

# Air quality and bird health status in three types of commercial egg layer houses

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**Primary Audience:** Egg Producers, Poultry Housing Specialists, Integrators, Veterinarians

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## SUMMARY

In this field observational study, 3 types of laying-hen houses, namely, high-rise (HR), manure-belt (MB), and cage-free floor-raised (FR), were monitored for air temperature, RH, CO<sub>2</sub>, and atmospheric NH<sub>3</sub> under winter and summer conditions in Iowa. Under winter conditions, the HR and MB houses had more comfortable temperature and NH<sub>3</sub> levels (mean 24.6 and 20.6°C, and maximum 9 to 24 ppm of NH<sub>3</sub>, respectively) than the FR houses (mean 15.5°C and maximum 85 to 89 ppm of NH<sub>3</sub>, respectively), and house temperature varied more with outside conditions. Under summer conditions, house temperature showed the least increase above ambient in the FR houses (mean 0.3°C vs. 4.7 and 1.2°C for the MB and HR houses, respectively), and NH<sub>3</sub> levels were similar for all housing types (mean 3 to 9 ppm). Examination of the hen health status revealed differences in pathogen prevalence between housing systems for winter and summer, but not conclusively in favor of one system over another. Results of this study indicate that the benefits of each system were season dependent. Further monitoring of the environment, bird health, and production performance over an extended period (e.g., 1 yr) to quantify the benefits and limitations of each system is warranted. Information of this nature will aid in optimizing hen housing systems for enhanced bird welfare and sustained production efficiency for the egg industry.

**Key words:** ammonia, temperature, *Campylobacter*, *Salmonella*, high-rise, manure belt, cage-free

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## DESCRIPTION OF PROBLEM

Bird welfare is an increasing issue of concern for the egg industry. Housing systems play a critical role in the welfare of laying hens, and various systems are implemented throughout the world. A segment of the US egg industry has begun modifying housing systems from conventional cages to alternative (noncaged) systems, although this trend is more prevalent in Europe.

Behavioral benefits of cage-free systems are well documented, as are the disadvantages [1, 2]. Caged systems offer opportunities for better management and environmental control, reduced production costs, and more efficient use of resources. Important considerations for welfare also include environmental quality and hen health, but these parameters are not well documented for different laying-hen housing systems.

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Different housing systems create unique management scenarios and can result in different housing environments for the same weather. Environmental temperatures not only influence hen comfort and performance, but also affect other environmental parameters, such as NH<sub>3</sub> and dust levels in poultry houses [3]. Ammonia emissions from layer houses have been shown to differ considerably among high-rise (HR), manure-belt (MB), and cage-free systems [4, 5].

Bird welfare guidelines recommended by the United Egg Producers state that NH<sub>3</sub> levels in chicken houses should ideally be less than 10 ppm and should not exceed 25 ppm [6]. Studies have shown that laying hens find atmospheric NH<sub>3</sub> highly aversive at concentrations of 25 ppm [7]. Air quality for the humans working in poultry houses is also a concern. The National Institute for Occupational Safety and Health has established an 8-h time-weighted average limit of 25 ppm of NH<sub>3</sub> for humans [8]. The Occupational Safety and Health Administration has a permissible 8-h time-weighted average exposure limit of 50 ppm for humans [9].

Ample literature has documented the adverse effects of elevated atmospheric NH<sub>3</sub> levels on poultry, such as reduced production performance and poor health of broilers [10–13], reduced egg production [14], damaged respiratory tract [15, 16], increased susceptibility to Newcastle disease virus [17], increased incidence of air sacculitis [18] and keratoconjunctivitis (blind eye) [19], and prevalence of *Mycoplasma gallisepticum* (MG) [20]. Egg quality may also be adversely affected by high levels of atmospheric NH<sub>3</sub>, as measured by reduced albumen height, elevated albumen pH, and albumen liquefaction [21]. To ensure good bird health and performance, it is recommended that atmospheric NH<sub>3</sub> in poultry houses not exceed 25 ppm [6], which may be difficult to achieve in some housing types in cold weather. During summer (warm or hot weather), it may be difficult for houses with high numbers of birds to provide sufficient ventilation to maintain comfortable temperatures, even at the maximum ventilation rate.

The health state of the bird affects not only bird welfare, but also the microbial food safety of the consumer. Epidemiological studies indicate that the prevalence of *Salmonella* or *Campylobacter* varies with housing system,

diet, season, and age of the birds [22–27]. A California study reported fewer *Salmonella* Enteritidis in caged birds (1.7%) than in free-range birds (50%), with a similar pattern for other group D *Salmonella* in caged (1.5 per 10,000) and free-range (14.9 per 10,000) hens [28]. Likewise, significantly more *Salmonella* were isolated from floor pens than from batteries of caged laying hens [29]. *Salmonella* prevalence in noncaged barns (61.5%) and free range (54%) exceeded that for caged systems (34%) in the United Kingdom [30]. Similarly, among the multiple risk factors for *Salmonella* infection in laying hens of the same age, confining birds to a cage lowered the risk of *Salmonella* when compared with free-ranging hens [31]. In contrast, others reported that *Salmonella* prevalence was highest in laying hens housed in conventional cage systems (46.3%) and was lowest in free-range flocks (21.9%) [32]. Still others reported no significant differences in *Salmonella* status when free-range vs. caged layers were evaluated [33]. No studies have compared the prevalence of *Campylobacter* in layers maintained in different housing systems.

To fully assess the welfare of birds in a specific system, it is important to evaluate the system as a whole, including health, environment, behavior, handling and management practices, worker education and training, and economics. Few studies have compared air quality at the bird level in HR, MB, and cage-free littered floor-raised (FR) laying-hen facilities. Reports regarding hen health status and the prevalence of foodborne pathogens in these housing systems have been contradictory.

Therefore, the objective of this field observational study was to characterize air quality and hen health status in 3 relatively common types of laying-hen housing—HR, MB, and FR—under both warm and cold climatic conditions in Iowa. These results may be useful for improving laying-hen husbandry and system operation.

## MATERIALS AND METHODS

### *Description of the Laying-Hen Houses Monitored*

Four houses in each hen-housing system (FR, HR, and MB) were selected for each monitoring period based on farm access and availability. The

characteristics of the houses are described below and are summarized in Tables 1, 2, and 3.

The 4 FR houses were located on 3 separate sites (sites 1, 2, and 3) within 16 km (10 mile) of one another, featuring partially or fully littered floors; automated feeding, watering, and egg collection; and nest boxes. One house was used to produce organic eggs, in which hens were allowed access to outdoor pasture under suitable weather. Two houses had a partially slatted floor located along the center of the house, and manure that accumulated beneath the slatted floor was removed several times per year. Three houses were naturally ventilated, whereas the fourth one was mechanically ventilated. Three houses had an east-west orientation, and one of the naturally ventilated houses had a north-south orientation. The same FR houses were monitored for both summer and winter conditions.

