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Production Performance

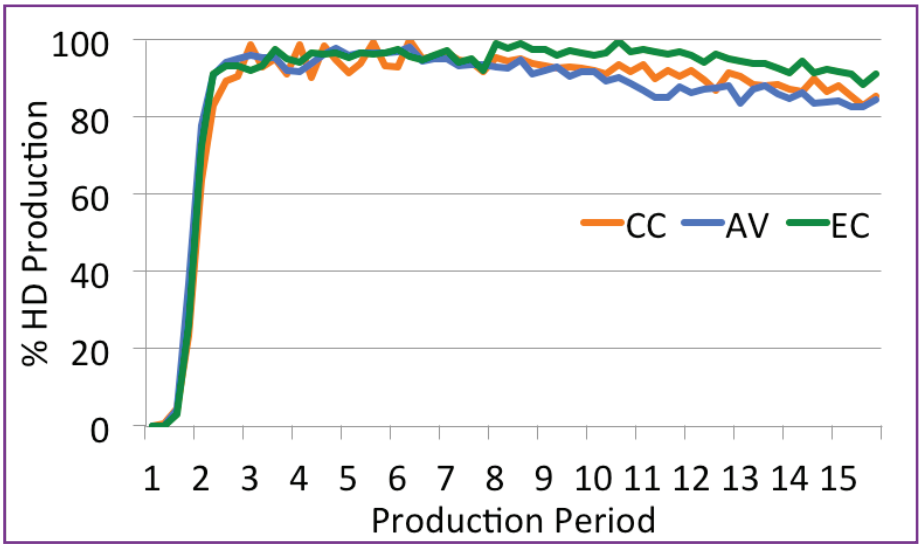
Table 1. Production summary for two commercial flocks housed in different environments.

	Conventional Cage	Cage-free Aviary	Enriched Colony	Lohmann Management Guide Reference
Eggs per hen housed (Flock 1)	352	340	363	354.2
Eggs per hen housed (Flock 2)	371	345	382	354.2
Average Hen-day Production (%, Flock 1)	87.3	86.6	90.5	86.8
Average Hen-day Production (%, Flock 2)	90.0	88.0	94.3	86.8
Water use, L/100 hen-day (Flock 1)	1.54	1.27	1.36	-
Water use, L/100 hen-day (Flock 2)	1.53	1.29	1.33	-
Water/Feed, kg/kg (Flock 1)	2.06	1.64	1.73	-
Water/Feed, kg/kg (Flock 2)	2.05	1.74	1.76	-
FC, kg/dozen eggs (Flock 1)	1.44	1.49	1.42	-
FC, kg/dozen eggs (Flock 2)	1.40	1.44	1.38	-
FC, kg feed/kg egg (Flock 1)	2.02	2.12	1.99	2.0-2.1
FC, kg feed/kg egg (Flock 2)	1.96	2.04	1.94	2.0-2.1
78-wk body weight, kg (Flock 1)	1.56	1.53	1.55	1.71-1.86
78-wk body weight, kg (Flock 2)	1.67	1.60	1.59	1.71-1.86

Research Results Report Appendix

Production Performance

A.



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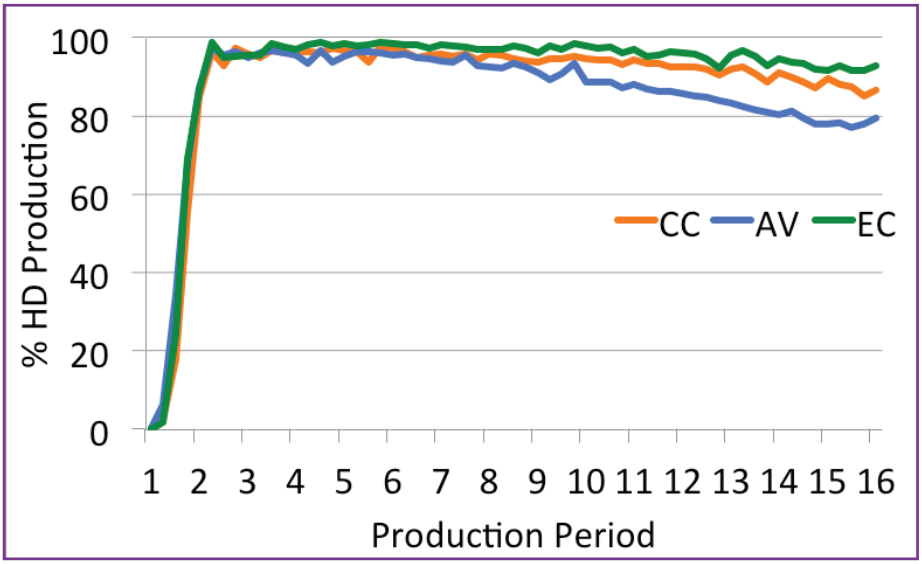
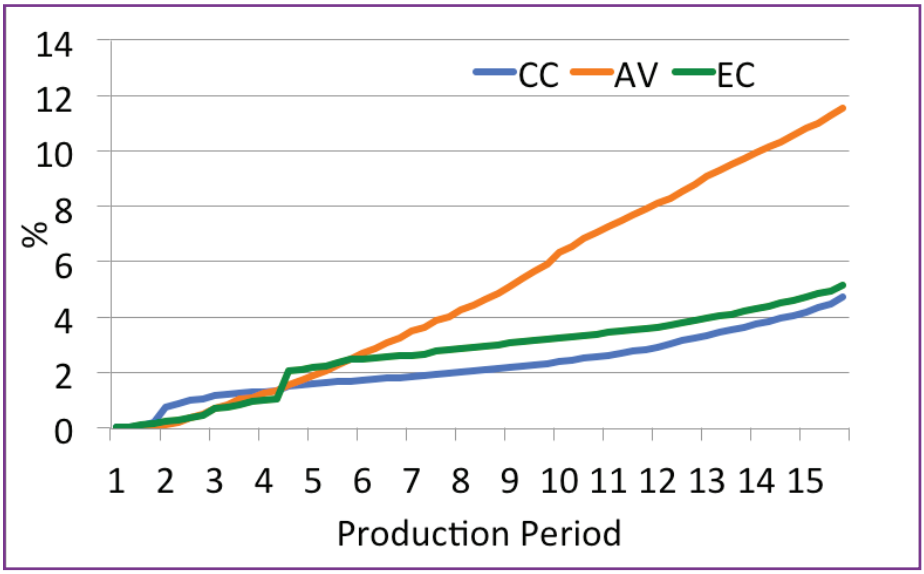


Figure 1. A) Hen-day production in three housing systems for flock one. B) Hen-day production in three housing systems for flock two. The production period is a 28 day period beginning with 19 weeks of age

Research Results Report Appendix

Production Performance

A.



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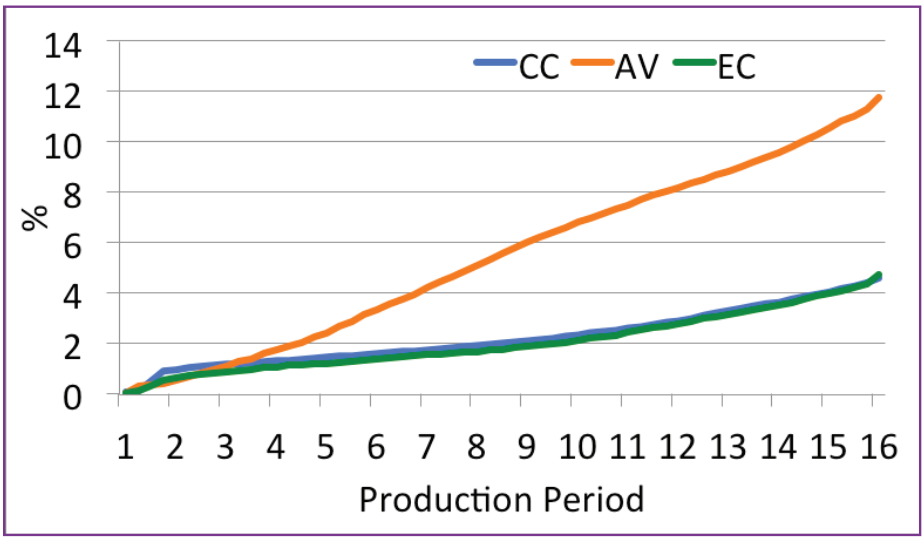

Figure 2. A) Mortality in three housing systems for flock one. B) Mortality in three housing systems for flock two. The production period is a 28 day period beginning with 19 weeks of age

Research Results Report Appendix

Hen Health and Welfare

Table 2. Resource use by hens in the Enriched Colony system

Measure	Observed Usage
Nest Use	97% of eggs laid in nest
Daytime Perch Use	8 – 13% of hens
Nighttime Perch Use	44 – 80% of hens
Foraging on Scratch pad	≤ 2%
Dust bathing on Scratch pad	6%

Research Results Report Appendix

Hen Health and Welfare

Table 3. Resource use by hens in the Aviary system

Measure	Observed Usage
Nest Use	97% of eggs laid (2.3% system, 0.7% floor)
Daytime Perch Use*	30% of hens
Nighttime Perch Use	52% of hens
Dust Bathing in Open Litter	0-41% of hens on open litter
Open Litter Area Occupied	15-39%

*Before aviary opening

Research Results Report Appendix

Hen Health and Welfare

Table 4. Major differences observed in the physical condition of hens from three housing systems as determined by the Welfare Quality Assessment®. Hens from each housing system were assessed at peak, middle, and end of lay for both flocks. The reported values represent the range observed over those sampling periods.

Measure	Conventional	Enriched	Aviary
Claw Length	3.0 – 3.4 cm	2.8 – 3.2 cm	3.1 – 3.5 cm
Foot Lesion Incidence	60 – 95% of hens	14 – 72% of hens	21 – 84% of hens
Foot Lesion Severity[1]	0% of hens	0% of hens	2 – 7% of hens
Keel Abnormalities	3 – 22% of hens	8 – 41% of hens	18 – 49%
Feather Cleanliness	1 - 33% hens dirty	0 – 20% hens dirty	15 – 60% hens dirty
Feather Lipids[2]	18.7 – 23.6	17.1 – 19.8	10.8 – 15.8
Feather Loss Pattern	Throat and Belly	Throat, Belly, and Head	Head

[1]Severity scores ranged from 0: no lesion, 1: lesions more than 0.5 cm, and 2: foot swelling visible from the dorsal surface. The higher the score, the more severe the foot lesion.

[2]Feather lipids measured as mg lipid/gram feather from the breast and back of the hens.

