Comparative evaluation of three egg production systems: *Housing characteristics and management practices*

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ABSTRACT This paper is an integral part of the special publication series that arose from the multidisciplinary and multi-institutional project of the Coalition for Sustainable Egg Supply (**CSES**). The CSES project involves 3 housing systems for egg production at the same research farm site in the Midwest, USA, namely, a conventional cage (**CC**) house, an aviary (**AV**) house, and an enriched colony (**EC**) house. The CC house (141.4 m L × 26.6 m W × 6.1 m H) had a nominal capacity of 200,000 hens (6 hens in a cage at a stocking density of 516 cm^2/hen), and the cages were arranged in 10 rows, 8 tiers per cage row, with a perforated aisle walkway at 4-tier height. The AV house (154.2 m L × 21.3 m W × 3.0 m H) and the EC house (154.2 m L × 13.7 m W × 4.0 m H) each had a nominal capacity of 50,000 hens. The AV house had 6 rows of aviary colonies, and the EC house had 5 rows of 4-tier enriched colonies containing perches, nestbox, and scratch pads (60 hens per colony at a stocking density of 752 cm^2/hen). The overarching goal of the CSES project, as stated in the opening article of this series, was to comprehensively evaluate the 3 egg production systems from the standpoints of animal behavior and well-being, environmental impact, egg safety and quality, food affordability, and worker health. So that all the area-specific papers would not have to repeat a detailed description of the production systems and the management practices, this paper is written to provide such a description and to be used as a common reference for the companion papers.

Key words: conventional cage, aviary, enriched colony, egg production, hen house

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INTRODUCTION

The majority (approximately 95%) of laying-hen houses in the United States use conventional cage **(CC)** systems. However, concerns have been increasing about CC systems in connection with animal welfare. Some states have passed regulations that require significant increases in hens' space allocations (e.g., California Proposition 2) or phasing out CC systems (e.g., Michigan) and transitioning to alternative housing systems that feature a larger living space and amenities (perch, nestbox, scratching pad, and litter floor) to better accommodate hens' natural behaviors. In the process of developing such regulations and assessing the potential impacts of such changes on the entire egg supply chain (egg industry and general public alike), it became clear that research-based information concerning the viability of such systems under U.S. production conditions was severely lacking. Accommodating animals' natural behaviors is only one part of the overall objectives of any production system; other elements, such as environmental impact, food affordability, food safety/security, and indoor living/working conditions for the animals and their caretakers, are equally important and must be considered as well. It was on the basis of this need for research information that a multidisciplinary and multi-institutional public–private partnership was formed to carry out the Coalition for Sustainable Egg Supply **(CSES)** project.

The background, objectives, and implementation of the **CSES** project are described in the opening paper (Swanson et al., 2014) of this special publication series. In short, the CSES project represents collaborations among egg producers, land-grant universities, government agencies, food-supply companies, and allied industries. The overarching goal of the project was to comprehensively evaluate 3 hen housing systems [CC, aviary (**AV**), and enriched colony (**EC**)] for egg production, with regard to animal behavior and well-being, environmental impact, egg safety and quality,

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food affordability, and worker health. Each research area within the CSES project focused on specific aspects and impacts of the housing systems. Collaborative efforts among research areas were coordinated to develop, complement, and enhance the holistic research goal of the project.

The objective of this paper is to describe the hen housing systems, the manure storage facility, and farm management practices. It will serve as the primary reference on housing systems for the area-specific papers in the special publication series of the CSES project, including animal behaviors and welfare (R.A. Blatchford, unpublished data, 2015; D.L.M. Campbell, unpublished data, 2015), egg quality and safety (Jones et al., 2014), economic implications (Matthews and Sumner, 2014), environmental impact (Shepherd et al., 2014; Zhao et al., 2014), flock performance and health (Karcher et al., 2014; P. Regmi, unpublished data, 2015; Regmi et al., 2014), and worker health and safety.

HEN HOUSING SYSTEMS

General Information

The 3-year CSES project covered 2 single-cycle production flocks (17 or 19 to 78 weeks, no molt). All 3 houses monitored in the study were located at the same commercial egg production farm in the Midwest, USA (Figure 1). The CC house was an existing one with a 200,000-hen capacity that was built in 2005. It was cleaned with high-pressure air and disinfectants before the hens were placed for the CSES project and during the downtime between the 2 flocks. The AV and EC houses, each with 50,000-hen capacity, were designed and built on the same farm specifically for the comparative CSES study.

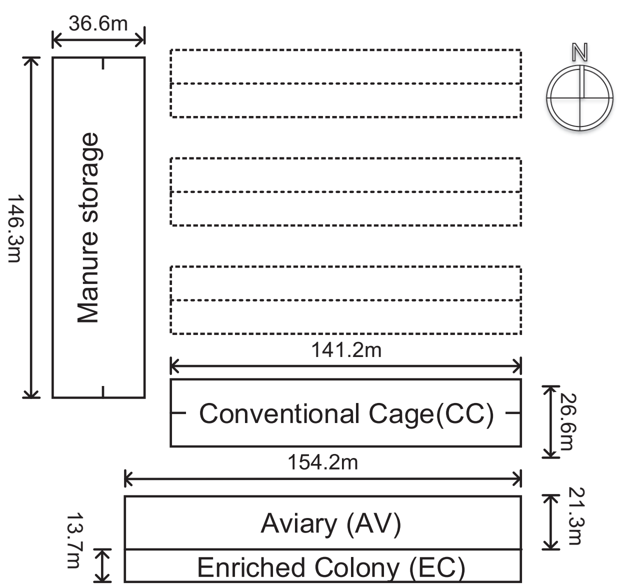


Figure 1. Schematic layout of the farm showing the siting of 3 experimental laying-hen houses and the manure storage facility (solid lines) and 3 other conventional houses (dashed lines) that shared the same manure storage facility with the experimental houses.