The sets of MB and HR houses monitored were each located at a commercial egg-production site (sites 4 and 5, respectively, Tables 1 to 3). Manure was removed daily from the MB houses, whereas it was scraped from the dropping boards into the lower-level storage area 4 times daily in the HR houses, and the stored manure was cleaned out once a year (generally in the fall). Two of the same MB houses were monitored for both summer and winter conditions; the additional houses monitored were not the same for each monitoring period. For summer conditions, only 3 MB houses were available during summer because of an unexpected event. Three of the same HR houses were monitored for both summer and winter conditions; the fourth house monitored was not the same for each monitoring period.

### **Monitoring of Environmental Conditions**

Environmental variables measured near the bird level included  $\text{NH}_3$ ,  $\text{CO}_2$ , air temperature, and RH. Each house was monitored continuously over a 20- to 24-h period in winter and summer. All 12 houses in the study contained adult laying hens of various ages, but hens within a house were of the same age (Tables 1 to 3). Ammonia and  $\text{CO}_2$  concentrations inside the barns were measured at 30-min intervals by using portable monitoring units previously developed for monitoring poultry building  $\text{NH}_3$  and  $\text{CO}_2$  emissions [34, 35]. A 3-location composite air sam-

ple across the width of the house and nearly one-third into the length of the house was taken for the air sampling (Figures 1 and 2). Air temperature and RH inside and outside the barns were recorded at 5-min intervals by using programmable, portable air temperature/RH (T/RH) loggers [36]. One T/RH logger was placed at each sampling port. For caged houses, an additional T/RH logger was placed in the cage aisle near each sampling port (approximately 1.5 m, or 5 ft, distance from the logger inside the cage).

### **Examination of Hen Health Status**

Ten birds were randomly selected from each house on the day of monitoring for assessment of health status, tracheal condition, and prevalence of *Campylobacter* and *Salmonella*. For winter sampling, a total of 40 noncaged and 79 caged ( $n = 40$  MB and  $n = 39$  HR) hens were examined. For the summer, noncaged birds (total of 40) and caged birds (total of 70:  $n = 30$  for HR, and  $n = 40$  for MB) were assayed. Blood samples were taken from each hen, and sera from these samples were subsequently tested for the presence of antibodies against MG and *Mycoplasma synoviae* (MS) by the serum plate agglutination test. Birds were killed via injection of sodium pentobarbital, and trachea, small intestine, and ceca samples were collected.

**Tracheal Analysis.** Tracheas were fixed in 10% neutral buffered formalin, dehydrated in a graded series of ethanol, and embedded in paraffin. Sections were cut (4  $\mu\text{m}$  in thickness) and stained with hematoxylin and eosin for examination by light microscopy.

**Intestinal Homogenates.** Ceca and small intestine were collected and refrigerated (4°C). A 10% (wt/vol) homogenate was prepared in buffered peptone water as described previously [37].

**Detection and Identification of *Campylobacter* spp. and *Salmonella*.** For identification of *Campylobacter*, presumptive *Campylobacter* isolates were confirmed and speciated as *Campylobacter coli* or *Campylobacter jejuni* by polymerase chain reaction as described previously [37]. For identification of *Salmonella*, the buffered peptone water homogenate (10% wt/vol) was incubated (24 h, 37°C) aerobically. After incubation, 1 mL of the enrichment was transferred to 10 mL of tetrathionate Hajna broth [38] and incubated (24 h, 42°C) aerobically.

**Table 1.** Description of the laying hen houses monitored: floor-raised (FR)<sup>1</sup>

Season	Description	FR 1, site 1	FR 2, site 1	FR 3, site 2	FR 4, site 3
	Ventilation	Natural	Mechanical, side inlets and fans	Natural, with chimneys	Natural
	Orientation	East-west	East-west	North-south	East-west
	Manure management	Litter, wood shavings added once at the start of the flock	Litter, wood shavings added once at the start of the flock, partial slatted floor with auger removal	Litter, sawdust added every 2 wk, partial slatted floor with auger removal	Litter, wood shavings added once at the start of the flock
Winter 2006	Date monitored	Jan. 10 to 11	Jan. 10 to 11	Jan. 10 to 11	Jan. 10 to 11
	Bird age	76 wk	36 wk	32 wk	53 wk
	Flock size (initial)	3,500	6,000	8,700	10,000
Summer 2006	Date monitored	Aug. 7 to 8	Aug. 7 to 8	Aug. 7 to 8	Aug. 7 to 8
	Bird age	43 wk	67 wk	63 wk	36 wk
	Flock size (initial)	3,500	6,000	8,700	10,000
	House dimensions	40 × 160 ft; 12 × 49 m	50 × 210 ft; 15 × 64 m	40 × 300 ft; 12 × 91 m	66 × 180 ft; 20 × 55 m
	Bird housing	Cage-free, free-range organic	Cage-free	Cage-free	Cage-free, n-3 diet
	Birds per group (W/S <sup>2</sup> )	3,500	6,000	8,700	10,000
	Breed	Brown (U <sup>3</sup> )	Brown (U)	Brown (U)	Brown (U)
	Space allowance, in <sup>2</sup> /bird (W/S); cm <sup>2</sup> /bird (W/S)	263 + dpa <sup>4</sup> ; 1,698 + dpa <sup>4</sup>	252; 1,626	199; 1,284	171; 1,103
	Water treatment	Peroxide	Peroxide	Peroxide	None, well water

<sup>1</sup>FR 1 to FR 4 refer to floor-raised houses 1 to 4.

<sup>2</sup>W/S = winter/summer.

<sup>3</sup>U = unknown, breed not documented.

<sup>4</sup>dpa = daily pasture access.

**Table 2.** Description of the laying hen houses monitored: manure-belt (MB)<sup>1</sup>

Season	Description	MB 1, site 4	MB 2, site 4	MB 3, site 4	MB 4, site 4	MB 5, site 4
	Ventilation	Mechanical, tunnel with lengthwise inlet	Mechanical, tunnel with lengthwise inlet	Mechanical, tunnel with lengthwise inlet	Mechanical, tunnel with lengthwise inlet	Mechanical, tunnel with lengthwise inlet
	Orientation	East-west	East-west	East-west	East-west	East-west
	Manure management	Removed daily	Removed daily	Removed daily	Removed daily	Removed daily
Winter 2006	Date monitored	Jan. 16 to 17	Jan. 16 to 17	Jan. 16 to 17	Jan. 16 to 17	DNM <sup>2</sup>
	Bird age	39 wk	98 wk	45 wk	109 wk	DNM
	Flock size (initial)	104,500	106,400	106,400	93,200	DNM
Summer 2006	Date monitored	DNM	DNM	Aug. 1 to 2	Aug. 1 to 2	Aug. 1 to 2
	Bird age	DNM	DNM	76 wk	32 wk	50 wk
	Flock size (initial)	DNM	DNM	106,400	106,400	106,400
	House dimensions	60 × 520 ft; 18 × 158 m	60 × 520 ft; 18 × 158 m	60 × 520 ft; 18 × 158 m	60 × 520 ft; 18 × 158 m	60 × 520 ft; 18 × 158 m
	Bird housing	Caged	Caged	Caged	Caged	Caged
	Birds per group (W/S <sup>3</sup> )	10	6	6	6	6
	Breed	W-36	W-36	W-36	W-36	W-36
	Space allowance, in <sup>2</sup> /bird (W/S); cm <sup>2</sup> /bird (W/S)	54; 348	54; 348	54; 348	54; 348	54; 348
	Water treatment	Ozonated	Ozonated	Ozonated	Ozonated	Ozonated

<sup>1</sup>MB 1 to MB 5 refer to manure-belt houses 1 to 5.<sup>2</sup>DNM = did not monitor.<sup>3</sup>W/S = winter/summer.