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Hen Health and Welfare

Table 5. Cumulative Mortality*

	Total Population	Total Mortality	Percentage Mortality	Number Necropsied
Flock 1				
Conventional	193,424	9,369	4.8	428*
Aviary	49,842	5,852	11.7	622
Enriched	46,795	2,439	5.2	387
Flock 2				
Conventional	198,816	9,140	4.6	369*
Aviary	49,677	5,858	11.8	554
Enriched	46,729	2,216	4.7	251

***Necropsies were performed on daily mortality each day during the first 15 days after placement of Flock 1, then every other day for the month following, and then twice a week for the remainder of the flock. Flock 2 had necropsies performed on daily mortality twice a week throughout. Because the CC housed almost four times the number of hens as the AV and EC, only one fourth of the daily mortality in that house was necropsied while all of the daily mortality in the AV and EC was necropsied**

Research Results Report Appendix

Hen Health and Welfare

Table 6: Mortality Causes (expressed as a percentage of the respective total mortality)

	Conventional * F1/F2**	Aviary F1/F2	Enriched F1/F2
Hypocalcemia	11.9/8.7	23.3/17.5	12.9/7.2
Egg Yolk Peritonitis	25.2/21.4	12.4/15.9	19.1/19.9
Peritonitis, other	0.2/1.1	0.5/0.0	0.0/0.4
Salpingitis	1.9/5.7	2.9/4.5	1.6/10.0
Internal Layer	0.0/1.1	1.0/0.2	0.0/0.8
Egg Bound	0.5/0.3	0.2/0.2	0.3/0.0
Caught in Structure	0.2/0.0	5.1/1.3	1.8/0.0
Pick Out (vent)	0.2/1.1	7.6/15.3	1.8/2.4
Excessively Pecked	0.0/0.0	1.8/2.2	1.8/0.8
Trauma	0.5/0.0	0.3/0.0	0.5/0.0
Fatty Liver Syndrome	1.6/4.6	2.9/0.5	1.8/1.6
Layer Hepatitis	1.4/1.9	0.2/0.5	1.6/2.0
Twisted Gut	0.5/0.8	0.5/0.5	1.0/2.0
Tumor, Ovary	0.0/0.8	0.3/0.5	0.3/0.4
Tumor, Other	0.0/0.0	0.0/0.0	0.0/0.4
Gout	1.2/0.5	1.5/1.8	0.8/1.6
Urolithiasis	0.0/0.0	0.0/0.0	0.0/0.0
Vent Prolapse	1.2/1.9	2.1/2.2	1.0/1.6
Out of Production	5.1/9.5	2.4/6.1	2.8/15.5
Emaciated	7.7/9.8	6.6/10.8	6.2/14.3
Dehydrated	11.0/35.8	6.0/33.0	12.7/41.4
Necrotic Enteritis	9.4/8.9	0.2/0.0	4.9/11.6
Bleed Out	4.7/3.5	0.3/0.7	1.3/3.6
Bumble Foot	0.0/0.3	2.3/2.9	0.3/0.4
Cull	4.2/1.4	3.2/0.4	4.1/0.8
Rotten	13.1/17.9	22.8/19.1	24.0/13.9

***Due to the population of this house being four times that of the other houses, only 1/4 of daily mortality had the cause of death determined.**

**** F1 = Flock 1; F2 = Flock 2**

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Hen Health and Welfare

Table 7. Mortality at Placement due to Trauma (First 15 days of Housing)

	Conventional F1/F2*	Aviary F1/F2	Enriched F1/F2
Fractured Wing	0/2	0/0	4/1
Fractured Leg	19/1	5/0	23/0

*** F1 = Flock 1; F2 = Flock 2**

Table 8. Bone Issues

	Conventional F1/F2*	Aviary F1/F2*	Enriched F1/F2
Collapsed Ribs	19/17	11/29	7/10
Moderate Rib Beading	3/7	11/14	2/4
Mild Rib Beading	25/32	48/65	22/34
Recent Keel Fracture	18/10	17/13	14/3
Old Keel Fracture	11/27	75/183	9/43
S-shaped Keel	27/54	72/120	24/43
Folded Keel	8/14	4/23	2/4

*** F1 = Flock 1; F2 = Flock 2**

Research Results Report Appendix

Food Safety and Quality

Table 9. Type and total number of samples collected per housing system[1]

Sample type	Conventional cage	Enriched colony	Cage-free aviary
Environmental swabs			
System wire	80	80	80
Nest box		80	80
Scratch pad		80	
Manure scraper[2]	80	80	32
Forage area drag swab			16
Shell pools			
System wire	80	13	63
Nest box		80	80
Floor			77

[1]Samples collected over 4 production periods. Pathogens assessed on all swabs/shell pools. Enumeration of aerobes and coliforms conducted on up to 10 swabs/shell pools for each sample type*housing system combination each collection period.

[2]Only pathogen detection conducted on manure scraper swabs.

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Food Safety and Quality

Table 10. Total aerobes, coliforms, *Salmonella* spp., and *Campylobacter* spp. associated with environmental swabs from commercial conventional cage, enriched colony cage, and aviary housing systems[1]

Sample type	Average total aerobes[3] (log cfu/mL)	Average total coliforms[3] (log cfu/mL)	*Salmonella* spp. (no. positive/total no. samples)	*Campylobacter* spp. (no. positive/total no. samples)
Aviary drag swabs	7.5 ± 0.1	4.0 ± 0.3	69 % (11/16)	100 % (16/16)
Aviary manure scraper[2]			100 % (32/32)	41 % (13/32)
Aviary nest box	5.5 ± 0.1	1.6 ± 0.2	28 % (22/80)	10 % (8/80)
Aviary system wire	5.3 ± 0.1	2.1 ± 0.2	18 % (14/80)	74 % (59/80)
Conventional manure scraper[2]			99 % (79/80)	0 % (0/80)
Conventional system wire	4.8 ± 0.1	2.3 ± 0.2	25 % (20/80)	63 % (50/80)
Enriched manure scraper[2]			89 % (71/80)	40 % (32/80)
Enriched nest box Enriched scratch pad	5.6 ± 0.1 6.8 ± 0.1	2.7 ± 0.2 3.8 ± 0.2	16 % (13/80) 23 % (18/80)	64 % (51/80) 93 % (74/80)
Enriched system wire	4.7 ± 0.1	1.7 ± 0.2	16 % (13/80)	65 % (52/80)
P value			0.0002	0.0001

[1]Samples collected over 4 production periods. Pathogens assessed on all swabs. Enumeration of aerobes and coliforms conducted on up to 10 swabs for each sample type, each collection period.

[2]Only pathogen detection conducted on manure scraper swabs.

[3]Significant sample type * production period interaction (P < 0.0001).

Research Results Report Appendix

Food Safety and Quality

Table 11. Total aerobes, coliforms, *Salmonella* spp., and *Campylobacter* spp. associated with shell emulsion pools from commercial conventional cage, enriched colony cage, and aviary housing systems[1]

Sample type	Average total aerobes[3] (log cfu/mL)	Average total coliforms[3] (log cfu/mL)	*Salmonella* spp. (no. positive/total no. samples)	*Campylobacter* spp. (no. positive/total no. samples)
Aviary floor	4.9 ± 0.1	1.0 ± 0.1	7.8 % (6/77)	2.6 % (2/77)
Aviary nest box	3.5 ± 0.1	0.2 ± 0.1	1.3 % (1/80)	5.0 % (4/80)
Aviary system wire	4.1 ± 0.1	0.6 ± 0.1	4.8 % (3/63)	4.8 % (3/63)
Conventional system wire	2.8 ± 0.1	0.1 ± 0.1	7.5 % (6/80)	1.3 % (1/80)
Enriched nest box	2.6 ± 0.1	0.2 ± 0.1	7.5 % (6/80)	5.0 % (4/80)
Enriched system wire[2]	3.5 ± 0.1	0.2 ± 0.1	0 % (0/12)	16.7 % (2/12)

[1]Samples collected over 4 production periods. Pathogens assessed on all shell pools. Enumeration of aerobes and coliforms conducted on up to 10 shell pools for each sample type, each collection period.

[2]Means represent the first 3 production periods. No enriched system wire shell pools were produced during the final period of collection.

[3]Significant sample type * production period interaction (P < 0.0001).

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Food Safety and Quality

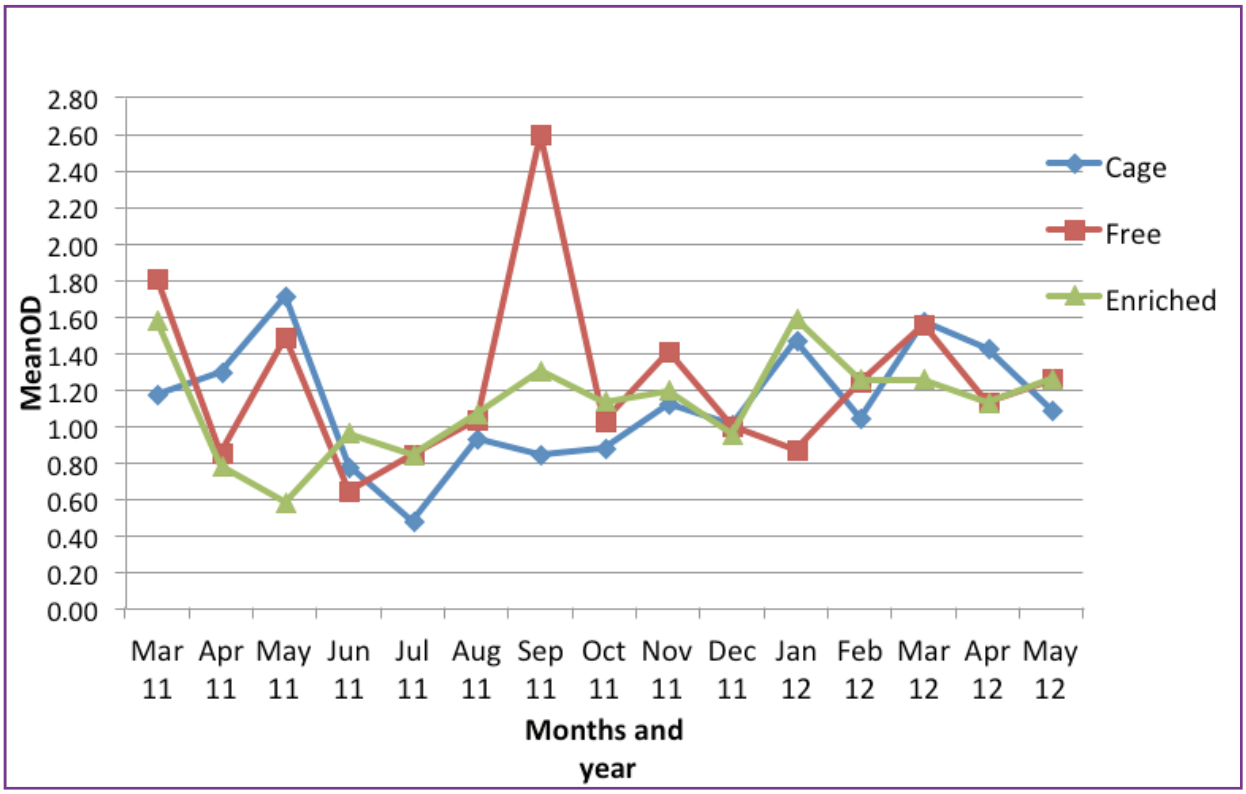

Figure 3. Intensity of immune response of birds in egg layer flocks housed under 3 different types of housing (conventional cages – Cage, cage-free aviary = Free, and enriched colony = Enriched on the figure legend). Immune response was measured by the serum level of anti -*Salmonella* lipopolysaccharides (LPS) from crop washings of sampled birds. Low immune response is indicated by optical density (Mean OD on the Y axis) of 0.1-0.15, medium immune response is indicated by optical density of 0.15-0.2, and high immune response is indicated by optical density higher than 0.2. The shape of the graph suggests that between the months of June and July (summer) there were no significant differences among the 3 different housing types. However, between the months of August and October hens in the Aviary mounted a higher immune response to *Salmonella* than hens in the other housing systems.

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Food Safety and Quality

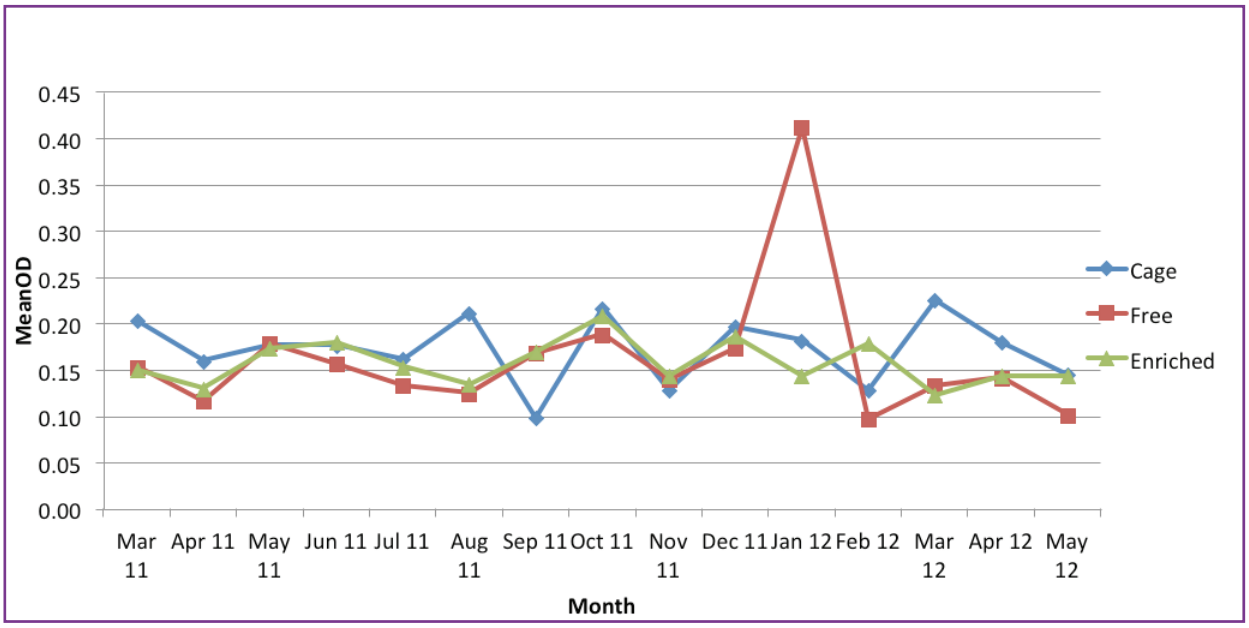

Figure 4. Intensity of immune response of birds in egg layer flocks housed under 3 different types of housing (conventional cages – Cage, cage-free aviary = Free, and enriched colony = Enriched on the figure legend). Immune response was measured based on the level of anti-*Salmonella* lipopolysaccharides (LPS) from crop washings of sampled birds. Low immune response is indicated by optical density (Mean OD on the Y axis) of 0.1-0.15, medium immune response is indicated by optical density of 0.15-0.2, and high immune response is indicated by optical density of higher than 0.2. The shape of the graph suggests that there are no significant differences among the 3 different housing types throughout most of the months of observation. However, between December 2011 and February 2012, hens in the Aviary mounted a higher immune response to *Salmonella* than hens in the other housing systems.