Lohmann LSL white hens of the same age were used for both flocks and in all 3 housing systems. Pullets placed in the CC and EC houses were reared in CC pullet facilities, while pullets placed in the AV house were reared in an AV-style pullet housing system (NATURA Rearing System Type 1600a, Big Dutchman Inc., Holland, MI, USA[1]) to ensure proper transition and adaptation to the aviary laying environment. Flock 1 pullets were placed in the respective research houses at 19 weeks of age (16 to 24 April 2011) and were depopulated at 78 weeks of age (2 to 7 June 2012). Flock 2 pullets were placed in the research houses at 17 weeks of age (25 to 29 June 2012) and depopulated at 78 weeks of age (26 to 29 August 2013). All hens were beak trimmed at the same hatchery at 1 d of age using infrared trimming technique.

The lighting period in all 3 housing systems for each flock was gradually increased from a 12-h light and 12-h dark schedule at placement to a 16-h light and 8-h dark schedule over a 12-week period, following the commercial management guidelines. Under 16L:8D, lighting in the CC and EC houses came on at 05:30 and went off at 21:30, with an average light intensity of 10 lux measured at the feeder (minimum of 5 lux across all feeders). The AV house incorporated a 15-min dim light period (0 to 10 lux) in the morning (05:30 to 05:45) before the main lights came on, and again in the evening (19:45 to 21:30), to simulate the dawn/dusk period and to encourage hens' return to the colonies in the evening.

Feed was provided twice per day in the CC and EC houses, with the first feeding immediately after the lights came on and the second feeding at 13:00. The feeding schedule in the AV house was adjusted throughout the flock to maintain the target hen body weight, with 3 to 5 feedings a day. Commercial feed was independently formulated for each housing system based on egg production level, feed consumption, and ingredient costs. More detailed information on the diet compositions can be found in one of the papers (Karcher et al., 2014) in this series. Manure on belts was removed from the house twice a week, weighed with a certified onsite grain scale, and placed in the respective on-farm storage facility. This twice-a-week manure removal did not include the litter (mixture of manure and wood shavings) on the floor in the AV house. A portion of the litter accumulated on the floor of the AV house was removed during flock 1 (30 August 2011 and 9 February 2012), with the remainder removed at the end of the flock. Litter on the floor of the AV house was not removed until the end of the production cycle in flock 2. All removed manure or litter was weighed with a certified grain scale and placed in the manure storage facility. Drinking water was provided *ad libitum* in all houses.

To acclimate the hens to the colonies and establish the desired laying habits, hens in the AV house were

[1]Mention of company or product names is for presentation clarity and does not represent endorsement by the authors or their affiliations; nor does it imply exclusion of other suitable products.

Table 1. Summary of housing characteristics and management for conventional cage (CC) house, aviary (AV) house, and enriched colony (EC) house.

	Housing System		
Items	CC	AV	EC
Interior house dimension (L×W×H) (m)	141.4 × 26.6 × 6.1	154.2 × 21.3 × 3.0	154.2 × 13.7 × 4.0
House age at start of experiment (years)	6	0	0
Insulation (K m^2/W)			
Roof	0.3	0.3	0.3
Ceiling	5.3	4.8	5.8
Wall	2.7	2.7	2.7
Partition wall (between AV and EC houses)	–	2.7	2.7
Ventilation type	Tunnel	Cross	Cross
Air inlet	Ceiling slot inlet	Ceiling/perimeter slot inlets	Ceiling/perimeter slot inlets
Ventilation fans			
Diameter (m)	1.32 (52 in.)	Four 0.91 (36 in.) fans + fourteen 1.32 (52 in.) fans	Four 0.91 (36 in.) fans + fourteen 1.32 (52 in.) fans
Motor (kW)	1.1 (1.5 HP)	0.75 (1.0 HP)	0.75 (1.0 HP)
Number	44	18	18
Manure handling	Manure belt	Manure belt + litter	Manure belt
Manure removal	Every 3 to 4 d	Belt: every 3 to 4 d Litter: end of flock	Every 3 to 4 d
Manure-drying equipment	Two 40-kW blowers and perforated air duct above manure belt	Three 5.5-kW blowers and perforated air duct above manure belt	Ten 3-kW blowers and perforated air duct above manure belt
Manure storage	Communal + designated storage	Communal + designated storage	Communal + designated storage
Supplemental heat	–	Three 73.5-kW heaters	–
Photoperiod (≥ 28 weeks)	16 L:8 D (05:30–21:30)	16 L:8 D (05:30–21:30)	16 L:8 D (05:30–21:30)
Feeding (times per day)	2	3 to 5	2
Hen breed	Lohmann LSL White	Lohmann LSL White	Lohmann LSL White
Number of hens placed at start	Flock 1: 193,440 Flock 2: 199,680	Flock 1: 49,842 Flock 2: 49,842	Flock 1: 46,800 Flock 2: 46,800
Welfare elements	–	Perch, nestbox, litter area	Perch, nestbox, scratch pad

kept in the colonies (i.e., with no access to the litter floor area) from placement (17 or 19 weeks of age) to 25 weeks of age. In flock 1, hens were then given unlimited access to the litter area from 25 to 61 weeks of age (i.e., colonies were not closed at night); however, because of the large number of floor eggs, hens' access to the litter floor was partially restricted from 62 to 78 weeks of age by closing the colony gates from 05:00 to 11:00. In flock 2, hens were kept in the colonies from 05:00 to 11:00 from 25 to 78 weeks of age, to reduce the incidence of floor eggs, but otherwise had access to the litter floor.