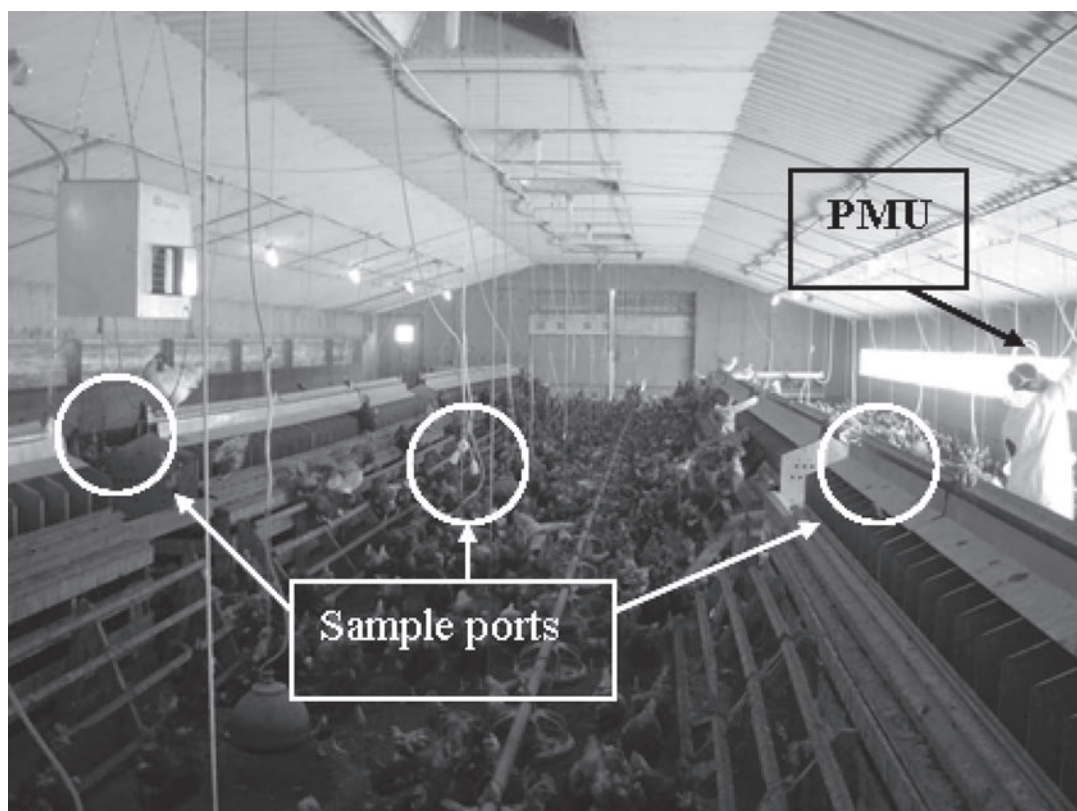
**Table 3.** Description of the laying hen houses monitored: high-rise (HR)<sup>1</sup>

Season	Description	HR 1, site 5	HR 2, site 5	HR 3, site 5	HR 4, site 5	HR 5, site 5
	Ventilation	Mechanical, ceiling inlet with side fans in manure storage area	Mechanical, ceiling inlet with side fans in manure storage area	Mechanical, ceiling inlet with side fans in manure storage area	Mechanical, ceiling inlet with side fans in manure storage area	Mechanical, ceiling inlet with side fans in manure storage area
	Orientation	East-west	East-west	East-west	East-west	East-west
	Manure management	Removed between flocks	Removed between flocks	Removed between flocks	Removed between flocks	Removed between flocks
Winter 2006	Date monitored	Jan 21 to 22	Jan 21 to 22	Jan 21 to 22	Jan 21 to 22	DNM <sup>2</sup>
	Bird age	42 wk	46 wk	93 wk	142 wk	DNM
	Flock size (initial)	66,061	65,141	64,727	80,174	DNM
Summer 2006	Date monitored	DNM	Jul 24 to 25	Jul 24 to 25	Jul 24 to 25	Jul 24 to 25
	Bird age	DNM	99 wk	22 wk	72 wk	39 wk
	Flock size (initial)	DNM	65,141	63,006	73,600	66,061
	House dimensions	48 × 430 ft; 15 × 131 m	48 × 430 ft; 15 × 131 m	48 × 430 ft; 15 × 131 m	48 × 430 ft; 15 × 131 m	48 × 430 ft; 15 × 131 m
	Bird housing	Caged	Caged	Caged	Caged	Caged
	Birds per group (W/S <sup>3</sup> )	8	8	9/8	6/5	8
	Breed	W-36	W-36	W-36	W-36	W-36
	Space allowance, in <sup>2</sup> /bird (W/S); cm <sup>2</sup> /bird (W/S)	59; 381	59; 381	56/61; 361/394	56/61; 361/394	59; 381
	Water treatment	None	None	None	None	None

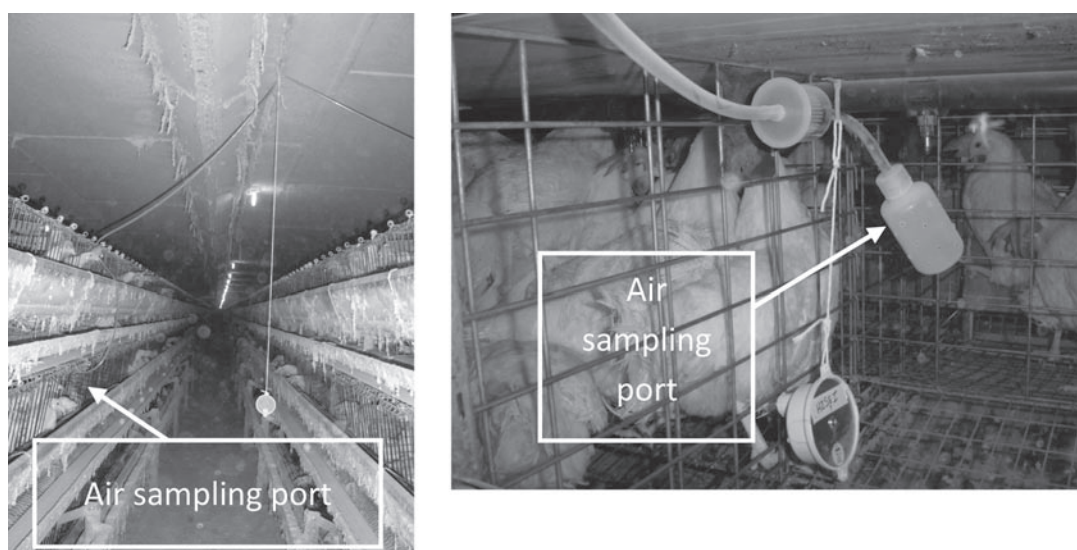
<sup>1</sup>HR 1 to HR 5 refer to high-rise houses 1 to 5.