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Environment

Table 12. Summary of ambient and indoor temperature, relative humidity (RH), and ventilation rate (VR) in the conventional cage (CC), aviary (AV), and enriched colony (EC) houses.*

Variable	Ambient	CC	AV	EC
Temperature, °C	8.9±11.2 (9.9±10.6 / 8.1±11.8)	24.6±1.9 (24.7±1.9 / 24.4±2.0)	26.7±1.1 (26.9±1.2 / 26.6±1.0)	25.2±1.3 (25.1±1.5 / 25.3±1.1)
RH, %	71±14 (68±14 / 73±14)	57±9 (54±8 / 60±8)	54±7 (52±8 / 55±7)	56±9 (54±9 / 58±8)
VR, $m^3\ h^{-1}\ hen^{-1}$	-	1.9±1.6 (1.9±1.6 / 1.8±1.5)	1.9±1.8 (1.8±1.8 / 1.9±1.8)	2.2±2.0 (2.1±1.9 / 2.2±2.0)

Note: Values outside the parenthesis are mean±SD for both flocks, and those in the parenthesis are respective mean±SD values for flock 1 (before slash) and flock 2 (after slash).

Table 13. Summary of ammonia (NH_3), carbon dioxide (CO2), particulate matter (PM_{10} and $PM_{2.5}$) concentrations for ambient environment and in the conventional cage (CC), aviary (AV) and enriched colony (EC) houses.

Variable	Ambient	CC	AV	EC
NH_3, ppm	0.4±0.5 (0.4±0.7/0.3±0.2)	$4.0^{a,b}$±2.4 (4.4±2.6 / 3.6±2.1)	6.7^{a}±5.9 (7.8±6.8 / 5.8±4.9)	2.8^{b}±1.7 (3.1±1.9 / 2.6±1.5)
CO_2, ppm	452±25 (443±24/461±23)	2084^{c}±1034 (2019±987 / 2141±1072)	2475^{a}±1280 (2337±1132 / 2596±1388)	2216^{b}±1112 (2172±1062 / 2256±1155)
CH_4, ppm	5.7±5.1 (6.3±5.5/5.2±4.8)	10.9^{a}±5.7 (14.8±4.3 / 7.9±4.7)	11.7^{a}±5.4 (15.6±4.0 / 8.6±4.3)	11.9^{a}±5.9 (16.2±4.3 / 8.5±4.7)
PM_{10}, mg m^{-3}	-	0.59^{b}±0.16 (0.46±0.14/0.65±0.14)	3.95^{a}±2.83 (3.23±2.16/4.53±3.16)	0.44^{c}±0.18 (0.30±0.11/0.52±0.16)
$PM_{2.5}$, mg m^{-3}	-	0.035^{b}±0.013 (0.019±0.006 / 0.042±0.009)	0.410^{a}±0.251 (0.285±0.159 / 0.452±0.262)	0.056^{b}±0.021 (0.020±0.005 / 0.063±0.015)

Note: Values outside the parentheses are mean±SD for both flocks, and those inside the parentheses are respective mean±SD values for flock 1 (before slash) and flock 2 (after slash). a,b,c The means of gas or PM concentration in three housing systems (CC, AV or EC) with different superscript letters significantly differ (P < 0.05). Ambient concentrations are not included in the comparison.

*Tables 12-14 and Figures 5-15 are reprinted from the March 2015 issue of *Poultry Science*, volume 94, pages 518-522 and 534-543.

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Environment

Table 14. Summary of house-level, manure storage, and farm-level daily emission rates of ammonia (NH_3), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and particulate matter (PM_{10} and $PM_{2.5}$) for the conventional cage (CC), aviary (AV), and enriched colony (EC) housing systems over the 27-month monitoring period.

Gas or PM	Source	Housing System								
		Conventional Cage (CC)			Aviary (AV)			Enriched Colony (EC)		
		g hen^{-1} d^{-1}	g (kg egg)$^{-1}$	% of Total	g hen^{-1} d^{-1}	g (kg egg)$^{-1}$	% of Total	g hen^{-1} d^{-1}	g (kg egg)$^{-1}$	% of Total
NH_3	House	0.085^{b}	1.62	28	0.112^{a}	2.19	40	0.054^{c}	0.99	31
	Manure Storage	0.21^{a}	4.00	72	0.18^{a}	3.52	60	0.11^{b}	2.02	69
	Farm	**0.29**	**5.52**	**100**	**0.30**	**5.88**	**100**	**0.16**	**2.94**	**100**
CO_2	House	68.3^{b}	1,300	89	74.0^{a}	1,450	90	74.4^{a}	1,365	91
	Manure Storage	8.1	154	11	8.0	157	10	7.1	130	9
	Farm	**76.4**	**1,454**	**100**	**82.0**	**1,607**	**100**	**81.5**	**1,495**	**100**
CH_4	House	0.07	1.33	70	0.07	1.37	70	0.08	1.47	80
	Manure Storage	0.03	0.57	30	0.03	0.59	30	0.02	0.37	20
	Farm	**0.10**	**1.90**	**100**	**0.10**	**1.96**	**100**	**0.10**	**1.84**	**100**
N_2O	House	--	--	-	--	--	-	--	--	-
	Manure Storage	0.03	0.57	-	0.03	0.59	-	0.01	0.18	-
	Farm	**0.03**	**0.57**	**-**	**0.03**	**0.59**	**-**	**0.01**	**0.18**	**-**
PM_{10}	House	0.0157^{b}	0.299	100	0.1003^{a}	1. 909	100	0.0156^{b}	0.297	100
	Manure Storage	--	--	-	--	--	-	--	--	-
	Farm	**0.0157**	**0.299**	**100**	**0.1003**	**1. 909**	**100**	**0.0156**	**0.297**	**100**
$PM_{2.5}$	House	0.0009^{b}	0.018	100	0.088^{a}	0.168	100	0.0017^{b}	0.032	100
	Manure Storage	--	--	-	--	--	-	--	--	-
	Farm	**0.0009**	**0.018**	**100**	**0.017**	**0.168**	**100**	**0.0017**	**0.032**	**100**

Means of gaseous or particulate matter (PM) emission rates of the three housing systems with different subscript letters differ significantly ($P<0.05$).

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Environment

Table 15. Nitrogen (N) consumption in feed and distribution in eggs, manure, chicken body gain, and estimated loss.

House	Flock	Unit	Feed	Eggs	Manure	Chicken Body Gain	N loss
Conventional	1	g d^{-1} hen^{-1}	2.84	1.01	1.61	0.006	0.21
	2	g d^{-1} hen^{-1}	2.94	1.01	1.77	0.026	0.13
	Mean	g d^{-1} hen^{-1}	2.89	1.01	1.69	0.02	0.17
		%	100.0	35.0	58.5	0.6	5.9
Enriched	1	g d^{-1} hen^{-1}	3.03	1.08	1.82	0.005	0.12
	2	g d^{-1} hen^{-1}	2.99	1.00	1.88	0.024	0.08
	Mean	g d^{-1} hen^{-1}	3.01	1.04	1.85	0.01	0.10
		%	100.0	34.6	61.5	0.5	3.4
Aviary	1	g d^{-1} hen^{-1}	2.91	1.01	1.54	0.003	0.36
	2	g d^{-1} hen^{-1}	3.03	0.94	1.61	0.027	0.44
	Mean	g d^{-1} hen^{-1}	2.97	0.97	1.58	0.01	0.40
		%	100.0	32.7	53.0	0.5	13.5
Overall		g d^{-1} hen^{-1}	2.96	1.01	1.71	0.02	0.22
		%	100.0	34.1	57.7	0.5	7.6

Research Results Report Appendix

Environment

Table 16. Carbon (C) consumption in feed and distribution in eggs, manure, chicken body gain, and estimated loss.

House	Flock	Unit	Feed	Eggs	Manure	Chicken Body Gain	N loss
Conventional	1	g d^{-1} hen^{-1}	42.36	7.63	10.58	0.035	24.11
	2	g d^{-1} hen^{-1}	40.48	7.70	11.66	0.147	20.97
	Mean	g d^{-1} hen^{-1}	41.42	7.66	11.12	0.09	22.54
		%	100.0	18.5	26.9	0.2	54.4
Enriched	1	g d^{-1} hen^{-1}	44.12	8.17	12.28	0.027	23.64
	2	g d^{-1} hen^{-1}	41.09	7.56	12.14	0.145	21.24
	Mean	g d^{-1} hen^{-1}	42.61	7.87	12.21	0.09	22.44
		%	100.0	18.5	28.7	0.2	52.7
Aviary	1	g d^{-1} hen^{-1}	44.01	7.68	11.60	0.018	24.71
	2	g d^{-1} hen^{-1}	39.82	6.56	11.03	0.155	22.06
	Mean	g d^{-1} hen^{-1}	41.91	7.12	11.32	0.09	23.39
		%	100.0	17.0	27.0	0.2	55.8
Overall		g d^{-1} hen^{-1}	41.98	7.55	11.55	0.09	22.79
		%	100.0	18.0	27.5	0.2	54.3

Table 17. Sulfur (S) consumption in feed and distribution in eggs, manure, chicken body gain, and estimated loss.

House	Flock	Unit	Feed	Water	Eggs	Manure	Chicken Body Gain	S loss
Conventional	1	g d^{-1} hen^{-1}	0.33	0.03	0.10	0.24	0.000	0.03
	2	g d^{-1} hen^{-1}	0.32	0.03	0.09	0.25	0.002	0.00
	Mean	g d^{-1} hen^{-1}	0.33	0.03	0.09	0.25	0.00	0.02
		%	91.5	8.5	26.5	68.9	0.3	4.2
Enriched	1	g d^{-1} hen^{-1}	0.35	0.03	0.11	0.27	0.000	0.00
	2	g d^{-1} hen^{-1}	0.32	0.03	0.08	0.25	0.002	0.02
	Mean	g d^{-1} hen^{-1}	0.34	0.03	0.09	0.26	0.00	0.01
		%	92.7	7.3	26.0	71.3	0.3	2.4
Aviary	1	g d^{-1} hen^{-1}	0.35	0.03	0.10	0.23	0.000	0.04
	2	g d^{-1} hen^{-1}	0.33	0.03	0.08	0.23	0.002	0.04
	Mean	g d^{-1} hen^{-1}	0.34	0.03	0.09	0.23	0.00	0.04
		%	92.9	7.1	25.1	63.3	0.3	11.3
Overall		g d^{-1} hen^{-1}	0.33	0.03	0.09	0.25	0.00	0.02
		%	92.4	7.6	25.9	67.8	0.3	6.0

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Table 18. Phosphorus (P) consumption in feed and distribution in eggs, manure, chicken body gain, and estimated loss.

