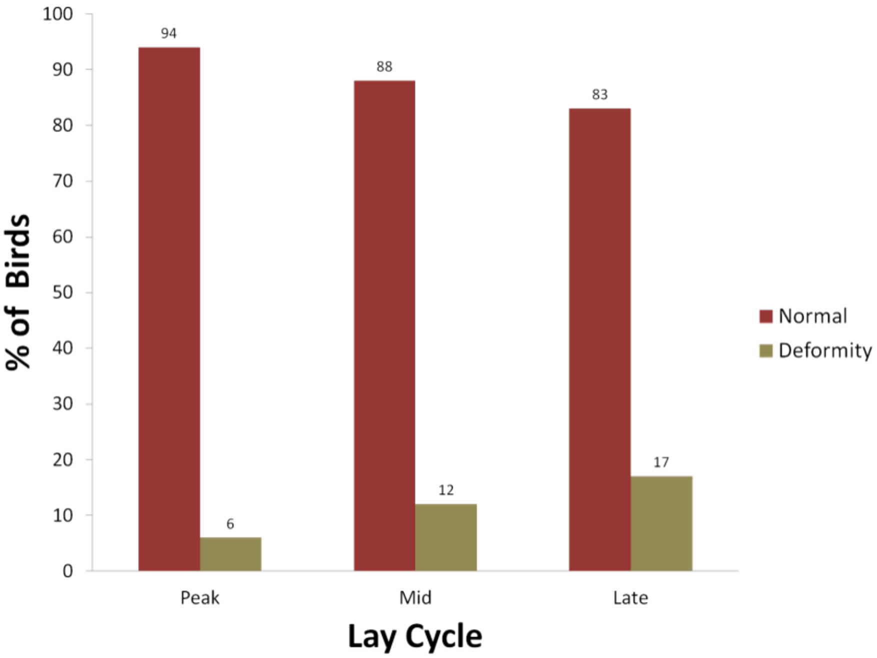

Figure 17. Keel score of laying hens in the aviary houses. Score of 0=normal/no deformity; 2=deformity. Data presented as percentage of hens.

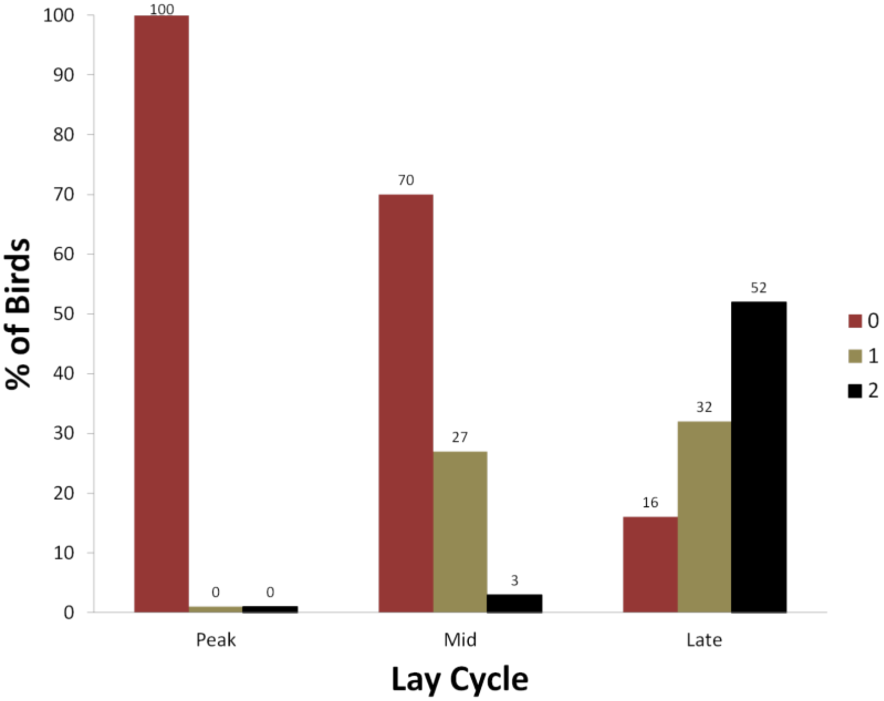

Figure 18. Feather scores of laying hens in the aviary houses. Score of 0=no to slight wear; 1=moderate wear; and 2=bare spot>5 cm. Data presented as percentage of hens.