<sup>2</sup>DNM = did not monitor.

<sup>3</sup>W/S = winter/summer.



**Figure 1.** Photograph of the monitoring configuration in the floor-raised house. PMU = portable monitoring unit [34] for  $\text{NH}_3$  and  $\text{CO}_2$  analysis of air samples. The circles indicate the locations of sample ports.



**Figure 2.** Photographic views of the bird-level sampling port in a caged house (sampling port placed inside an adjacent empty cage; temperature/RH loggers placed inside the cage and in the aisle, with a distance of approximately 1.5 m or 5 ft).

### Data Analysis and Presentation

For environmental conditions, data were summarized for each house and combined into mean plots for each variable during each monitoring period. To describe the combined effects of air temperature and RH under warm conditions, the temperature-humidity index (THI) for laying hens was calculated using the relationship  $THI = 0.6T_{db} + 0.4T_{wb}$ , where  $T_{db}$  = dry-bulb temperature and  $T_{wb}$  = wet-bulb temperature [39]. Daily mean environmental conditions were each compared for housing type, and differences were determined by least squares means. For the health status data, 2-factor repeated measures analyses were used in 2 different comparisons between winter and summer prevalence of *Campylobacter* and *Salmonella*. The first comparison examined differences among birds under the 3 housing schemes (noncaged FR, caged HR, and caged MB) over 2 trials (winter and summer) using 4 replicates. The second comparison examined differences between caged and noncaged birds over winter and summer with an unequal number of replicates. Differences were considered statistically significant at  $P < 0.05$ .

## RESULTS AND DISCUSSION

### Bird-Level Environmental Conditions

Environmental conditions differed for all 3 housing types. There was greater variability among the FR houses, which were independently operated, with different housing configurations and flock management practices. Variability was less for houses located on the same site and operated under the same management, as was the case for the MB and HR houses. House ventilation systems differed, which would explain some of the observed variations in environmental conditions. Additionally, the FR houses had only 1 level of birds, with 3 to 5 times more space per bird than the HR or MB houses, resulting in much less heat production as well as lower CO<sub>2</sub> concentrations. Interestingly, conditions were the most similar for houses FR 1 and FR 2, located on the same site with the same management personnel, although 1 house was naturally ventilated and the other was mechanically ventilated.

**Winter.** The 24-h mean, maximum, and minimum values of each variable for each housing system in winter are summarized in Table 4 and

depicted in Figure 3. Temperatures and NH<sub>3</sub> levels were within comfortable or recommended ranges throughout the monitoring period for the HR and MB houses. In comparison, NH<sub>3</sub> concentrations in the FR houses substantially exceeded the recommended level of 25 ppm, with a daily mean of 46 ppm, as compared with 14 ppm for the HR houses and 7 ppm for the MB houses. The maximum concentration in the FR houses reached 85 to 89 ppm. Temperatures in the FR houses tended to fluctuate with the outside conditions. The bird-level temperature was considerably cooler in the FR houses than in the HR or MB houses, averaging  $15.5 \pm 1.5^\circ\text{C}$  vs.  $20.6 \pm 0.8^\circ\text{C}$  for the HR houses and  $24.6 \pm 1.0^\circ\text{C}$  for the MB houses. Compared with the HR or MB houses, the smaller number of hens per unit space, and thus lower heat production, in the FR houses was the primary reason for their cooler temperature. The lower metabolic heat production in the FR houses corresponded to lower CO<sub>2</sub> concentrations (mean  $\pm$  SE),  $2,021 \pm 199$  ppm for FR, as compared with  $2,433 \pm 95$  ppm for HR and  $3,072 \pm 36$  ppm for MB. Frequent (daily, in this case) removal of manure from the MB houses greatly reduced NH<sub>3</sub> concentrations. This result was consistent with those reported previously [5].

Simple operating adjustments could have improved the conditions in the naturally ventilated FR houses. For these FR houses, the addition and operation of minimum ventilation fans could have significantly reduced NH<sub>3</sub> concentrations during the night when side curtains were closed. Litter management likely had a significant impact on NH<sub>3</sub> generation, with drier litter lessening NH<sub>3</sub> volatilization. A thin layer of wood shavings was periodically spread over the litter in house FR 3, which subsequently contributed to its lower NH<sub>3</sub> levels in winter, even at night when the curtains were closed. Moreover, ventilation of house FR 3 could have been enhanced by the chimneys located longitudinally along the center of the house. Consequently, house FR 3 had the best air quality among all the FR houses in winter.

**Summer.** The 24-h mean, maximum, and minimum values of each variable in summer are summarized in Table 5 and depicted in Figure 4. Maximum NH<sub>3</sub> concentrations were within the recommended level (25 ppm) for all houses, with the exception of house FR 3 (42 ppm) and

**Table 4.** Winter conditions: 24-h mean, maximum, and minimum values for each laying-hen house and resulting overall mean and SE for each type of housing system<sup>1</sup>

24-h value <sup>2</sup>	Floor-raised						Manure-belt						High-rise						
	FR 1	FR 2	FR 3	FR 4	Mean	SE	MB 1	MB 2	MB 3	MB 4	Mean	SE	HR 1	HR 2	HR 3	HR 4	Mean	SE	
<b>NH<sub>3</sub>, ppm</b>																			
Mean	59	57	20	50	46 <sup>a</sup>	9	6	8	7	6	7 <sup>b</sup>	0	8	10	20	17	14 <sup>b</sup>	3	
Max	85	86	30	89	72	14	9	10	10	9	9	0	11	14	26	24	18	4	
Min	45	46	3	20	28	10	4	6	6	5	5	0	7	9	16	8	10	2	
<b>CO<sub>2</sub>, ppm</b>																			
Mean	2,150	2,376	1,451	2,108	2,021 <sup>c</sup>	199	3,122	2,987	3,037	3,142	3,072 <sup>a</sup>	36	2,455	2,260	2,691	2,326	2,433 <sup>b</sup>	95	
Max	2,713	3,159	2,161	4,261	3,073	445	3,986	3,434	3,469	3,885	3,694	141	2,643	2,678	2,953	2,643	2,729	75	
Min	1,369	2,091	884	919	1,316	281	2,507	2,472	2,713	2,643	2,583	57	2,091	2,056	2,437	2,056	2,160	93	
<b>T, °C</b>																			
Mean	16.8	18.6	11.4	15.3	15.5 <sup>c</sup>	1.5	27.1	25.1	23.8	22.6	24.6 <sup>a</sup>	1.0	22.8	18.8	20.2	20.6	20.6 <sup>b</sup>	0.8	
Max	17.8	19.5	14.9	20.7	18.2	1.3	28.3	26.5	25.3	23.8	26.0	1.0	24.7	19.3	21.1	21.3	21.6	1.1	
Min	14.8	17.5	8.2	9.4	12.5	2.2	24.9	23.1	22.3	21.7	23.0	0.7	20.4	18.3	18.8	19.8	19.3	0.5	
<b>RH, %</b>																			
Mean	69	64	66	62	65 <sup>a</sup>	1	36	37	47	41	40 <sup>c</sup>	2	41	51	56	50	50 <sup>b</sup>	3	
Max	72	79	72	69	73	2	44	41	54	46	46	3	45	56	62	64	57	4	
Min	63	59	59	55	59	2	29	33	40	37	34	2	37	49	52	42	45	3	
<b>Ambient T, °C</b>																			
Mean	11.9	13.4	8.0	11.6	11.2	1.1					2.2							-0.1	
Max	14.6	16.5	10.7	14.8	14.1	1.2					21.3							1.4	
Min	10.2	12.3	6.1	7.1	8.9	1.4					-4.7							-1.2	
<b>Ambient RH, %</b>																			
Mean	71	69	70	67	69	1					92							89	
Max	76	83	76	71	77	2					100							93	
Min	60	64	60	59	61	1					51							82	
T rise above ambient, °C	4.8	5.2	3.4	3.7	4.3 <sup>b</sup>	0.4	24.9	22.9	21.6	20.4	22.5 <sup>a</sup>	1.0	22.9	18.8	20.2	20.6	20.6 <sup>a</sup>	0.8	