House	Flock	Unit	Feed	Eggs	Manure	Chicken Body Gain	P loss
Conventional	1	g d^{-1} hen^{-1}	0.56	0.09	0.43	0.001	0.03
	2	g d^{-1} hen^{-1}	0.52	0.10	0.42	0.005	0.00
	Mean	g d^{-1} hen^{-1}	0.54	0.09	0.43	0.00	0.02
		%	100.0	17.5	78.7	0.6	3.1
Enriched	1	g d^{-1} hen^{-1}	0.57	0.10	0.46	0.001	0.01
	2	g d^{-1} hen^{-1}	0.54	0.10	0.43	0.005	0.00
	Mean	g d^{-1} hen^{-1}	0.55	0.10	0.44	0.00	0.01
		%	100.0	17.5	80.4	0.5	1.5
Aviary	1	g d^{-1} hen^{-1}	0.55	0.09	0.43	0.001	0.03
	2	g d^{-1} hen^{-1}	0.53	0.09	0.42	0.006	0.02
	Mean	g d^{-1} hen^{-1}	0.54	0.09	0.42	0.00	0.03
		%	100.0	16.3	78.3	0.6	4.7
Overall		g d^{-1} hen^{-1}	0.55	0.09	0.43	0.00	0.02
		%	100.0	17.1	79.2	0.6	3.1

Table 19. Potassium (K) consumption in feed and distribution in eggs, manure, chicken body gain, and estimated loss.

House	Flock	Unit	Feed	Eggs	Manure	Chicken Body Gain	K loss
Conventional	1	g d^{-1} hen^{-1}	0.77	0.08	0.69	0.000	0.005
	2	g d^{-1} hen^{-1}	0.77	0.07	0.70	0.002	0.001
	Mean	g d^{-1} hen^{-1}	0.77	0.07	0.70	0.001	0.003
		%	100.0	9.4	90.1	0.15	0.35
Enriched	1	g d^{-1} hen^{-1}	0.84	0.07	0.77	0.000	0.003
	2	g d^{-1} hen^{-1}	0.76	0.07	0.69	0.002	0.002
	Mean	g d^{-1} hen^{-1}	0.80	0.07	0.73	0.001	0.003
		%	100.0	8.7	90.8	0.12	0.31
Aviary	1	g d^{-1} hen^{-1}	0.83	0.08	0.71	0.000	0.04
	2	g d^{-1} hen^{-1}	0.76	0.06	0.67	0.002	0.02
	Mean	g d^{-1} hen^{-1}	0.80	0.07	0.69	0.00	0.03
		%	100.0	8.8	86.7	0.14	4.18
Overall		g d^{-1} hen^{-1}	0.79	0.07	0.70	0.00	0.01
		%	100.0	9.0	89.2	0.1	1.6

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Table 20. Average characteristics of feed, eggs, manure, layers and water in Flock 1 (wet basis).

Material	House	TS (%)	N (%)	C (%)	S (%)	P (%)	K (%)
Feed	Conventional	89.97	2.64	39.46	0.31	0.52	0.72
Feed	Enriched	89.21	2.75	40.08	0.32	0.52	0.77
Feed	Aviary	89.06	2.67	40.35	0.32	0.51	0.76
Eggs	Conventional	29.06	1.85	13.99	0.18	0.17	0.14
Eggs	Enriched	29.87	1.91	14.43	0.19	0.17	0.13
Eggs	Aviary	31.74	1.89	14.39	0.19	0.17	0.14
Manure (3d)	Conventional	41.99	2.39	15.45	0.35	0.63	1.02
Manure (3d)	Enriched	48.38	2.78	18.00	0.39	0.65	1.06
Manure (3d)	Aviary	48.84	2.70	18.47	0.37	0.66	1.00
Manure (4d)	Conventional	44.93	2.44	16.20	0.36	0.66	1.05
Manure (4d)	Enriched	55.60	2.96	20.59	0.46	0.78	1.34
Manure (4d)	Aviary	51.44	2.63	19.10	0.39	0.76	1.31
Chicken	Conventional	34.72	3.12	17.47	0.23	0.65	0.22
Chicken	Enriched	35.56	3.02	18.32	0.23	0.61	0.21
Chicken	Aviary	37.02	3.22	18.71	0.25	0.69	0.24
Water	Conventional				0.0139		
Water	Enriched				0.0138		
Water	Aviary				0.0144		

Note: TS-total solids, N-nitrogen, C-carbon, S-sulfur, P-phosphorus, K-potassium

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Table 21. Average characteristics of wood shaving and litter in aviary house in Flock 1 (wet basis).

Material	Sampling Date	TS (%)	N (%)	C (%)	S (%)	P (%)	K (%)
Wood shavings	4/16/2011	92.18	0.12			0.02	
Litter	8/8/2011	75.31	2.19			1.14	0.00
Litter	11/14/2011	84.64	2.86	30.12	0.74	1.05	
Litter	12/13/2011	78.55	2.74	28.58	0.44	0.97	
Litter	2/13/2012	84.75	3.17	32.04	0.62	1.09	1.94
Litter	3/12/2012	86.20	3.09	32.36	0.62	1.08	1.94
Litter	6/4/2012	87.42	2.53	29.33	0.58	1.04	1.74

Note: TS-total solids, N-nitrogen, C-carbon, S-sulfur, P-phosphorus, K-potassium

Table 22. Average characteristics of feed, eggs, manure and litter in Flock 2 (wet basis).

Material	House	TS (%)	N (%)	C (%)	S (%)	P (%)	K (%)
Feed	Conventional	89.00	2.77	38.17	0.30	0.49	0.73
Feed	Enriched	88.83	2.79	38.43	0.30	0.50	0.71
Feed	Aviary	88.76	2.89	38.02	0.32	0.51	0.73
Eggs	Conventional	31.65	1.90	14.43	0.17	0.18	0.13
Eggs	Enriched	30.88	1.85	14.01	0.15	0.18	0.13
Eggs	Aviary	30.42	1.87	13.11	0.16	0.17	0.13
Manure 3d	Conventional	48.05	2.62	17.68	0.39	0.64	1.06
Manure 3d	Enriched	54.69	3.15	20.06	0.41	0.73	1.14
Manure 3d	Aviary	45.32	2.50	16.56	0.35	0.64	0.94
Manure 4d	Conventional	50.79	2.88	18.65	0.40	0.67	1.12
Manure 4d	Enriched	58.89	3.32	21.70	0.44	0.76	1.22
Manure 4d	Aviary	47.78	2.63	17.29	0.36	0.66	0.99
Litter	Aviary	82.47	3.25	30.48	0.66	0.97	1.81

Note: TS-total solids, N-nitrogen, C-carbon, S-sulfur, P-phosphorus, K-potassium

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Table 23. Characteristics of load-in manure samples of conventional cage (CC), enriched colony (EC) and aviary (AV) manure storage rooms in events 1 and 2 (wet basis).

Manure age (d)	Item	CC		AV		EC	
		Mean	SD	Mean	SD	Mean	SD
Event 1							
3	TS (%)	39.15	4.56	44.49	2.50	51.08	4.44
	N (%)	2.17	0.47	2.45	0.03	3.01	0.45
	C (%)	14.27	1.64	17.05	0.62	19.33	2.26
	S (%)	0.32	0.01	0.35	0.02	0.41	0.05
	P (%)	0.60	0.12	0.60	0.07	0.70	0.07
	K (%)	1.00	0.01	0.98	0.04	1.22	0.15
4	TS (%)	49.04	5.15	47.17	6.65	58.18	7.61
	N (%)	2.68	0.39	2.41	0.31	3.00	0.21
	C (%)	17.70	1.73	17.51	1.57	22.08	3.60
	S (%)	0.39	0.07	0.37	0.04	0.47	0.07
	P (%)	0.68	0.10	0.72	0.10	0.75	0.15
	K (%)	1.11	0.08	1.31	0.25	1.34	0.22
Event 2							
3	TS (%)	50.98	4.05	45.64	2.81	58.14	5.74
	N (%)	2.83	0.13	2.51	0.29	3.31	0.22
	C (%)	18.75	2.01	16.71	1.18	21.27	2.11
	S (%)	0.40	0.03	0.34	0.02	0.44	0.03
	P (%)	0.61	0.06	0.66	0.07	0.75	0.10
	K (%)	1.09	0.08	0.93	0.11	1.18	0.09
4	TS (%)	53.67	6.26	49.23	3.31	63.78	3.76
	N (%)	3.02	0.14	2.88	0.13	3.63	0.34
	C (%)	19.87	2.33	17.90	1.20	23.67	1.37
	S (%)	0.42	0.03	0.37	0.02	0.48	0.02
	P (%)	0.66	0.05	0.70	0.05	0.82	0.06
	K (%)	1.15	0.09	1.02	0.09	1.30	0.15
Mean							
	TS (%)	48.21	5.01	46.63	3.82	57.79	5.39
	N (%)	2.67	0.28	2.56	0.19	3.24	0.31
	C (%)	17.64	1.93	17.29	1.14	21.59	2.34
	S (%)	0.38	0.03	0.36	0.03	0.45	0.04
	P (%)	0.64	0.08	0.67	0.06	0.76	0.10
	K (%)	1.09	0.07	1.06	0.12	1.26	0.15

Note: TS-total solids, N-nitrogen, C-carbon, S-sulfur, P-phosphorus, K-potassium

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Table 24. Characteristics of load-out manure samples of conventional cage (CC), enriched colony (EC) and aviary (AV) manure storage rooms in events 1 and 2 (wet basis).

Event	Item	CC		AV		EC	
		Mean	SD	Mean	SD	Mean	SD
1	TS (%)	48.30	7.63	55.47	6.57	50.82	6.64
	N (%)	2.03	0.65	3.03	0.53	2.71	0.62
	C (%)	15.07	2.73	19.16	1.97	16.69	2.90
	S (%)	0.43	0.07	0.39	0.05	0.32	0.04
	P (%)	0.79	0.12	0.86	0.10	0.79	0.07
	K (%)	1.29	0.13	1.35	0.19	1.39	0.11
2	TS (%)	60.83	0.80	53.98	0.33	63.73	1.65
	N (%)	3.82	0.21	3.04	0.33	4.43	0.12
	C (%)	20.91	0.10	19.28	0.29	22.83	0.62
	S (%)	0.59	0.01	0.49	0.02	0.60	0.01
	P (%)	0.99	0.01	0.85	0.02	0.93	0.04
	K (%)	1.56	0.04	1.30	0.04	1.56	0.04
Mean	TS (%)	54.57	4.22	54.73	3.45	57.27	4.15
	N (%)	2.92	0.43	3.04	0.43	3.57	0.37
	C (%)	17.99	1.41	19.22	1.13	19.76	1.76
	S (%)	0.51	0.04	0.44	0.03	0.46	0.03
	P (%)	0.89	0.07	0.85	0.06	0.86	0.06
	K (%)	1.42	0.08	1.33	0.12	1.48	0.07

Note: TS-total solids, N-nitrogen, C-carbon, S-sulfur, P-phosphorus, K-potassium

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Table 25. Manure storage event, period, and nutrient losses in conventional cage (CC), aviary (AV) and manure enriched colony (EC) storage rooms.