Air temperature for the control of the ventilation system in all 3 houses was set at 25.6°C from 46 weeks to the end of flock 1 and at 24.4°C from 32 weeks of age to the end of flock 2.

The farm staff performed daily routine tasks of checking the indoor temperature and status of equipment operation (e.g., water lines, feed lines, egg belts, lights, manure-drying blowers, ventilation fans), checking hen health and removing mortalities, partially cleaning the hen house (sweeping the dust and feathers off the floor), and recording performance data. Total daily egg production was recorded with a FANCOM IDM.16 module (Fancom BV, Panningen, The Netherlands) in each housing system. Within the AV house, eggs laid outside the nestbox were manually collected and counted daily. These eggs were partitioned into 2 categories – floor eggs (eggs laid on the litter floor) and system eggs (eggs laid within the colony structure but outside the nestbox). The case weight of the eggs (1 case = 360 eggs or 30 dozen) was measured 3 times a week. Daily feed use was recorded with a BINTRAC system (Herdstar, Mankato, MN, USA) (i.e., the change in feed bin weight measured with load-cell scales); and daily water use was measured with positive displacement flow meters (C700 B-Pulser, Elster AMCO Water, Ocala, FL, USA). The caretakers manually weighed 96 hens (16 cages of 6 hens per cage) in the CC house and 100 hens in the AV and EC houses each once a week.

A summary of housing characteristics and management practices of the 3 housing systems is presented in Table 1. The resource allowance for hens in each housing system is presented in Table 2. The following sections provide more details.

Conventional Cage (CC) House

The 2-level CC house had dimensions of 141.4 × 26.6 × 6.1 m (464 × 87 × 20 ft) (L × W × H) and an east–west orientation, with a perforated aisle walkway (also referred to as a catwalk deck by the producer) at a height of 2.7 m separating the upper and lower levels. Figure 2 shows the schematic layout and cross-sectional views of the CC house. The house had 10 cage rows along the length, each with 8 tiers (4 in the upper level and 4 in the lower level). Each tier contained 416 identical back-to-back cages (0.61 m wide × 0.51 m deep × 0.43 m high at the front and 0.37 m high at the back, or 24 in. wide × 20 in. deep × 17 in. high at the front and 14.5 in. high at the

Table 2. Resource allowances for hens in conventional cage (CC) house, aviary (AV) house, and enriched colony (EC) house.

Parameter	Housing System		
	CC	AV*	EC
Hens per cage or colony unit (CU)	6 (per cage)	142 (per CU)	60 (per CU)
Total available space (cm^2/hen)	516	1,257[1]/1,253[2]	752
Wire mesh flooring (cm^2/hen)	516	547	640
Solid surface flooring (cm^2/hen)	–	104	–
Forage area (cm^2/hen)	–	520[1]/516[2] (litter floor)	50 (scratch pad)
Nest space (cm^2/hen)	–	86	62
Perch space (cm/hen)	–	11.8 (in-colony), 1.7 (litter floor)	15.1
Feeder space (cm/hen)	10.2	10.2	12.1
Nipple drinker (hens per drinker)	6	8.9	7.5

*The AV house had 6 colony rows and each row had 58.5 colony units (CU's). The house was partitioned into 10 pens along the length of the house with wire mesh, and each pen had 5–6 CU's per single outer row and 10–12 CU's per double inner rows.

[1]Hen number or space for inner rows; [2]hen number or space for outer rows.