<sup>a-c</sup>Indicates difference in means across rows (comparison between FR, MB and HR for each variable),  $P < 0.05$ .

<sup>1</sup>FR 1 to FR 4 refer to floor-raised houses 1 to 4; MB 1 to MB 4 refer to manure-belt houses 1 to 4; and HR 1 to HR 4 refer to high-rise houses 1 to 4.

<sup>2</sup>T = temperature.

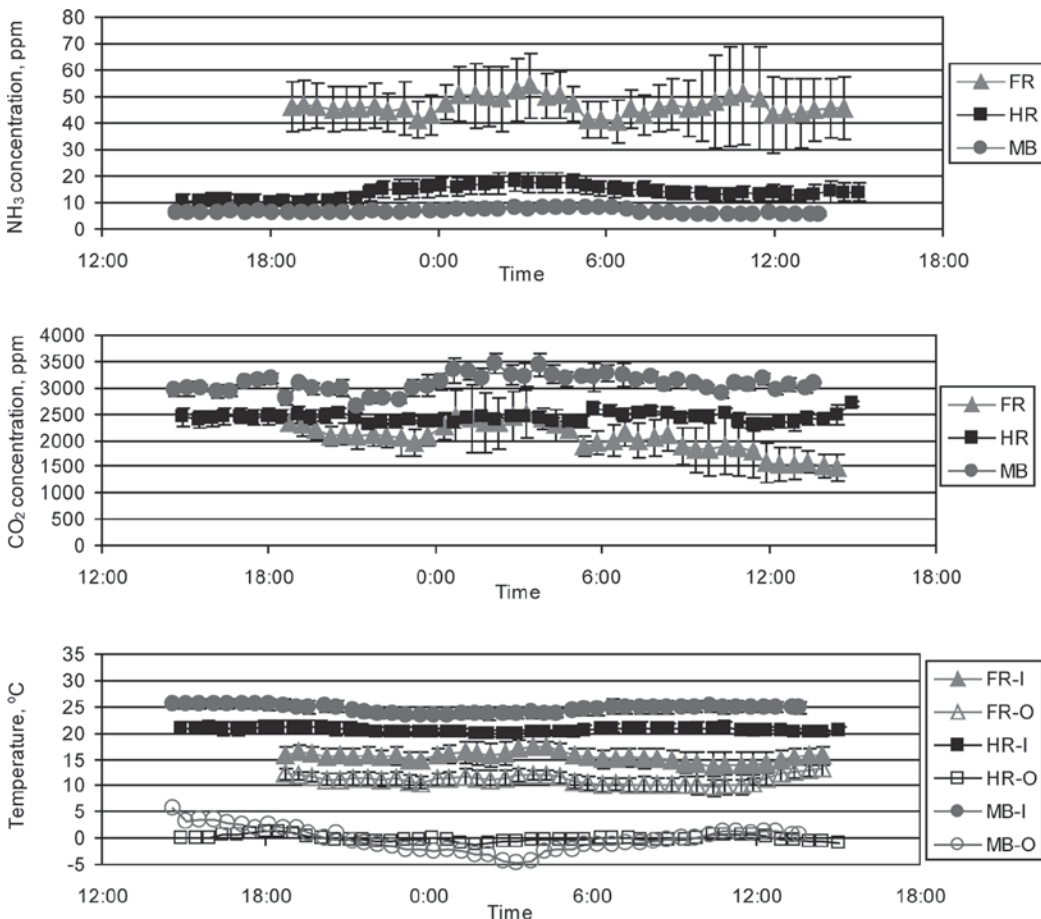
house FR 4 (29 ppm). All daily mean NH<sub>3</sub> levels were below 25 ppm. Temperatures in the FR houses showed fewer increases above ambient than those in the HR or MB houses (0.3°C or 1% rise for FR, 1.2°C or 4% rise for HR, and 4.7°C or 18% rise for MB). The THI also showed less increase above ambient for the FR vs. HR or MB houses, and the HR houses had the greatest THI increase above ambient. The outcome resulted from the reduced bird density in the FR houses.

Orientation of the naturally ventilated houses is critical in summer months, when wind provides the main ventilation. In Iowa, the predominant summer wind is from south or southeast; hence, an east-west orientation would be more conducive to natural ventilation. House FR 3 was oriented north-south and encountered the poorest air quality among the FR houses monitored during the summer monitoring period.

The tunnel ventilation used in the MB houses in this case needs to be configured properly; namely, the eave inlet dampers must be properly adjusted to achieve a relatively uniform air distribution along the length of the building. Some dead spots were noted in the MB houses during the summer, leading to less desirable air quality at these locations. The dead spots were most obvious in areas with higher mortalities, although spatial mortality was not quantified for comparison. Nevertheless, temperature distribution along our cross-section seemed to be more uniform in the MB houses than in the HR houses, particularly during summer.

**Temperature Gradient Between Cages and Aisles**

Figures 5 and 6 display the differences in air temperature between the aisle and the cage interior. Air temperature tended to be higher near the cage interior (an empty cage between occupied



**Figure 3.** Winter conditions (mean ± SE) of NH<sub>3</sub>, CO<sub>2</sub>, and temperature (I = inside, O = outside) in the floor-raised (FR), high-rise (HR), and manure-belt (MB) laying hen houses monitored.