Manure Source		CC			AV			EC		
Manure storage event		1	2	Mean	1	2	Mean	1	2	Mean
Manure load-in period (d)		171	185	178	171	185	178	171	185	178
Storage period (d)		202	244	223	203	245	224	203	245	224
Inventory of laying-hen (hen)		12123	14717	13420	15223	14267	14745	12184	13753	12968
Manure	Load-in (kg)	149064	164455	156759	144009	140355	142182	139664	143773	141718
	Loss (%)	26.6	31.3	28.9	27.1	26.3	26.7	26.4	27.8	27.1
	Loss (g d^{-1} hen^{-1})	19.1	18.9	19.0	15.0	14.0	14.5	17.7	15.7	16.7
Total solid(TS)	Load-in (kg)	66037	86206	76122	66187	66575	66381	76886	87708	82296
	Loss (%)	20.0	20.2	20.1	12.0	16.1	14.0	32.1	24.6	28.3
	Loss (g d^{-1} hen^{-1})	6.4	6.4	6.4	3.0	4.1	3.6	11.8	8.5	10.2
	Uncertainty (%)	14.9	7.4	11.1	13.3	4.6	9.0	12.3	5.9	9.1
Nitrogen (N)	Load-in (kg)	3624	4823	4224	3499	3784	3641	4196	4992	4594
	Loss (%)	38.6	10.5	24.6	8.9	16.8	12.9	33.7	7.9	20.8
	Loss (g d^{-1} hen^{-1})	0.68	0.19	0.43	0.12	0.24	0.18	0.68	0.15	0.42
	Uncertainty (%)	23.3	5.8	14.6	17.2	10.8	14.0	17.1	6.3	11.7
Carbon (C)	Load-in (kg)	23931	31817	27874	24917	24285	24601	29145	32335	30740
	Loss (%)	31.1	25.7	28.4	19.2	17.9	18.6	41.2	26.7	33.9
	Loss (g d^{-1} hen^{-1})	3.59	3.00	3.30	1.84	1.65	1.74	5.76	3.39	4.57
	Uncertainty (%)	14.5	8.1	11.3	9.8	5.0	7.4	14.9	5.9	10.4
Sulfur (S)	Load-in (kg)	531	677	604	522	505	514	617	663	640
	Loss (%)	11.75	1.78	6.8	21.15	0.16	10.7	46.84	6.64	26.7
	Loss (g d^{-1} hen^{-1})	0.03	0.00	0.02	0.04	0.00	0.02	0.14	0.02	0.08
	Uncertainty (%)	17.1	5.5	11.3	11.7	6.0	8.9	11.9	4.5	8.2
Phosphorus (P)	Load-in (kg)	957	1051	1004	960	955	958	1019	1129	1074
	Loss (%)	9.37	-6.83	1.3	6.29	8.17	7.2	19.94	14.68	17.3
	Loss (g d^{-1} hen^{-1})	0.04	-0.03	0.01	0.02	0.03	0.03	0.10	0.07	0.08
	Uncertainty (%)	18.0	6.3	12.2	11.9	6.5	9.2	14.3	8.2	11.3
Potassium (K)	Load-in (kg)	1572	1848	1710	1668	1371	1519	1791	1785	1788
	Loss (%)	10.3	4.8	7.5	15.1	1.7	8.4	20.3	9.1	14.7
	Loss (g d^{-1} hen^{-1})	0.08	0.03	0.06	0.10	0.01	0.05	0.17	0.06	0.12
	Uncertainty (%)	9.9	6.0	7.9	16.9	8.1	12.5	12.5	7.6	10.1

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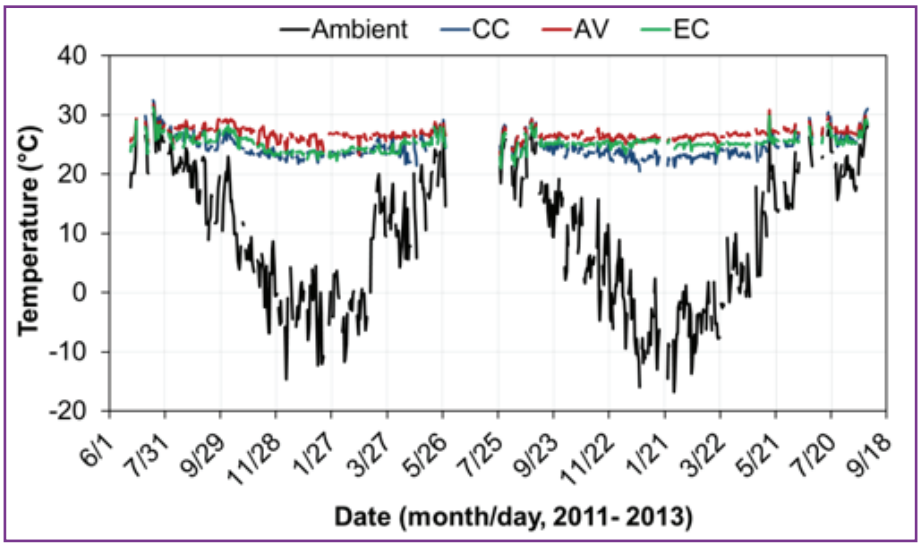

Figure 5. Daily mean ambient temperature and indoor temperatures of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses during the 2-flock production period.

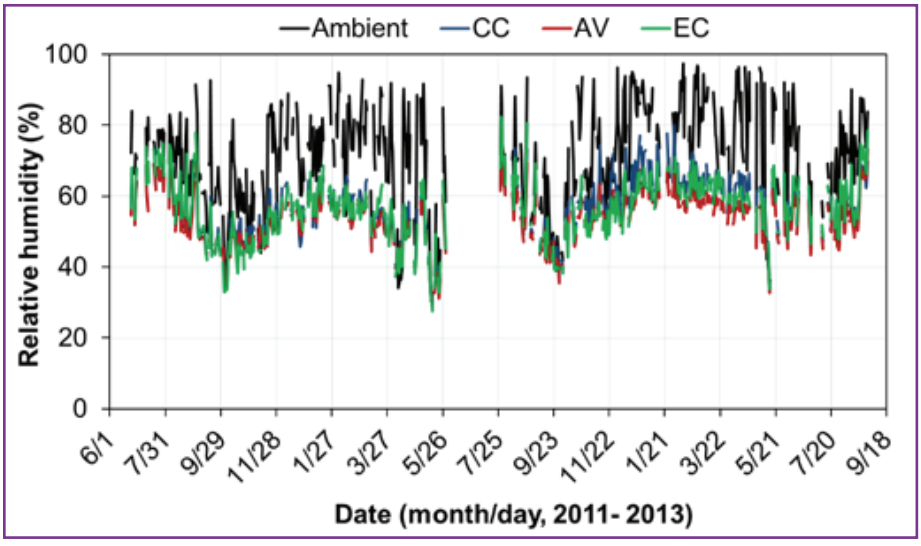

Figure 6. Daily mean ambient relative humidity (RH) and indoor RH of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses during the 2-flock production period.

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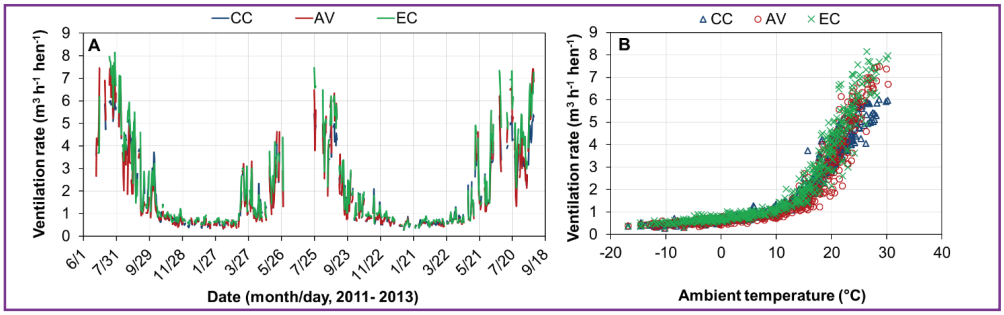

Figure 7. Daily mean ventilation rate (VR) of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses. (A) Daily mean VR; (B) Daily mean VR vs. ambient temperature.

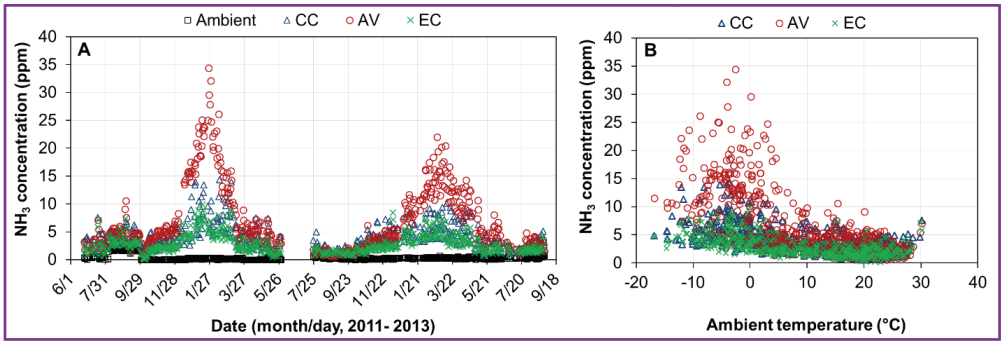

Figure 8. Daily mean ammonia (NH_3) concentrations of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses. (A) Daily mean NH_3 concentration; (B) Daily mean NH_3 concentration vs. ambient temperature.

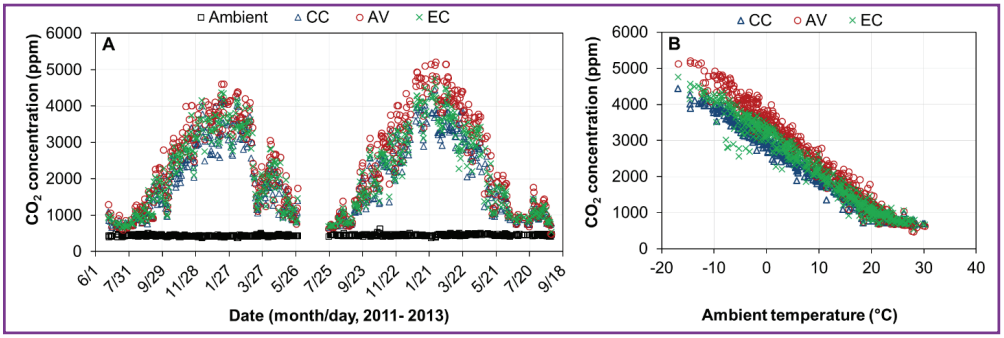

Figure 9. Daily mean carbon dioxide (CO_2) concentrations of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses. (A) Daily mean CO_2 concentration; (B) Daily mean CO_2 concentration vs. ambient temperature.

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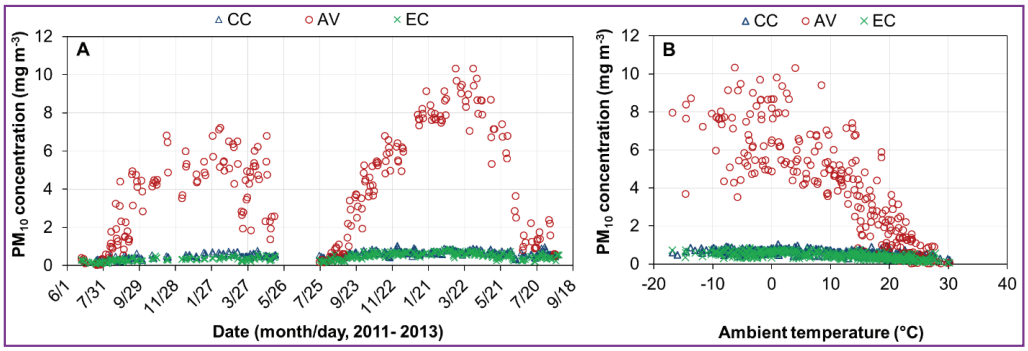

Figure 10. Daily mean carbon dioxide (CO_2) concentrations of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses. (A) Daily mean CO_2 concentration; (B) Daily mean CO_2 concentration vs. ambient temperature.

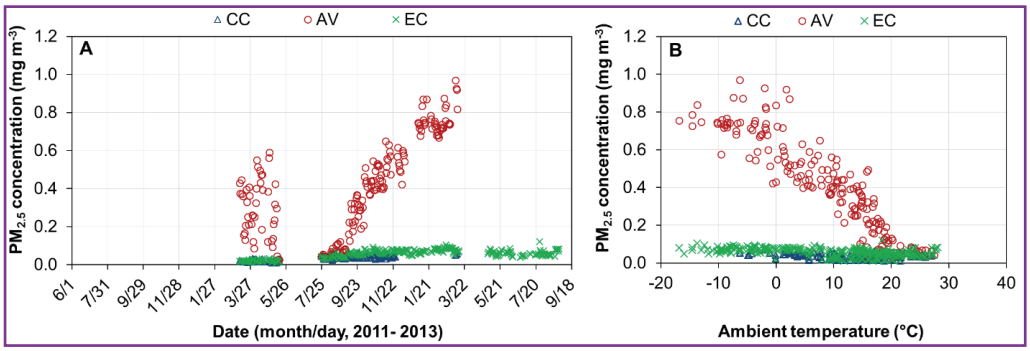

Figure 11. Daily mean $PM_{2.5}$ concentrations of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses. (A) Daily mean $PM_{2.5}$ concentration; (B) Daily mean $PM_{2.5}$ concentration vs. ambient temperature.