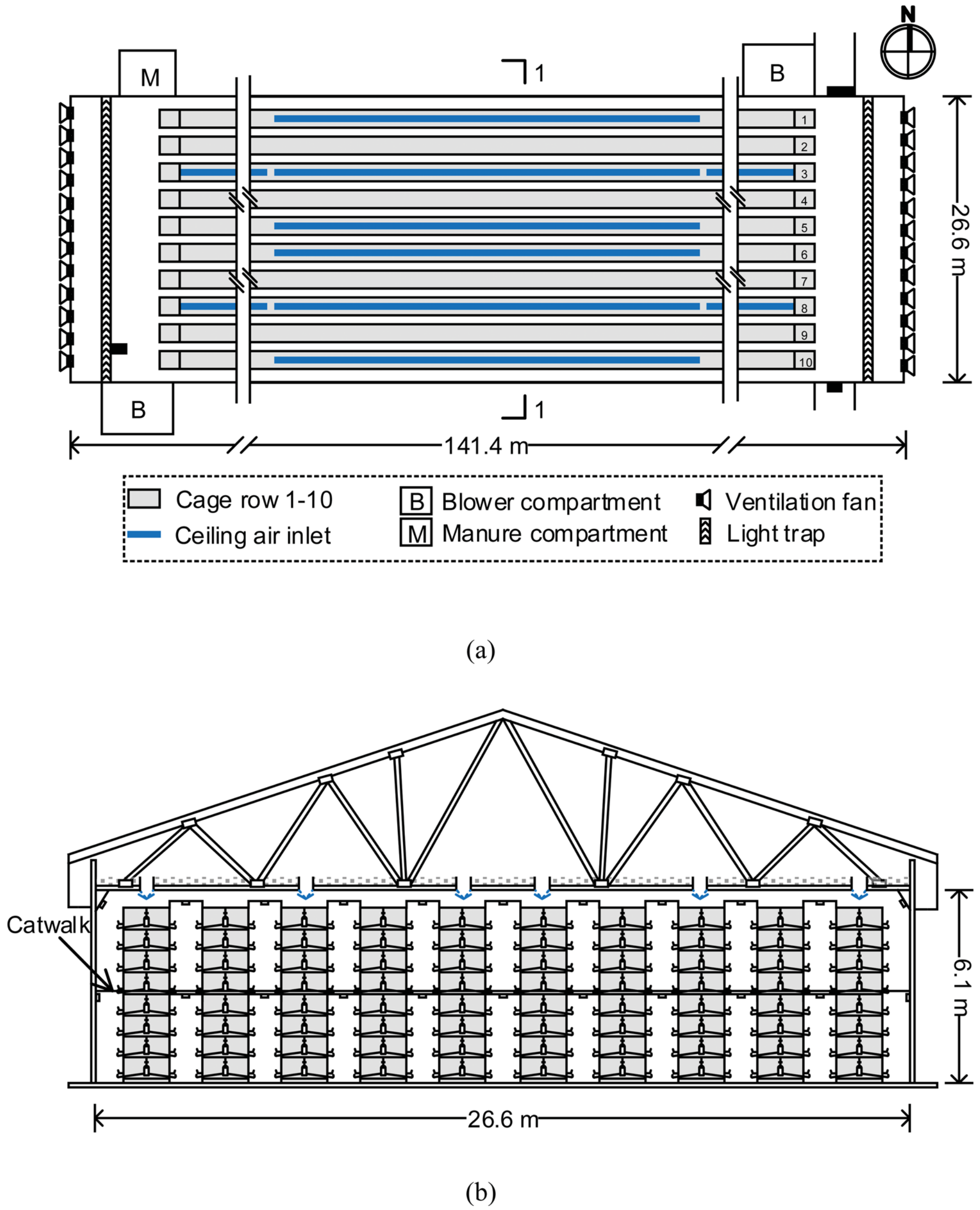


Figure 2. Schematic layout (a) and 1-1 cross-sectional (b) views of conventional cage housing system.

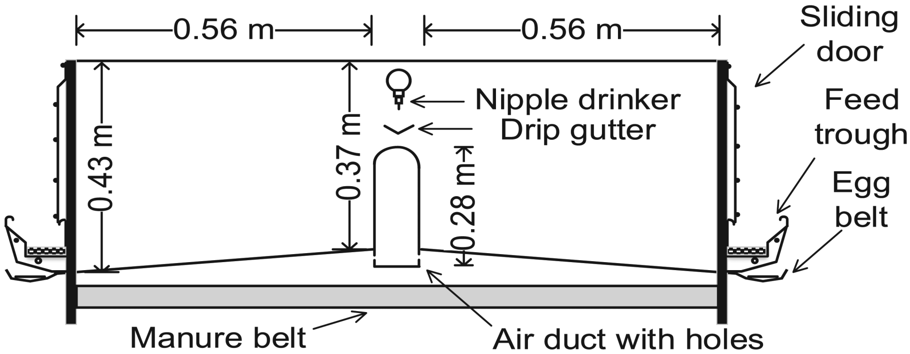


Figure 3. Cross-sectional view of back-to-back cages in conventional cage housing system.

back). Each cage housed 6 hens at an average stocking density of 516 cm^2/hen (80 $in.^2$/hen). Two nipple drinkers were installed between each pair of cages, i.e., shared by 12 hens. The actual number of hens kept in the CC house is provided in another paper (Karcher et al., 2014) of the series as well as in Table 1.

As shown in Table 1, the CC building envelope had an insulation value of 2.7 K m^2/W (R-value of 15) in the walls with 14-cm-thick fiberglass batting, 5.3 K m^2/W (R-value of 30) in the ceiling with 20-cm blown-in insulation, and 0.3 K m^2/W (R-value of 1.7) in the roof (18.4° slope) with 0.64-cm polyurethane foam board.

A manure belt placed under each tier of the entire length of the cages was used to remove the accumulated manure from the house every 3 to 4 d. The manure was continuously dried using recirculated room air provided by two 40-kW blowers housed in 2 compartments (7.0 × 5.9 × 6.1 m, or 23 × 19 × 20 ft) at the east and west ends of the house. The blowers recirculated the room air through 1.2-m-diameter pipes, which further distributed the air to the manure belts through perforated air ducts. The air ducts with an arch-shaped top were located above the manure belts and between the back-to-back cages (Figure 3). Small vent holes 4.8 mm in diameter spaced at 0.15 m on center (**O.C.**) were located near the bottom of the air duct (4 holes per cage), with a nominal airflow rate of 0.94 m^3/h/hen (0.55 CFM/hen).

Building ventilation was automatically controlled with a FANCOM F38 control system (Fancom BV, Panningen, The Netherlands). Air entered the attic space through eave inlets (along the entire length of the house), then into the hen house through continuous ceiling inlets above cage rows 1, 3, 5, 6, 8, and 10 (Figure 2). The ceiling inlets above cage rows 3 and 8 spanned the entire length of the cage rows (127 m), whereas those above the other rows had one-third of the row length (44 m) and were located in the middle section of each row. Openings of the inlets were automatically controlled according to the fan stage and building static pressure (**SP**) using the FANCOM system. Twenty-two ventilation fans were installed in the east end wall (10 fans aligned with the lower level and 12 fans with the upper level) and 22 fans in the west end wall (14 fans aligned with the lower level and 8 fans with the upper level). All fans were 1.32 m (52 in.) in diameter, single speed, and belt-driven (1.1 kW; 1.5 HP). The fans ventilated the house in 12 stages (Table 3).

Table 3. Number of fans at each ventilation stage and activating temperature in conventional cage (CC) house, aviary (AV) house, and enriched colony (EC) house.