Litter Use

Approximately 154% of the hens visited the litter during the day, indicated that some visited and returned to the tiers more than once a day. Movement of hens to (p=0.02) and from (p=0.014) the litter area was affected by time of day, with more hens moving during the mid-afternoon (14:30 to 15:30) and evening (19:30) time periods (fig 19). There was also a significant difference between sections of the house for frequency of movement to the litter (p=0.02; fig.20), but it is unclear if this represents differences due to group or due to week.

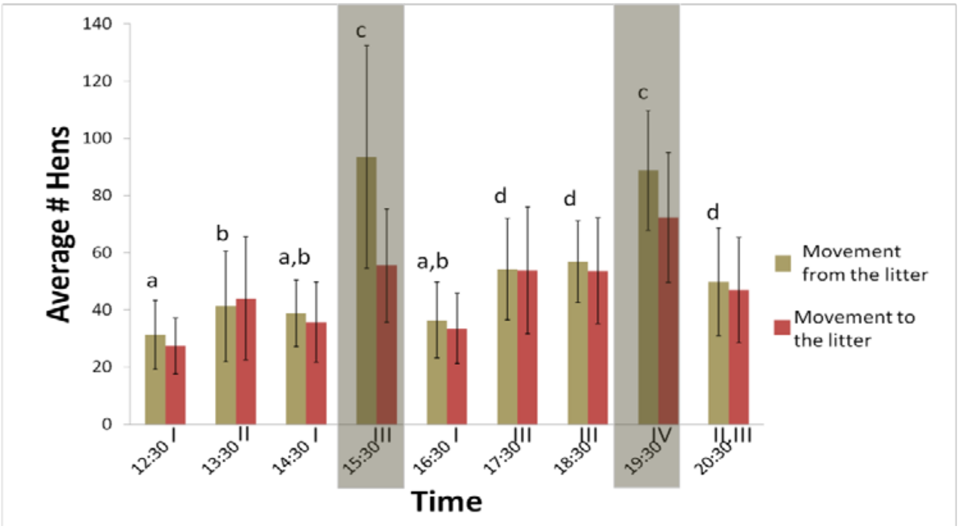

Figure 19. Average number of hens moving "IN" and "OUT" of the cages to the litter over time. Letters denote difference of movement into the cages and Roman numerals denote differences of movement to the litter. Shaded areas are times the hens were fed.

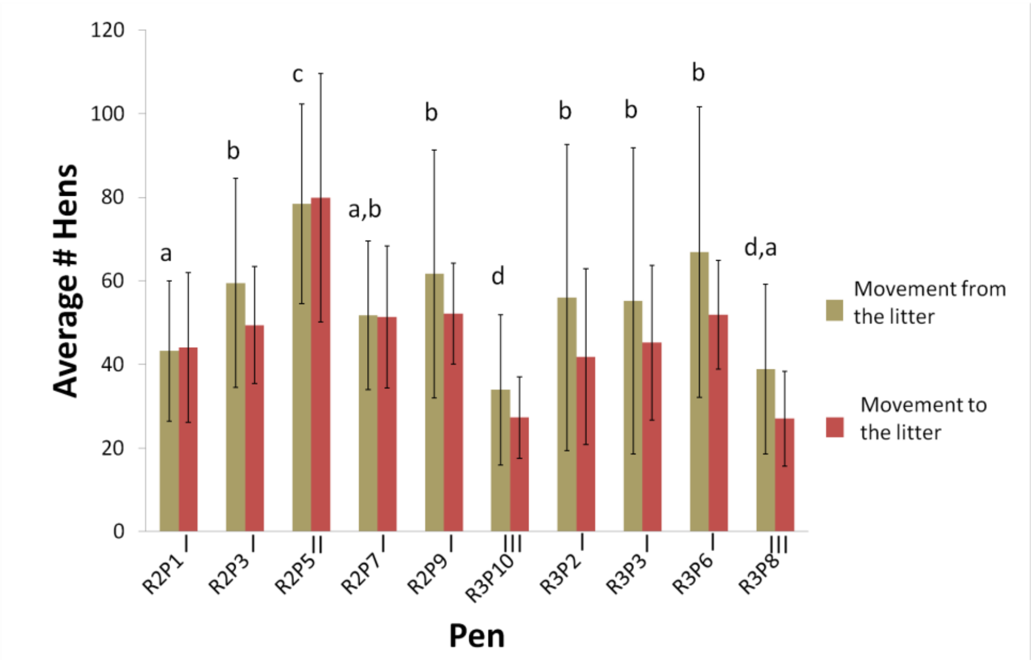

Figure 20. Average number of hens moving "IN" and "OUT" of the cages to the litter by section. Letters denote difference of movement into the cages and Roman numerals denote differences of movement to the litter.