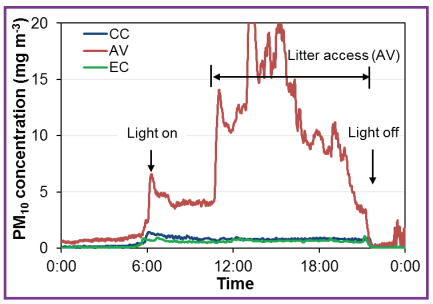

Figure 12. An example of diurnal PM_{10} concentrations of the conventional cage (CC), aviary (AV) and enriched colony (EC) houses. (A) Daily mean CO_2 concentration; (B) Daily mean CO_2 concentration vs. ambient temperature.

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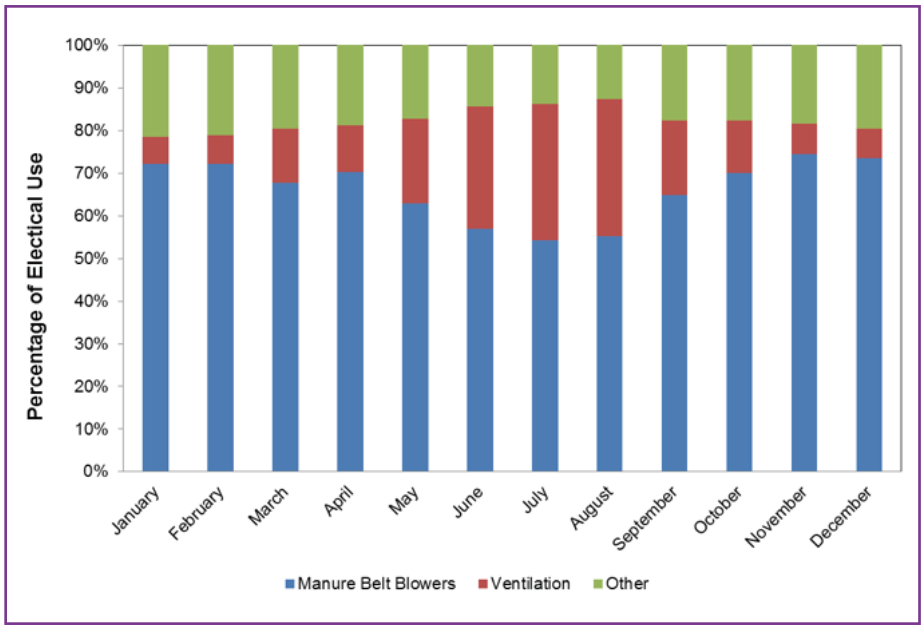

Figure 13. Electricity use distribution across all hen houses.

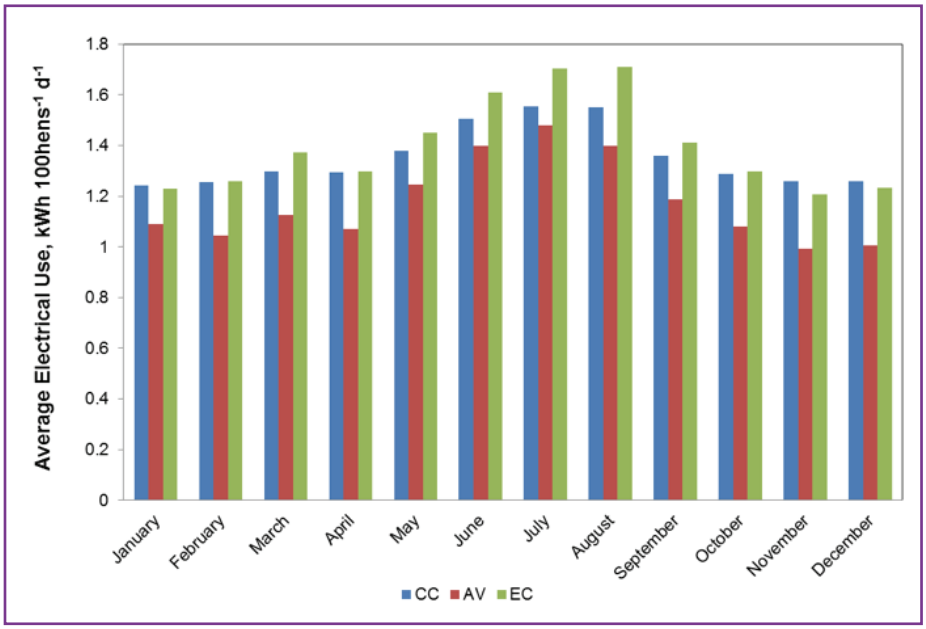

Figure 14. Average daily electricity use in the conventional cage (CC), aviary (AV) and enriched colony (EC) houses.

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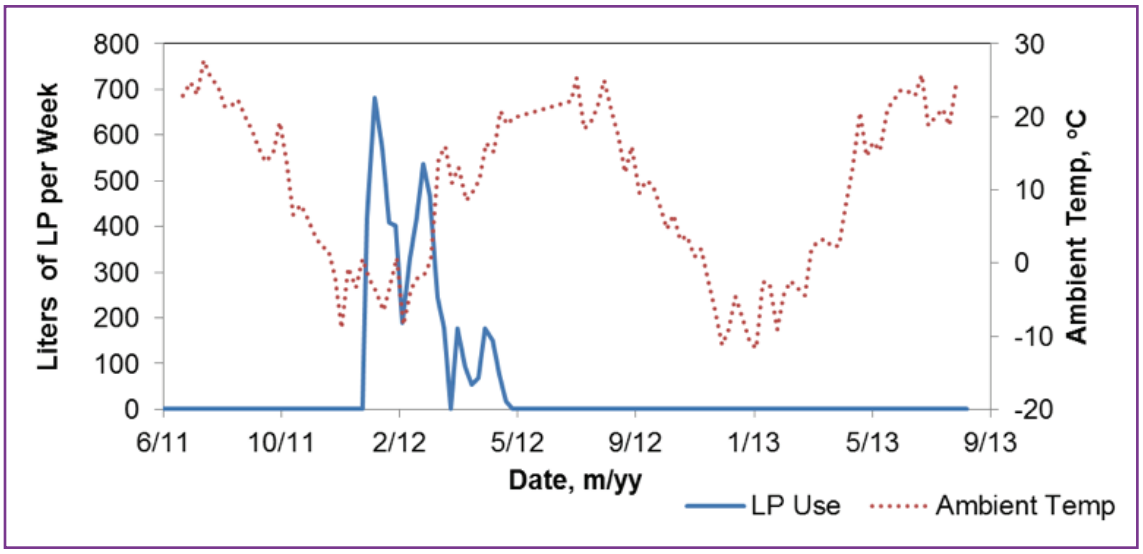

Figure 15. Weekly propane use in the aviary (AV) house.

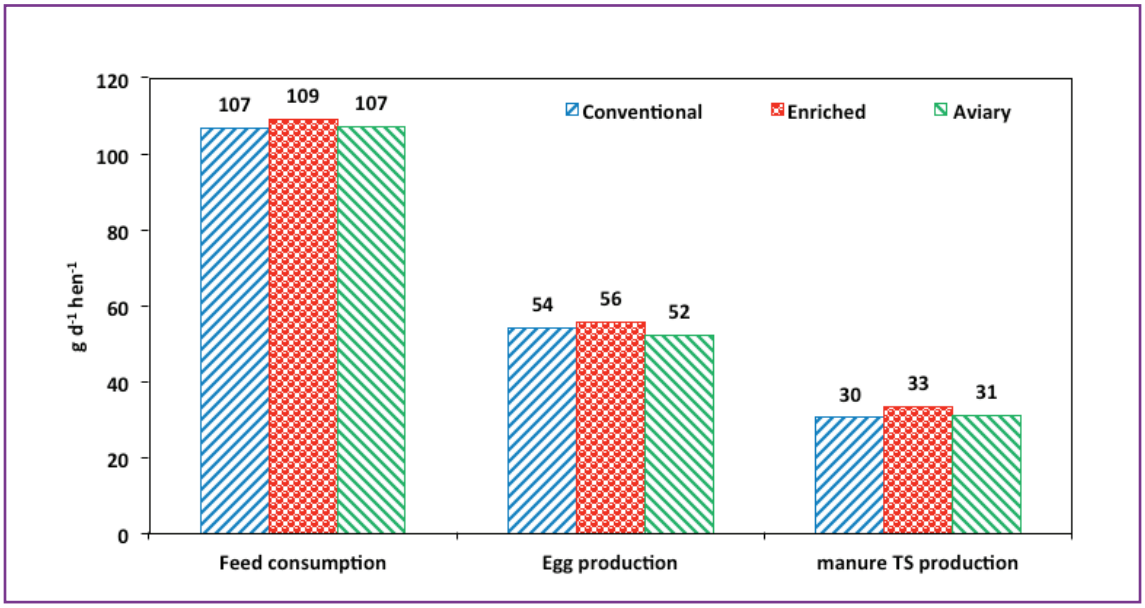

Figure 16. Feed consumption, egg production and manure (dry matter) production in different layer houses.

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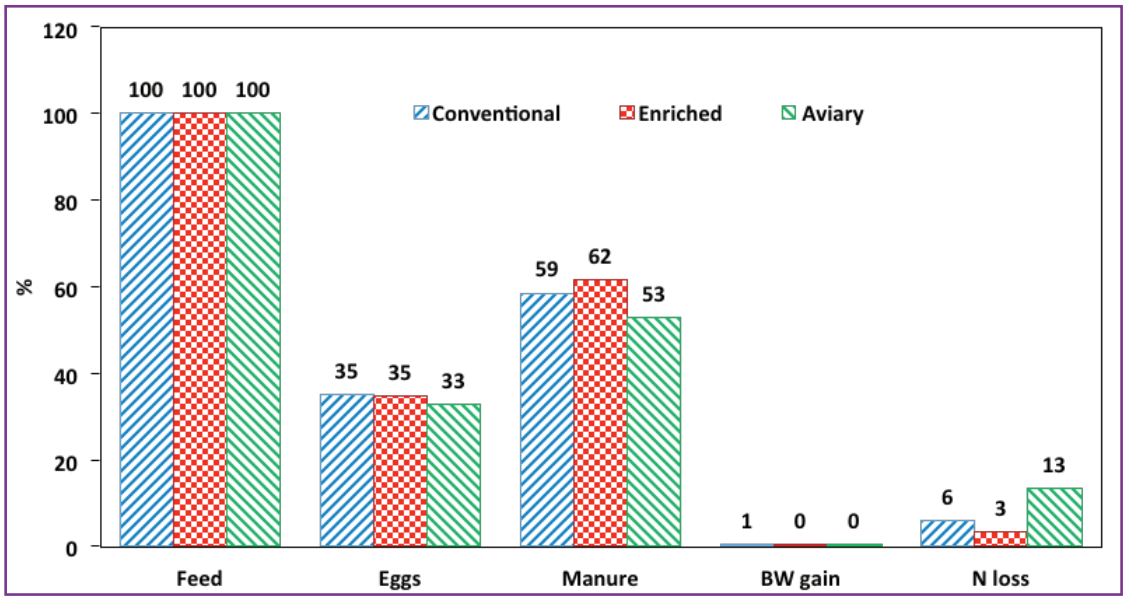

Figure 17. Nitrogen distribution at house level.