	CC			AV and EC		
Stage	Relative to setpoint temp (°C)	Number of fans added	Fan diameter (m)	Relative to setpoint temp (°C)	Number of fans added	Fan diameter (m)
1[1]	<0.5	2 (continuous)	1.32	<−0.5	2[2] (intermittent)	0.91
2	>0.5	1	1.32	−0.5 to 0.5	0	0.91
3	>1.0	1	1.32	>0.5	2	0.91
4	>1.5	2	1.32	>1.0	1	1.32
5	>2.0	2	1.32	>1.5	1	1.32
6	>2.5	2	1.32	>2.0	1	1.32
7	>3.0	4	1.32	>2.5	1	1.32
8	>3.5	6	1.32	>3.0	2	1.32
9	>4.0	6	1.32	>3.5	2	1.32
10	>4.5	6	1.32	>4.0	2	1.32
11	>5.0	6	1.32	>4.5	2	1.32
12	>5.5	6	1.32	>5.0	2	1.32
Total		44			18	

[1]Stage 1 is the lowest fan stage (minimum ventilation).

[2]The 2 low-stage fans are operated intermittently (ON and OFF) when indoor temperature is at least 0.5°C lower than setpoint temperature, and they are operated continuously for the remaining scenarios.

The two stage-1 fans were the fifth fans (counting from the north side) of both end walls of the lower level. Operation of the ventilation fans was controlled according to indoor temperature, with a minimum ventilation rate (**VR**) of 0.3 m^3/h/hen (0.2 CFM/hen) and a maximum VR of 6.0 m^3/h/hen (3.5 CFM/hen). More VR results are given in another companion paper by Zhao et al. (2014).

Custom-built light traps were installed between the end of cage rows and end-wall fans to prevent light penetration. The light traps were constructed with stacked ^-shaped metal baffles, with 0.15-m spacing between the baffles and a total depth of 0.5 m.

Compact fluorescent (13 W) tube lights in plastic enclosures were installed 4.9 m O.C. apart along the service aisles between cage rows (a total of 594 lights for the house). The lights were 2.5 m above the floor on the lower level and 2.3 m above the catwalk deck on the upper level.

Aviary (AV) House

The AV house measured 154.2 × 21.3 × 3.0 m (506 × 70 × 10 ft) (L × W × H) and was oriented east–west. The 2 end walls and the north side wall had insulation of 2.7 K m^2/W (R-value of 15) with 14-cm-thick fiberglass batting. The south partition wall (2.7 K m^2/W, R-value of 15) was shared with the EC house. The ceiling of the AV house was filled with 18-cm-thick blown-in insulation of 4.8 K m^2/W (R-value of 27). The roof (18.4° slope) of the AV house had a 0.64-cm polyurethane foam board insulation of 0.3 K m^2/W (R-value of 1.7).

The AV house had a capacity of 50,000 hens distributed in 6 colony rows (Figure 4), with each row divided by wire-mesh screens into 10 pens along the building length. From east to west (along the building length), pen 1 contained 5 full-colony units (NATURA60, Big Dutchman, Holland, MI, USA) and

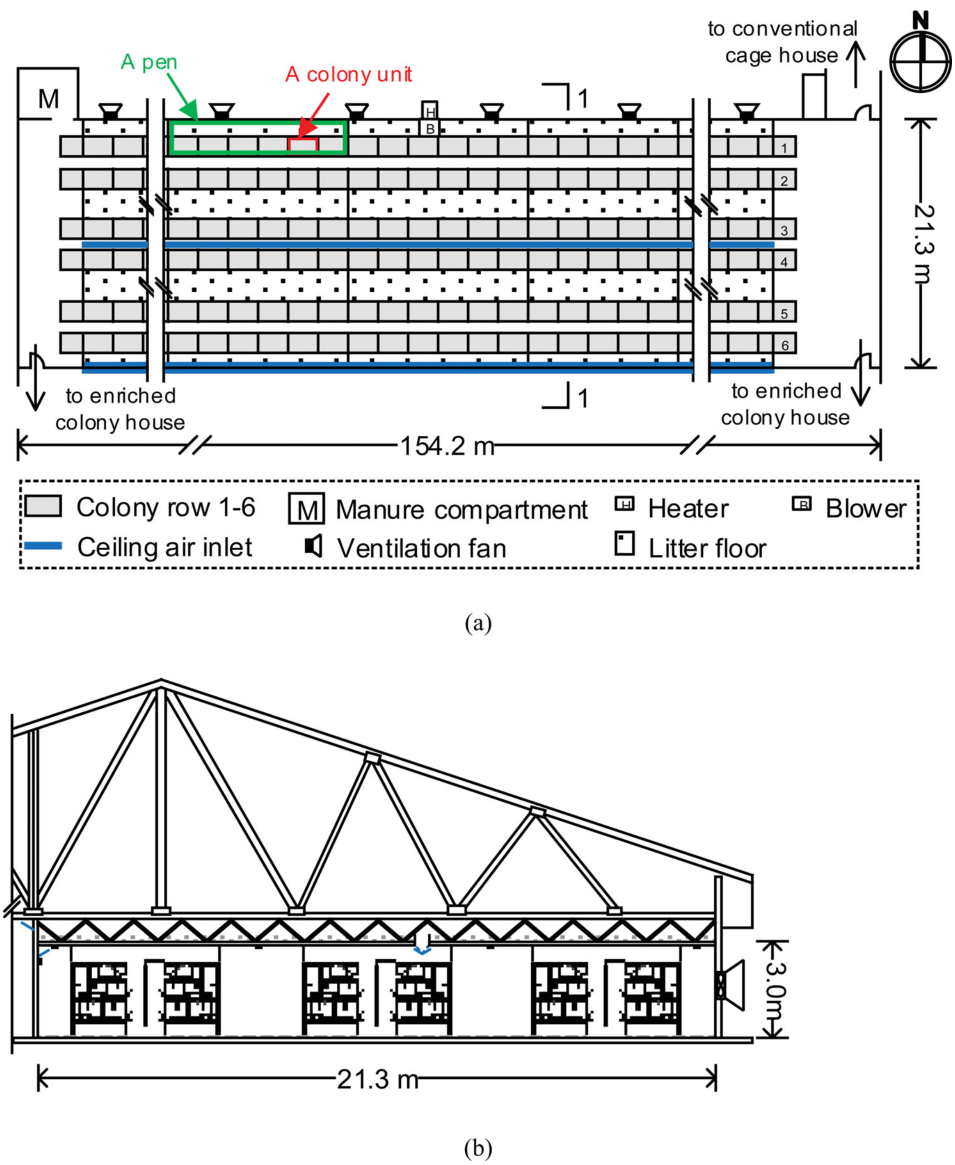


Figure 4. Schematic layout (a) and 1-1 cross-sectional (b) views of aviary housing system.