**Table 5.** Summer conditions: 24 h mean, maximum, and minimum values for each house and resulting overall mean and SE for each type of housing system<sup>1</sup>

24-h value <sup>2</sup>	Floor-raised						Manure-belt					High-rise					
	FR 1	FR 2	FR 3	FR 4	Mean	SE	MB 3	MB 4	MB 5	Mean	SE	HR 2	HR 3	HR 4	HR 5	Mean	SE
NH <sub>3</sub> , ppm																	
Mean	3	3	14	15	9	3	2	8	5	5	2	3	2	3	4	3	1
Max	6	6	42	29	21	9	4	14	7	8	3	5	3	7	8	6	1
Min	0	1	3	5	2	1	0	3	3	2	1	3	0	2	3	2	1
CO <sub>2</sub> , ppm																	
Mean	451	406	631	641	532 <sup>b</sup>	61	853	1,043	1,140	1,012 <sup>a</sup>	73	541	442	475	621	520 <sup>b</sup>	40
Max	643	578	1,059	1,059	835	130	1059	1,264	1,435	1,253	94	678	608	643	884	703	62
Min	368	333	368	438	376	22	643	884	884	804	70	473	368	403	508	438	32
T, °C																	
Mean	24.0	25.1	25.2	25.5	25.0 <sup>c</sup>	0.3	30.0	31.0	30.3	30.4 <sup>a</sup>	0.3	30.1	28.8	28.3	28.7	28.9 <sup>b</sup>	0.4
Max	28.5	30.3	30.1	30.0	29.7	0.4	32.1	32.8	32.1	32.3	0.2	33.8	33.3	34.9	33.4	33.9	0.4
Min	21.3	22.4	21.9	22.8	22.1	0.3	27.4	28.4	28.0	27.9	0.3	25.9	24.1	24.3	23.9	24.6	0.5
RH, %																	
Mean	66	61	62	62	63 <sup>b</sup>	1	73	71	71	72 <sup>a</sup>	1	46	47	53	52	50 <sup>c</sup>	2
Max	76	70	70	70	71	2	78	78	77	78	0	54	57	63	63	59	2
Min	50	42	46	46	46	2	66	64	65	65	1	35	37	37	39	37	1
THI, °C																	
Mean	18	18	19	19	19 <sup>b</sup>	0	25	26	25	26 <sup>a</sup>	0	20	19	20	20	19 <sup>b</sup>	0
Max	20	20	22	23	21	1	28	29	28	28	0	23	22	23	22	22	0
Min	17	17	17	18	17	0	23	24	23	23	0	18	17	18	18	18	0
Ambient T, °C																	
Mean	24.0	25.0	24.8	24.7	24.6	0.2				25.7							27.7
Max	30.0	32.3	29.8	30.2	30.6	0.6				32.3							33.4
Min	20.8	21.8	21.9	22.0	21.6	0.3				21.3							21.5
Ambient RH, %																	
Mean	66	60	67	65	64	2				94							48
Max	77	71	76	73	74	1				100							64
Min	46	37	48	45	44	2				62							31

*Continued*

**Table 5 (Continued).** Summer conditions: 24 h mean, maximum, and minimum values for each house and resulting overall mean and SE for each type of housing system<sup>1</sup>

24-h value <sup>2</sup>	Floor-raised						Manure-belt					High-rise					
	FR 1	FR 2	FR 3	FR 4	Mean	SE	MB 3	MB 4	MB 5	Mean	SE	HR 2	HR 3	HR 4	HR 5	Mean	SE
Ambient THI, °C																	
Mean	18	18	19	19	19	0				25						18	
Max	20	20	22	23	21	1				27						21	
Min	17	17	18	18	17	0				22						16	
T rise above ambient, °C	0.0	0.1	0.4	0.8	0.3 <sup>c</sup>	0.2	4.3	5.3	4.6	4.7 <sup>a</sup>	0.3	2.4	1.1	0.6	1.0	1.2 <sup>b</sup>	0.4

<sup>a-c</sup>Indicates a difference in means across rows (comparisons between FR, MB, and HR for each variable),  $P < 0.05$ .

<sup>1</sup>FR 1 to FR 4 refer to floor-raised houses 1 to 4; MB 3 to MB 5 refer to manure-belt houses 3 to 5; and HR 2 to HR 5 refer to high-rise houses 2 to 5.

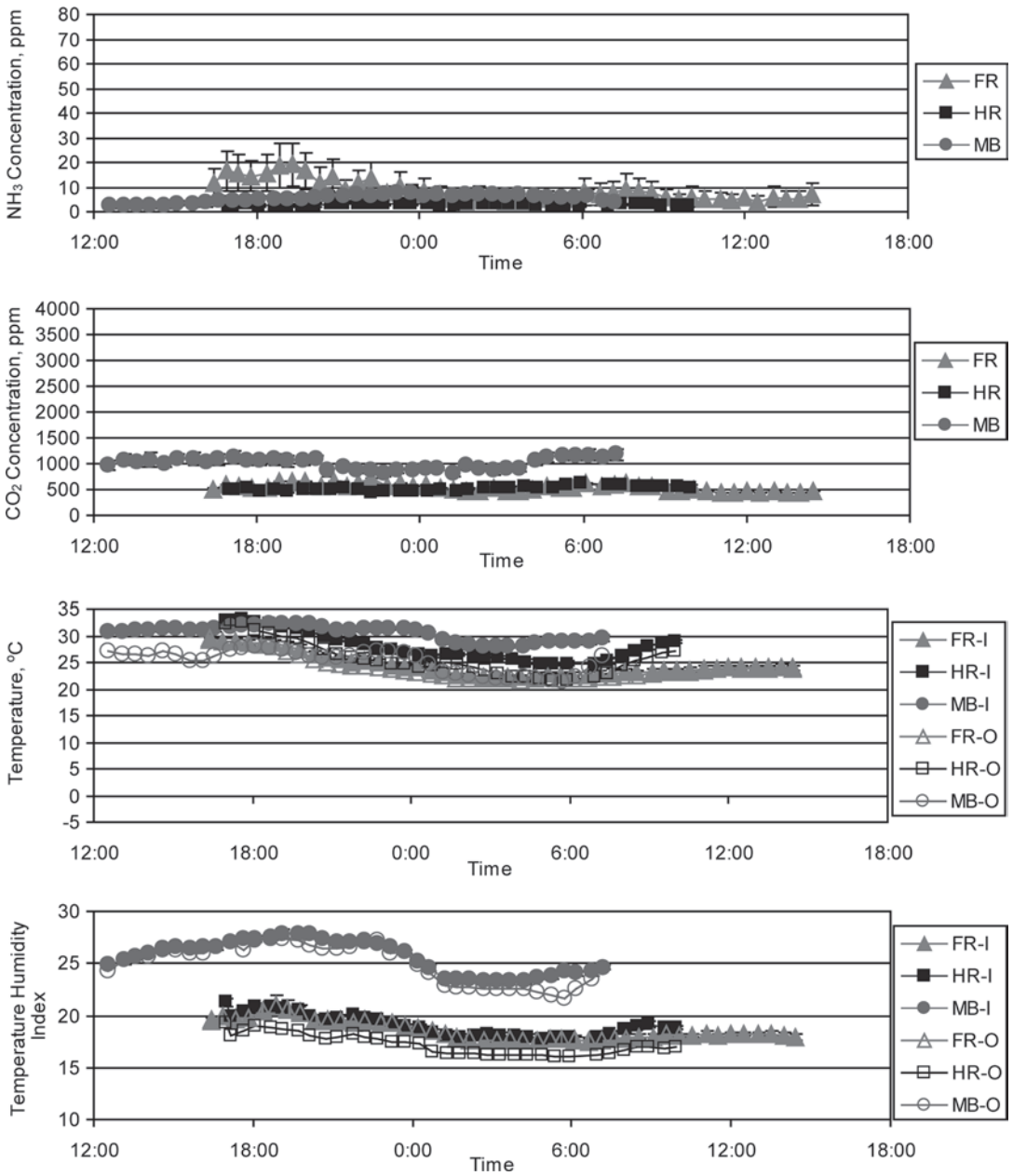
<sup>2</sup>T = temperature, °C; RH = relative humidity; THI = temperature-humidity index.