A Novel Quadruplex Multiplex PCR (mPCR) for Rapid Detection and Characterization of Salmonella Isolates from Laying-Hen Environments

In initial work we found that not only *Salmonella*, but also other commonly occurring members of the family Enterobacteriaceae, could grow and produce false positive results on XLT4 and BGN media, two *Salmonella*-selective media comprising the core of both the FDA and NPIP *Salmonella* procedures. Without a rapid identification tool such as our mPCR assay, such false positive strains would need to be investigated further via subsequent culture and serotyping, which would cost both time and money and would delay collection of the actionable results needed by egg producers to ensure both safety and process control. Based on comparison of mPCR and 16S rDNA sequencing results, all of the *Salmonella* strains tested here were correctly identified using the mPCR assay. Likewise, all false-positive environmental isolates were correctly identified as non-salmonellae via mPCR. These isolates were surprisingly diverse, belonging to various genera within the Enterobacteriaceae, including *Citrobacter*, *Enterobacter*, *Klebsiella*, *Escherichia*, *Providencia* and *Proteus*.

CONCLUSIONS/IMPLICATIONS

1) Average daily emissions rates of ammonia, carbon dioxide and methane for the aviary hen houses were found to be 0.15, 78, and 0.10 g/bird/day. These values are higher than reported values for manure-belt hen houses, but lower than reported values for high-rise hen houses. Particulate matter emissions of the aviary houses were found to be higher than reported values for layer barns, with emission rates of 105 and 8 mg/bird/day for PM10 and PM2.5, respectively.
2) Total heat production rate of the hens and house-level latent heat production rate for the aviary housing system averaged 6.15 and 1.85 W/kg. These values are comparable to the values found with traditional housing systems.
3) The aviary houses had 25 fewer eggs per hen housed during the production period of 18-80 week as compared to Hy-line brown layer guidelines. Cumulative mortality was 10.2% compared to the 4.2% suggested in the guideline. Feed conversion was somewhat poorer at 3.59 lb/doz eggs as compared to the guideline of 3.31 lb/doz.
4) The aviary barns do use some supplemental heat (22 gallons LP for one house – House 2 and106 gallons for the other house – House 3 with higher set-point temperature); however its primary usage was not in the coldest months but instead was used in the spring when there was a great fluctuation in the ambient temperature. The fluctuating temperature led to over-ventilation of the barns which in turn called for supplemental heating. Barn set-point temperature impacts LP use. The electric energy use in these barns is driven mainly by the ventilation fans, but in winter the blowers for manure drying are in fact the primary power consumer. The amount of time these blowers run should be evaluated.
5) The production cost for the aviary system was about 60% higher than for the conventional system. The higher cost mainly results from the higher housing and equipment costs relative to the larger space per bird housed in the aviary system. Hence it is critical to evaluate if/how the space per bird can be reduced without affecting the hen’s well-being. Poorer feed conversion, related to the hen genetics, also contributes to the higher production cost. Eggs in the aviary houses also had higher percentage of checks which may be improved by adjusting the diets or by equipment design/operation. The projected payback period for the aviary system may range from >40 years to 3 years, depending on feed cost and egg price.

6) Some welfare assessment parameters such as keel injuries changed over time within the same group of hens, and further research is needed to determine risk factors for correction. Litter was a valuable resource for these hens that, on average accessed the litter area more than once daily.

7) The mPCR assay approach provides an accurate and rapid method for quickly identifying *Salmonella* spp. among suspect isolates recovered from poultry production environments. Incorporation of this mPCR in an FDA/NPIP-based isolation workflow may speed the acquisition of actionable data on the presence of *Salmonella*, differentiate between generic *Salmonella*, *Salmonella* subspecies I, *S*. Typhimurium and *S*. Enteritidis, and eliminate wasteful downstream testing of false-positive non-*Salmonella* isolates.

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