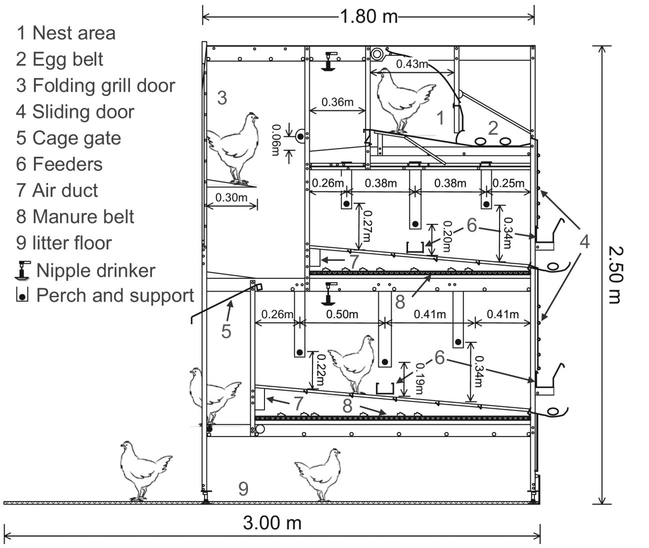


Figure 5. Schematic illustration of aviary colony with litter area (outer row).

one half-colony unit, pens 2 to 9 contained 6 full-colony units, and pen 10 contained 5 full-colony units – a total of 58.5 colony units per colony row (Figure 4a). The 2 outer colony rows had separate litter areas, while the 4 inner rows were paired, with each pair sharing a common litter area that was twice as wide as that for each of the outer rows (Figure 4b). Within the same pen, all hens shared the same litter area and had access to the different colony units.

The multitier aviary colony had dimensions of 2.4 m long × 1.8 m wide × 2.5 m high (8 × 6 × 8 ft). A schematic view of the aviary colony and its litter area is shown in Figure 5, and the allocation of resources is listed in Table 2. Each colony was equipped with a full-length noncurtained nestbox, 7 full-length (2.4 m) galvanized steel perches (19 to 34 cm off the wire-mesh floor), 16 nipple drinkers with drip cups, upper and lower rotating feeder lines (one longitudinal side of each feeder line was inside the colony, the other side outside; see Figure 5), and 2 manure belts located below the middle and bottom tiers, each with a perforated manure-drying air duct (Figure 5). Another perch was located outside the colony to help the hens' transition between the litter floor and the colony.

Fresh air entered the houses from the continuous (full-length) eave inlet into the attic space, then through the 2 continuous (full-length) ceiling air inlets whose openings were controlled by fan stage and SP. Eighteen ventilation fans, including four 0.91-m (36-in.) diameter single-speed fans (0.75 kW, 1 HP) and fourteen 1.32-m (52-in.) diameter single-speed fans (0.75 kW), were installed in the north sidewall of the house and operated in 12 stages (Table 3). The stage-1 fans were the 2 middle 0.91-m fans whose ON/OFF operation was controlled according to the minimum ventilation demand and remained on for subsequent stages. A FANCOM F38 control system (Fancom BV, Panningen, The Netherlands) was used to control the operation of the stage fans, based on the indoor temperature and its setpoint. The minimum VR was 0.3 m^3/h/hen (0.2 CFM/hen) and the maximum VR was 7.5 m^3/h/hen (4.4 CFM/hen). Commercially available light traps were installed before the intake of the exhaust fans to prevent light penetration. The light traps were constructed with W-shaped hard plastic baffles, with 2.5-cm spacing between the baffles and a depth of 23 cm.

Manure on the belts was continuously dried by recirculated room air provided by three 5.5-kW blowers (Big Dutchman Inc., Holland, MI, USA) through perforated air ducts above the manure belts. The air ducts had 6.4-mm-diameter vent holes spaced 20 cm O.C., with a nominal airflow rate of 0.78 m^3/h/hen (0.46 CFM/hen). Manure belts were operated every 3 to 4 d, removing all accumulated manure.

The AV house was equipped with three 73.3-kW (250,000 BTU/h) liquid propane heaters (Guardian Forced Air Heater, Model AD250, L.B. White Co., Onalaska, WI, USA) to provide supplemental heating when room temperature fell below 22.8°C (and off when room temperature reached 24.4°C). The heaters were mounted on the exterior of the north-side wall spaced 35.5 m apart; the heated air was directed into the building through the wall but was not further distributed throughout the barn.

Lighting was provided in the service aisles by 58-W, 1.5-m-long dimmable fluorescent tube lights (30 lights per aisle, 120 total for the house) (LUMILUX T8 58W/830, OSRAM GmbH, Munich, Germany) that were protected in glass tube casings. The tube lights were suspended vertically to achieve more uniform vertical distribution of light in the aviary colonies. The lights in each service aisle were connected to a winch system so that they could be lifted up when the caretakers worked in the aisle. For each litter area, thirty 35-W fluorescent tube lights (90 total for the house) were installed lengthwise underneath the ceiling. The distance between lights in both the service aisles and litter areas was 4.9 m O.C. Light-emitting diode (LED) rope lights (1 rope per colony row) were installed in the colony structure to encourage hens to return to the colony at night. Nestboxes were automatically closed 1 h prior to lights off to prevent hens from roosting in the nestboxes; they were reopened 1 h before lights were turned back on.