**Table 6.** *Mycoplasma synoviae* (MS) and *Mycoplasma gallisepticum* (MG) serology results [percentage of birds (n = 10) testing positive] from laying hens in 3 different housing systems<sup>1</sup>

Season	Positive, %	Floor-raised				Manure-belt					High-rise				
		FR 1	FR 2	FR 3	FR 4	MB 1	MB 2	MB 3	MB 4	MB 5	HR 1	HR 2	HR 3	HR 4	HR 5
Winter	MS	0	0	100	100	100	100	100	100	DNM <sup>2</sup>	100	100	100	100	DNM
	MG	100	0	0	0	0	100	0	0	DNM	100	100	100	100	DNM
Summer	MS	0	0	100	0	DNM	DNM	100	100	100	DNM	20	100	100	80
	MG	0	0	0	0	DNM	DNM	0	0	0	DNM	100	100	100	100

<sup>1</sup>FR 1 to FR 4 refer to floor-raised houses 1 to 4; MB 1 to MB 5 refer to manure-belt houses 1 to 5; and HR 1 to HR 5 refer to high-rise houses 1 to 5.

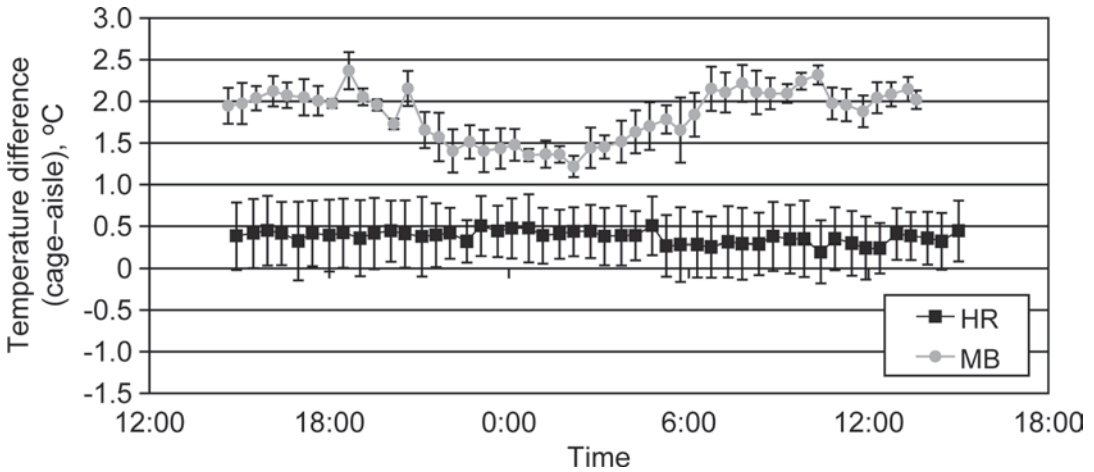
<sup>2</sup>DNM = did not monitor



**Figure 4.** Summer conditions (mean  $\pm$  SE) of NH<sub>3</sub>, CO<sub>2</sub>, temperature, and temperature-humidity index (THI; I = inside, O = outside) in the floor-raised (FR), high-rise (HR), and manure-belt (MB) laying hen houses monitored.  $THI = 0.6 \times T_{db} + 0.4 \times T_{wb}$ , where  $T_{db}$  is dry-bulb temperature and  $T_{wb}$  is wet-bulb temperature.

cages) than in the aisle during both winter and summer, especially for the MB houses. This was expected because the microenvironment in the birdcages contains more bird body heat, which takes air exchange or convection to be dissipated. As expected, the gradients were also more apparent in winter than in summer because of lower ventilation rate or convection in winter.

The magnitude of the differences tended to be smaller in the HR houses than in the MB houses, even though the differences fluctuated more during summer in the HR houses. This outcome suggests that it would be prudent to monitor the cage interior temperature periodically, and adjust the temperature set point, when necessary, to reflect the microenvironment that the birds



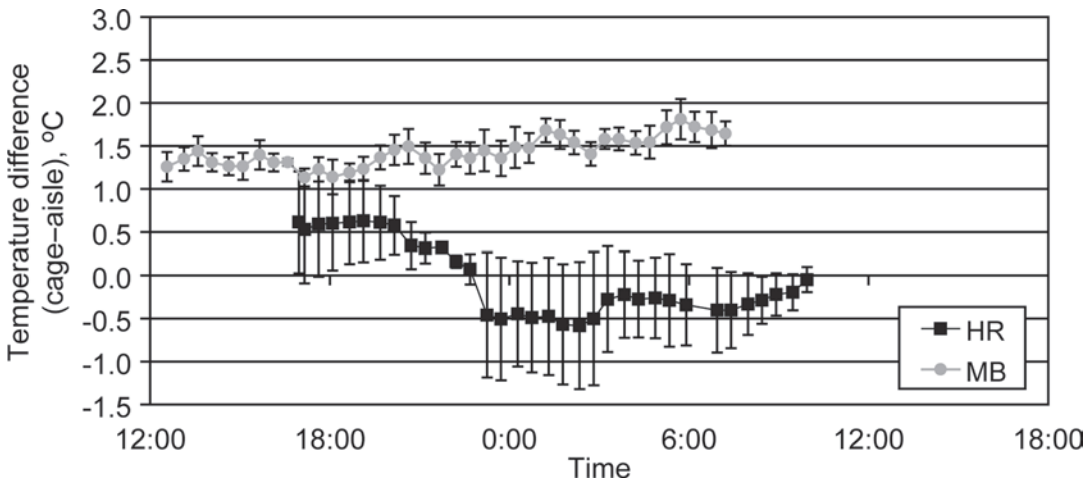
**Figure 5.** Winter conditions indicating the mean temperature difference between the cage interior and aisle for the high-rise (HR) and manure-belt (MB) laying hen houses monitored.

are experiencing. Alternatively, it is recommended that consideration be given to locating the thermostat temperature sensors closer to the bird microenvironment, that is, in empty cages surrounded by occupied cages, as used in the monitoring study.

**Hen Health Status**

**Tracheal Analysis.** Antibodies against MS, MG, or both were detected in sera from all hens except from house FR 2 (winter) and houses FR 1, FR 2, and FR 4 (summer; Table 6). The presence of antibodies against MS or MG indicates that flocks were infected with these pathogens. *Mycoplasma* spp. typically result in damage to

cilia on the mucosal surface of the trachea and in increased susceptibility of infected chickens to inhaled dust-borne pathogens. The immune response of hens to the presence of avian *Mycoplasma* colonizing the respiratory epithelium of the trachea is manifested by the accumulation of lymphocytes within the underlying lamina propria. Microscopic examination of hen tracheas revealed abnormally high numbers of lymphocytes within the lamina propria layer of the tracheal wall in birds from all houses except from house FR 2. Hens in house FR 2 were not infected by MG or MS, did not mount an immune response, and consequently did not have significant numbers of lymphocytes in the tra-



**Figure 6.** Summer conditions indicating the mean temperature difference between the cage interior and aisle for the high-rise (HR) and manure-belt (MB) laying hen houses monitored.

cheal wall. Because most hens in this study were infected with *Mycoplasma*, microscopic changes observed in the tracheas could not be distinguished from changes that might have resulted from exposure to NH<sub>3</sub> or particulate matter in the air. Intact cilia were present on the respiratory surface of all birds from all houses, and no eye lesions were observed.