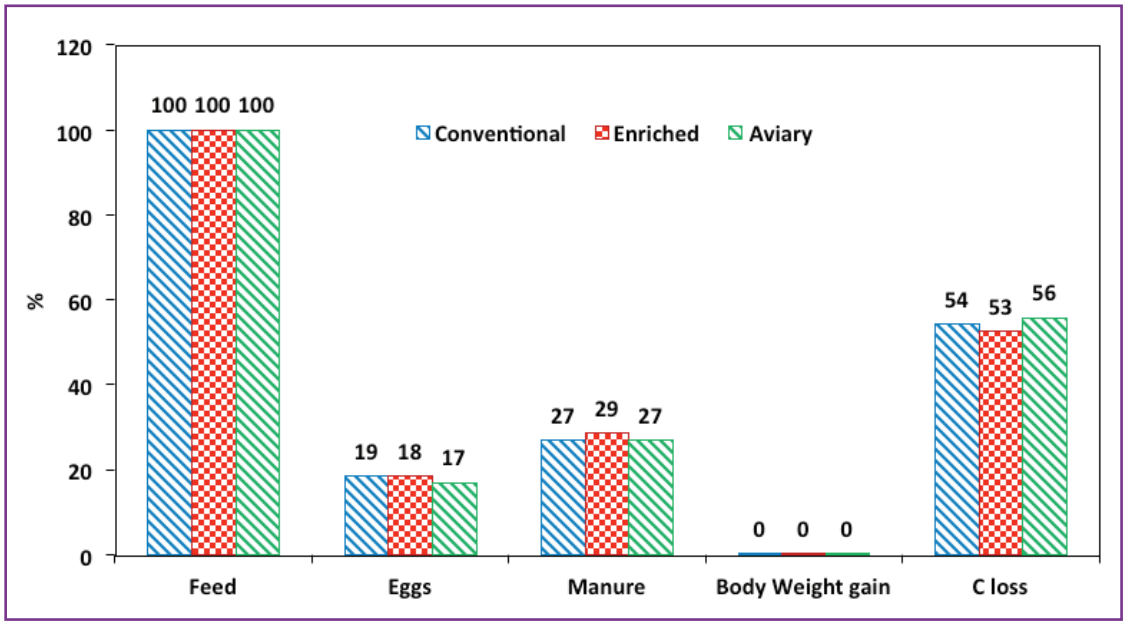

Figure 18. Carbon distribution at house level.

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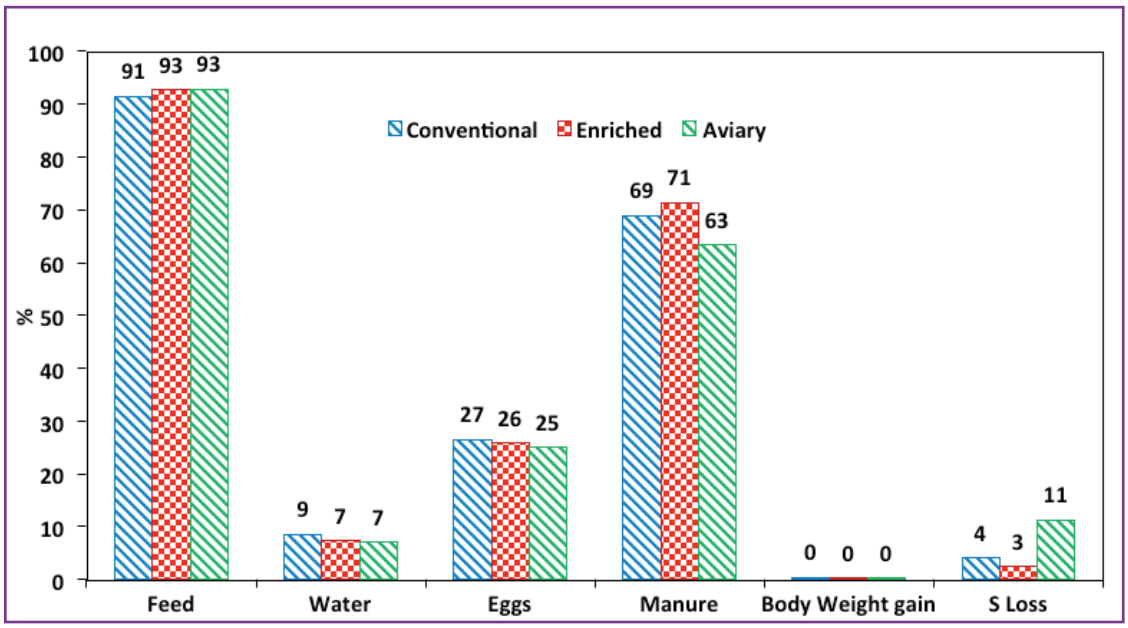

Figure 19. Sulfur distribution at house level.

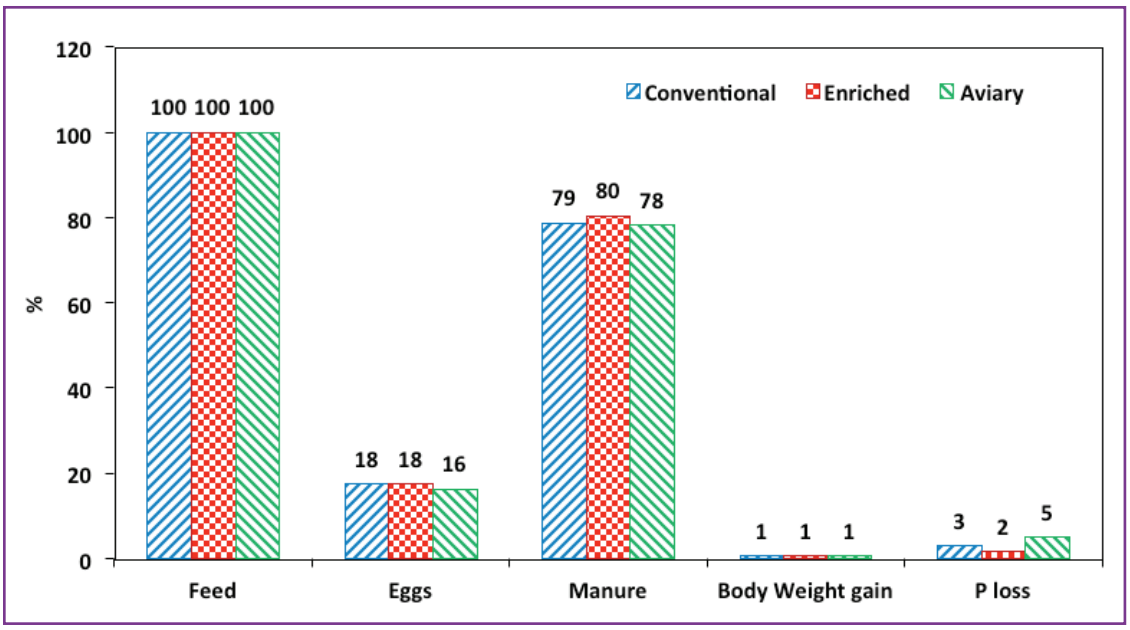

Figure 20. Phosphorus distribution at house level.

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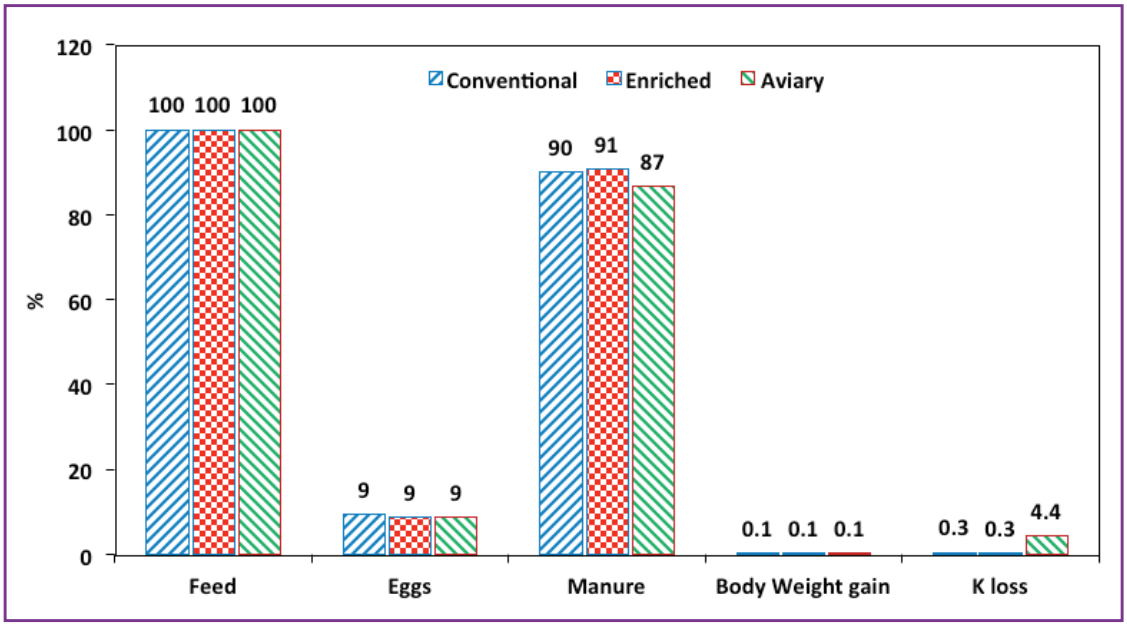

Figure 21. Potassium distribution at house level.

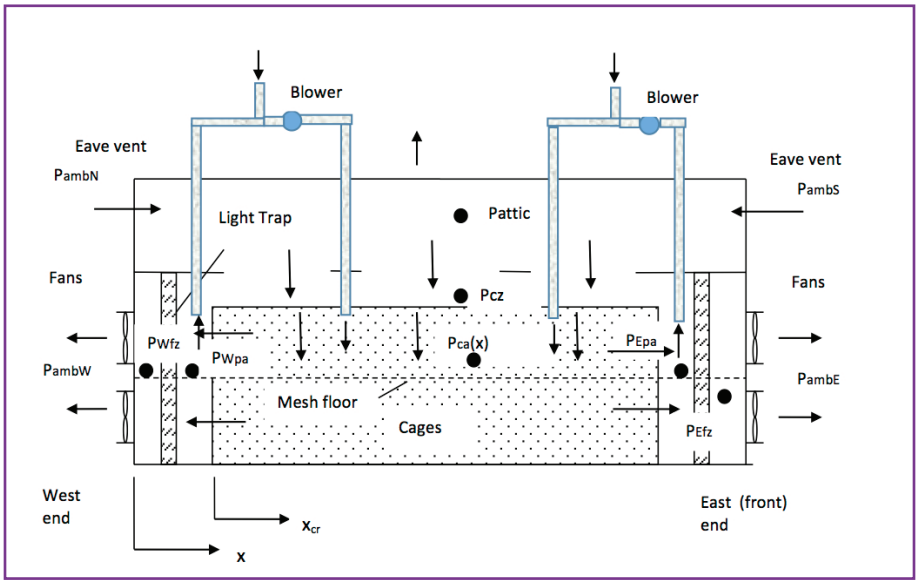

Figure 22. Schematic of air flow in conventional house used in ventilation and emission models (side view).

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Environment

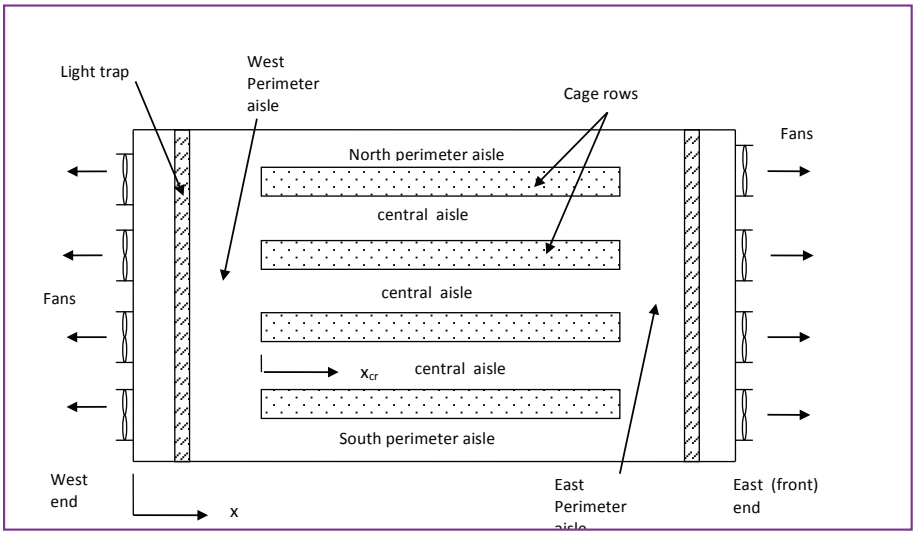

Figure 23. Schematic of air flow in conventional house used in ventilation and emission models (top view).