Enriched Colony (EC) House

The EC house measured 154.2 × 13.7 × 4.0 m (506 × 45 × 13 ft) (L × W × H) (Figure 6). It had 2.7 K m^2/W (R-value of 15) wall insulation with 0.14-m-thick fiberglass batting, 5.8 K m^2/W (R-value of 33) ceiling blown-in insulation, and 0.3 K m^2/W (R-value of 1.7) roof (18.4° slope) insulation. The EC house had a capacity of 46,800 laying hens distributed in 5 colony cage rows, each stacked 4 tiers high (39 colony

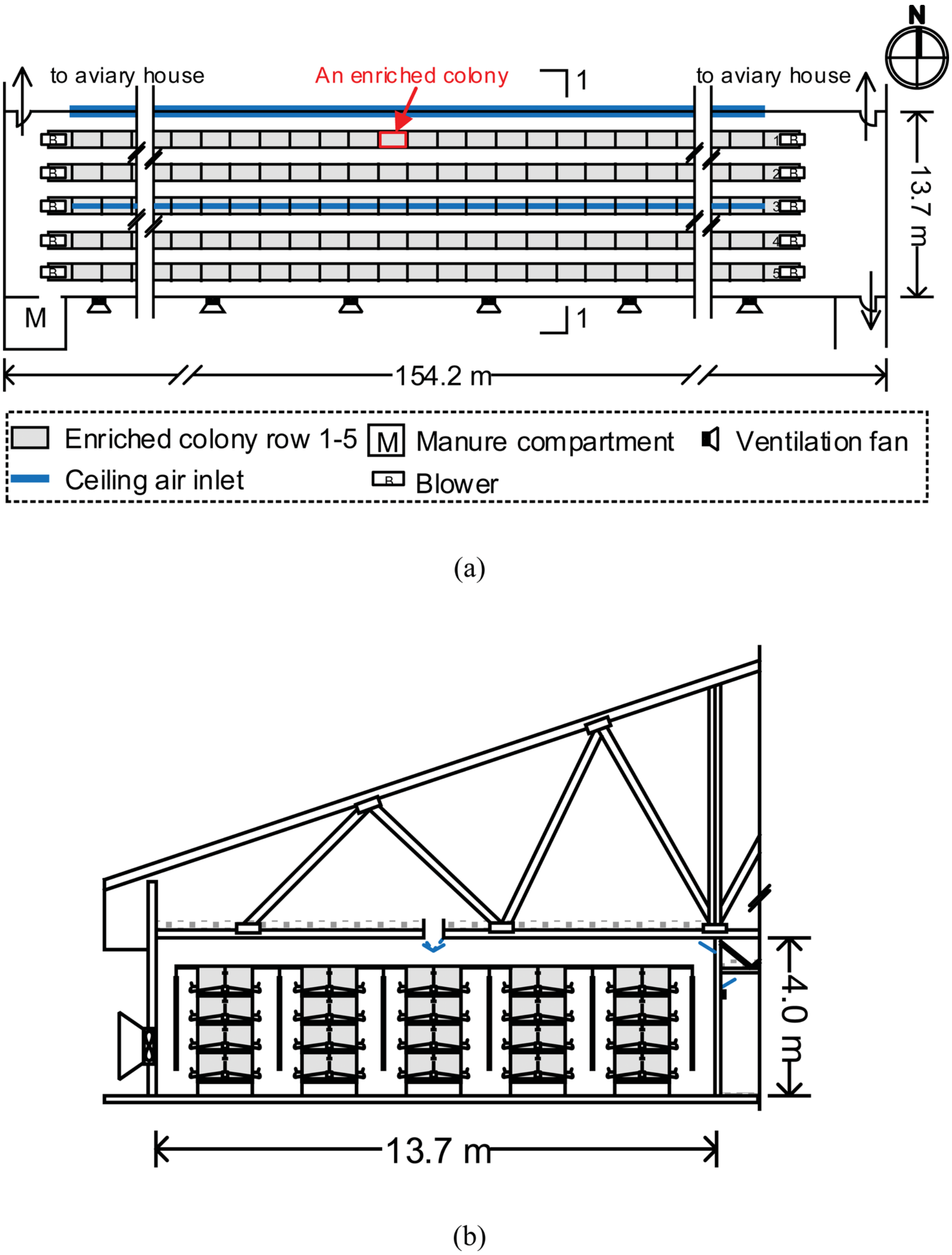
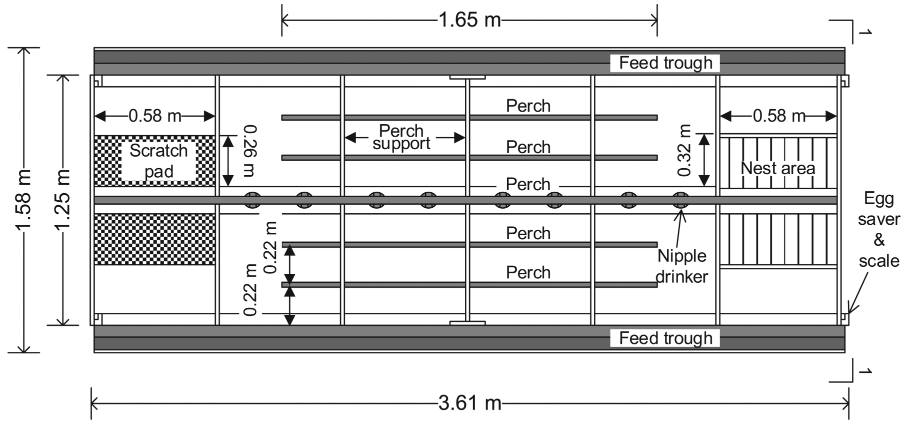