**Intestinal Homogenates.** *Campylobacter* and *Salmonella* were detected in winter and summer (Table 7). For winter conditions (Table 7), *Campylobacter* spp. prevalence was higher in birds in FR houses than in caged birds overall (80 vs. 49.4%,  $P < 0.05$ ) as well as between birds in FR and HR houses (80.0 vs. 38.5%,  $P < 0.05$ ), but there was no difference in overall *Campylobacter* spp. prevalence between hens in FR (80.0%) and MB houses (60.0%). The prevalence of *C. coli* was higher in hens in FR than in HR or MB houses (55.0 vs. 25.6 or 25.0%, respectively,  $P < 0.05$ ). No differences were detected when either *C. jejuni* or *Salmonella* prevalence values were correlated with housing systems. Prevalence numbers were too low to perform  $\chi^2$  tests for birds dually infected with *C. jejuni* and *C. coli*. For summer conditions (Table 7), results from bacteriological isolation of *Campylobacter* showed lower prevalence of *Campylobacter* spp. and *C. jejuni* for hens in FR

and HR houses than for hens in MB houses (27.5 and 20.0 vs. 65.0%; and 7.5 and 20.0 vs. 52.5%, respectively,  $P < 0.01$ ). When winter and summer databases for bacteriological isolation were compared, the prevalence of *Campylobacter* spp. in birds in the FR house was higher in winter than in summer (80.0 vs. 27.5%,  $P < 0.05$ ).

Monitoring for bacterial foodborne pathogens showed seasonal differences between the housing systems. The most plausible factor contributing to the higher prevalence of *C. coli* in winter for birds in the FR house may be the more direct contact with manure, which would facilitate fecal-oral transmission of enteric pathogens. Interestingly, during the summer monitoring, the prevalence of *Campylobacter* spp. and *C. jejuni* was significantly lower in birds from the FR and HR houses when compared with hens from the MB houses ( $P < 0.01$ ).

**Observational Nature of This Study**

Results from this study should be regarded as observational. Because the monitoring was conducted at a system level, the results could not be interpreted specifically to discern the source(s) of differences. Although statistics were calculated for comparison, conclusions based on these results should be considered carefully because selection of the houses for monitoring was based

**Table 7.** Prevalence (number of birds and percentage of birds testing positive) of *Campylobacter*, *Campylobacter coli*, *Campylobacter jejuni*, and *Salmonella* by the bacteriological isolation technique

Season	Bacterial pathogen	Noncaged floor-raised (n = 40)	Caged		
			Manure-belt (n = 40)	High-rise (n = 39)	Total (n = 79)
Winter	<i>Campylobacter</i>	32 (80.0%) <sup>a,A</sup>	24 (60.0%) <sup>a</sup>	15 (38.5%) <sup>b</sup>	39 (49.4%) <sup>B</sup>
	<i>C. jejuni</i>	7 (17.5%)	9 (22.5%)	4 (10.3%)	13 (16.5%)
	<i>C. coli</i>	22 (55.0%) <sup>a,A</sup>	10 (25.0%) <sup>b</sup>	10 (25.6%) <sup>b</sup>	20 (25.3%) <sup>B</sup>
	<i>C. jejuni/C. coli</i>	3 (7.5%)	5 (12.5%)	1 (2.6%)	6 (7.6%)
	<i>Salmonella</i>	0 (0.0%)	2 (5.0%)	2 (5.1%)	4 (5.1%)
Summer	Bacterial pathogen	Noncaged floor-raised (n = 40)	Caged		
			Manure-belt (n = 40)	High-rise (n = 30)	Total (n = 70)
Summer	<i>Campylobacter</i>	11 (27.5%) <sup>b</sup>	26 (65%) <sup>a</sup>	6 (20%) <sup>b</sup>	32 (45.7%)
	<i>C. jejuni</i>	3 (7.5%) <sup>b</sup>	21 (52.5%) <sup>a</sup>	6 (20%) <sup>b</sup>	27 (38.6%)
	<i>C. coli</i>	7 (17.5%)	0 (0.0%)	0 (0%)	0 (0.0%)
	<i>C. jejuni/C. coli</i>	1 (2.5%)	5 (12.5%)	0 (0%)	6 (8.6%)
	<i>Salmonella</i>	3 (7.5%)	1 (2.5%)	2 (6.7%)	3 (4.3%)

<sup>a,b</sup>Indicates a difference in means calculated for percentages across rows (comparisons between floor-raised, manure-belt, and high-rise for each variable),  $P < 0.05$ , calculated using percentage of birds testing positive.

<sup>A,B</sup>Indicates a difference in means calculated for percentages across rows (comparisons between floor-raised and caged total for each variable),  $P < 0.05$ , calculated using percentage of birds testing positive.

on the ability to access the facilities, as opposed to stringent statistical randomization and replication. It also should be acknowledged that data from 24-h environmental monitoring would likely be insufficient to yield concrete conclusions about different housing types. Nevertheless, data from the study provide good first-step, quantitative information about the environmental characteristics of different housing systems. For instance, the results demonstrated seasonal differences among housing systems for the prevalence of bacterial foodborne pathogens, but the results did not conclusively show that one system yielded lower pathogen frequencies than another, as has been reported in the Netherlands [1]. Further studies should include multiple representations of each housing type, different management schemes, and different housing configurations to better delineate the cause-effect relationships, preferably houses located and managed on the same premises. Future studies should also consider collecting environmental, physiological, and production data over an extended period of time (e.g., 1 yr).

## CONCLUSIONS AND APPLICATIONS

1. Differences in environmental conditions and pathogen frequency were observed among all 3 housing types during summer and winter conditions. During winter,  $\text{NH}_3$  levels were much higher in the FR houses ( $46 \pm 9$  ppm) than in the HR ( $14 \pm 3$  ppm) or MB ( $7 \pm 0$  ppm) houses. Air temperature in the FR houses also fluctuated more, following the outside temperature. Some of the air quality issues observed may be improved with management (periodic addition of fresh bedding), ventilation adjustments (e.g., use of minimum ventilation fan in cold weather), or both.
2. Pathogen prevalence varied within housing system for winter and summer. Producers should be aware and take proactive management measures during the seasons with higher prevalence for their respective housing type.
3. Assessment of each housing system as a whole made it unrealistic to discern the specific sources of benefits or limitations associated with each system. Neverthe-

less, results from 2 of the FR houses (FR 1 and FR 2) suggest that management likely plays a greater role in environmental conditions than housing type or ventilation type.

4. Differences observed in the air quality and the seasonal pathogen frequency merit further research to quantify and identify sources and mechanisms of these differences.
5. To better represent and control the bird-level microenvironment, it may be prudent to monitor the cage interior temperature periodically and adjust the temperature set point accordingly. Alternatively, one can consider locating the thermostat temperature sensors near the bird microenvironment, for example, by placing sensors in empty cages next to occupied cages.

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