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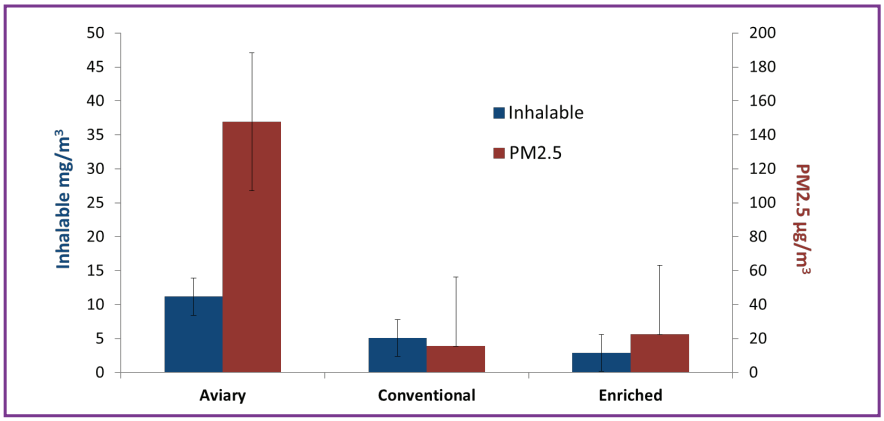
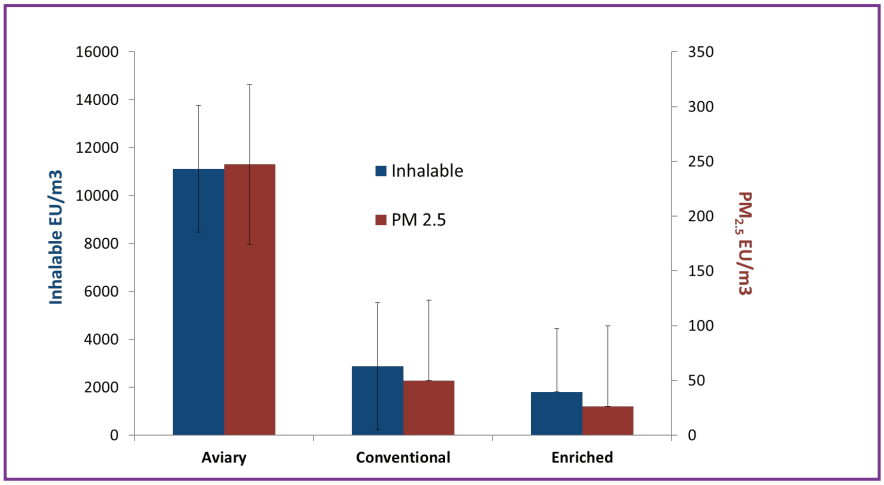
Worker Health and Safety

Figure 24a: Mean of personal inhalable and $PM_{2.5}$ concentrations by housing type.



Mean concentration /m3 and (95% Confidence Intervals)

Figure 24b: Mean of personal endotoxin concentrations in the inhalable PM and $PM_{2.5}$ fractions by housing type.



NOTES: Figure 24. At the workers breathing zone, the chart indicates that for both large particles (inhalable) and small particles capable of being breathed deep into the lung, the Aviary system had generated much larger concentrations than in either the other two systems (Fig 24a).Similarly for the endotoxin particles (fragments of bacteria) (Fig 24b). Please note that on each graph the large particles (inhalable) are in blue and the axis with their concentration is on the left. The smaller, $PM_{2.5}$ particles are in red and their axis is to the right. This information is important as it indicates the Aviary system generates far higher concentrations of potentially harmful materials in the breathing zone of the workers (not just in general emissions).

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Worker Health and Safety

Figure 25: New symptoms reported across a work shift.

	Irritated Eyes	Nasal Irritation	Throat Irritation	Cough	Mucous Phlegm	Shortness of breath	Itchy Rash
Summer							
A			2	3		1	1
C	1						
E		2					
Winter							
A		1			1		
C							
E		2			2		
Spring							
A				1			
C							1
E							

Key: The number indicates the total recorded.
Blue = Aviary, Green= Conventional, Purple= Enriched

NOTES: Figure 25. New respiratory symptoms were recorded if they occurred while the worker was on shift. Although the Aviary system (blue) had 10 new symptoms, and the Conventional Cage system only recorded two, there were so few new symptoms we could not test whether there was a true association between the Aviary and respiratory symptoms.

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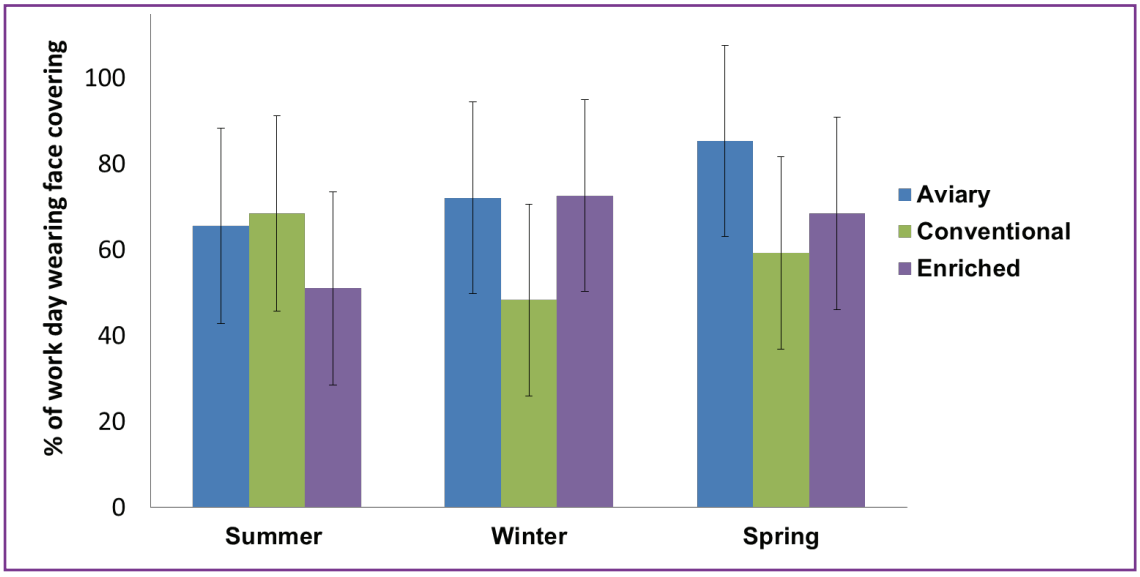
Worker Health and Safety

Figure 26: N95 Mask or Respirator use as a percentage of the work day.



NOTES: Figure 26. Mask or Respirator use was consistently highest in the Aviary system. However all workers no matter which housing they attended, frequently wore a mask. This is indicated by the vertical lines, which represent the most likely 95% range of true values (the 95% confidence interval) on the colored bars. The average percentage of the day that masks were worn was well over 50% (median = 70%), no matter what season or housing. This is important as it means they are less likely to suffer any consequences of breathing high concentrations of particles because they wear personal protective equipment so often.

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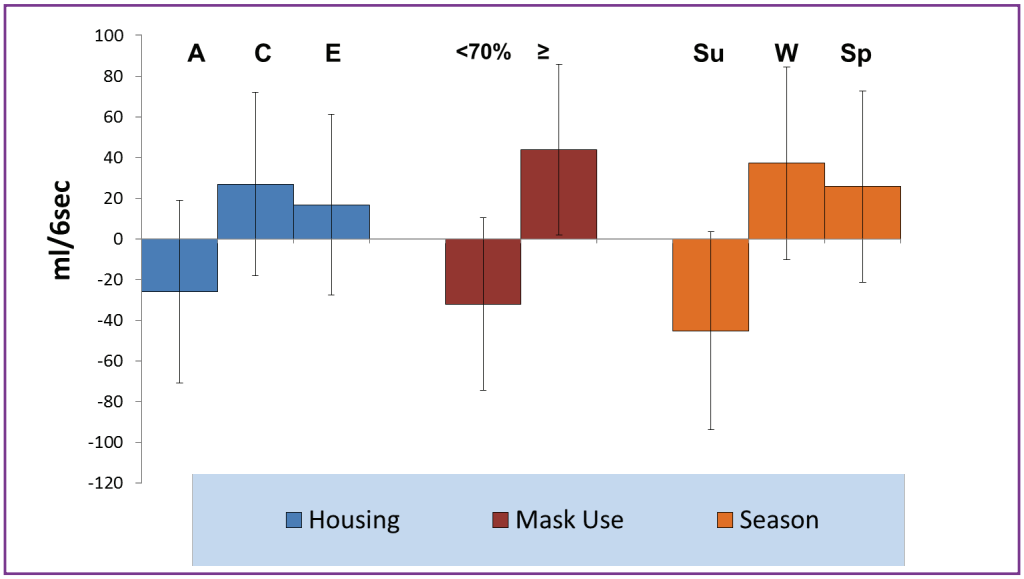
Worker Health and Safety

Figure 27: Change in Cross Shift Pulmonary Function (FEV_6): Separate Effects of House, Mask Use and Season.



Key A = Aviary, C= Conventional Housing E= Enriched Housing
<70% = mask/respirator worn less than 70% of the shift,
≥ = worn greater or equal to 70% time
Su = Summer, W = winter, Sp = spring (consecutive seasons)

NOTES: Fig 27. This chart represents one statistical model looking at a measure of lung volume (FEV_6). The mixed effects model included the housing type, % of the day a mask was worn, and the season, it also adjusted for the individual worker (each worker attended each system in a random pattern but for an equal number of days in each season).
When workers were in the Aviary system, they more often had a decrease in their lung volume as measured by the FEV_6, unlike in the other two systems, but the 95% confidence intervals (the vertical lines) indicate this result was not statistically significant. Workers who wore a mask less than 70% of the day or those working in the summer were also more likely to suffer a worse cross- shift change in their FEV_6. This indicates that there is a combined effect of season (ventilation rate is tied to season), mask use and possibly housing on the effect of a shift on workers respiratory health in poultry layer housing.

Research Results Report Appendix

Food Affordability

Table 26. Land and Facility Capital Costs by Housing System.

	Conventional[1]	Aviary	Enriched
Capital outlay		($ millions)	
Land	$0.02	$0.01	$0.01
House construction	$0.99	$1.22	$0.86
Equipment	$1.96	$0.73	$0.62
Total	$2.97	$1.96	$1.49
Annualized cost of capital outlays at constant interest plus depreciation			
5% (interest + depreciation)	$148,500	$98,000	$74,500
10% (interest + depreciation)	$297,000	$196,000	$149,000
Average eggs per year @ an average of 51 weeks of laying (dozen eggs)			
Eggs for 51 weeks production	5,079,500	1,212,900	1,243,500
Annualized cost of capital outlays per dozen eggs			
5% (interest + depreciation)	$0.029	$0.081	$0.060
10% (interest + depreciation)	$0.058	$0.162	$0.120

[1] The conventional house was built in 2004. We adjusted land, construction and equipment costs for price changes to their equivalent 2011 values using national producer price index for building construction and farm equipment and local price data for changes in land value.

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Food Affordability

Table 27. Average Operating and Capital Costs per Dozen Eggs for Each Housing System.

	Conventional	Aviary	Enriched
Feed cost	$0.425	$0.436	$0.417
Pullet cost	$0.148	$0.221	$0.143
Labor cost	$0.019	$0.074	$0.056
Energy cost	$0.014	$0.015	$0.014
Misc. cost	$0.005	$0.005	$0.005
Sum of operating costs	$0.612	$0.751	$0.636
Percentage higher operating costs compared to conventional	--	23%	4%
Capital costs (at 10%)	$0.058	$0.162	$0.120
Capital + Operating	$0.670	$0.913	$0.756
Percentage higher costs compared to conventional	--	36%	13%