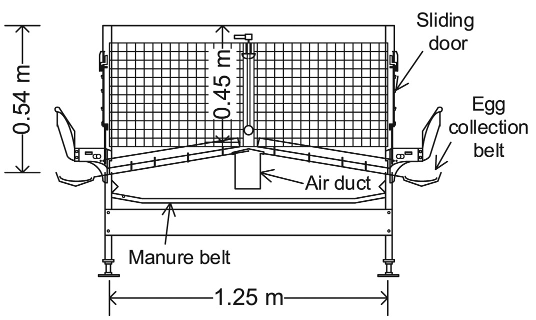
Figure 6. Schematic layout (a) and 1-1 cross-sectional (b) views of enriched colony housing system.

cages per tier). Underneath each tier was a manure belt. A colony cage (AVECH II, Big Dutchman, Holland, MI, USA) was 3.61 m (142 in.) long and 1.25 m (49.25 in.) wide (Figure 7). The height of the colony cage was 0.45 m (17.75 in.) (center) to 0.54 m (21.25 in.) (outside). Each colony cage was equipped with 4 galvanized-steel perches (0.032-m-diameter × 1.65 m, or 1.25-in.-diameter × 64-in.-long each), 2 scratch pads (0.58 × 0.26 m, or 22.75 × 10.25 in. each), 2 plastic-curtained nestboxes (0.58 × 0.32 m, or 22.75 × 12.5 in. each) each with a nest pad, 8 nipple drinkers with drip cups, rotation feeder lines (both longitudinal sides were outside the colony; see Figure 7), an egg saver wire, and a scale. The egg saver wire acted like a buffer that temporally held off the eggs from rolling onto the collection belt. It was automatically lifted every 15 min from 05:30 to 13:00, or every 60 min for the rest of the day to release the eggs onto the collection belt. A small amount of feed was dispensed onto the scratching pad at each feeding time (total delivered feed = 1.5 g/hen/day) for the purpose of accommodating the hens' foraging and dustbathing behaviors. Table 2 lists the allocation of the resources.

The EC house used continuous (or full-length) slot air inlets, one along the north partition wall (perimeter inlet) and the other on top of the middle cage row (ceiling inlet). The sizes and arrangement of the ventilation fans, the ventilation stages, and the temperature setpoints were identical to those in the AV house (Table 2). The minimum VR was 0.3 m^3/h/hen



(a)



(b)

Figure 7. Schematic layout (a) and 1-1 cross-sectional (b) views of enriched colony cage.

(0.2 CFM/hen) and maximum VR was 8.1 m^3/h/hen (4.8 CFM/hen).

Manure-drying blowers with 3-kW motors were installed at 2 ends of the colony cage rows: 2 blowers per row for a total of 10 blowers for the house. These blowers ran continuously to recirculate the room air to dry the manure through the perforated air duct above the belts in each tier (Figure 7b). The air duct had 6.4-mm-diameter vent holes spaced at 20 cm O.C., with a nominal airflow rate of 1.49 m^3/h/hen (0.88 CFM/hen). Manure belts were operated every 3 to 4 d, removing the accumulated manure from the house.

The service aisles were installed with 36-W, 2.6-m-long dimmable fluorescent tube lights at 7.2 m O.C. apart (20 lights per aisle, 120 total for the house). The tube lights were suspended vertically for even light distribution in the vertical plane. Lights in the same service aisle were connected to a winch system for easy uplifting, as needed.

MANURE STORAGE FACILITY

Manure from the 3 houses monitored for the CSES project and 3 additional 200,000-hen CC houses (similar in construction and management of the described CC house) was placed in a communal storage facility to the west of the houses. This sheet-metal-roofed facility measured 146.3 × 36.6 × 9.3 m (480 × 120 × 30 ft) (L × W × H), oriented south to north. The storage facility had a partial concrete wall (3 m tall for the south, west, and north perimeter and 1.8 m tall for the east perimeter), allowing manure to be stacked vertically to an approximate height of 5 m. A continuous 1.1-m-wide opening, equipped with manually operated curtains, ran above the length of the east and west concrete perimeter. Figure 8 shows a schematic drawing of the manure storage facility. The manure storage facility had a holding capacity of approximately 1-year manure production from the 6 houses. It was completely

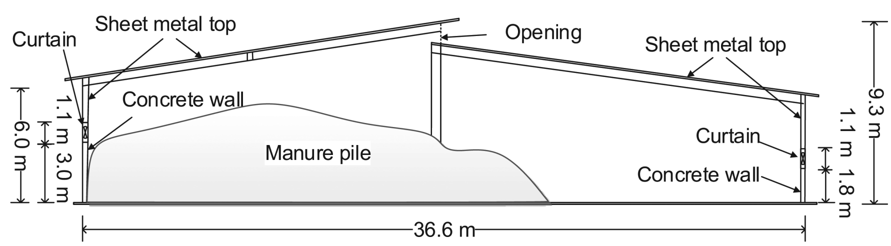


Figure 8. Cross-sectional view of manure storage.

emptied once per year in the fall, with partial manure removal in winter and spring when conditions allowed for land application. For this study, to accommodate quantification of air emissions from manure storage for the respective houses, separate storage bays were constructed. A detailed description of the instrumented manure storage bays is given in the companion environmental impact paper (Shepherd et al., 2014).

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