

PAPER

Performance of laying hens and economic viability of different climatization systems

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Abstract

Since thermal environment affects production, egg quality and laying hens' mortality rates, it is highly relevant to control the thermal environment within poultry houses so that the best financial profits could be obtained. Three commercial poultry houses with different climatization systems are analyzed in current research: a poultry house with tunnel-like ventilation and pad cooling; a poultry house with natural ventilation and nebulization; a poultry house with simple natural ventilation. Their thermal environment, production, egg quality and laying hens' mortality rates among different poultry houses and at different areas of the same poultry house are compared. Economic profits based on difference in electric energy consumption by climatization systems and on the laying hens' productivity of each poultry house are calculated. Electricity meters were installed within the electrical circuits of the climatization and light systems of the three poultry houses. Data were registered between December 2011 and March 2012 and results showed that all the poultry houses featured heterogeneity in internal thermal environment with faults in the climatization systems. Important differences were reported in egg production and quality caused by overheating. The poultry house with tunnel-like ventilation and pad cooling had the best thermal isolation from the external environment that resulted in a 12.04% improvement in production, decrease between 30 and 40% in laying hens' mortality rates and the best economic result.

Introduction

Eggs are highly important products within Brazilian economy and their production has grown during the last decades. Brazil produced 2.62 billion dozens of egg between April 2011 and March 2012, with an 8.9% increase during this period (IBGE, 2012). The municipality of Bastos and the surrounding region, in the Brazilian state of São Paulo, is one of the main egg producing regions, with an annual produce of 534.36 millions of dozens of eggs or 46.7% of the state produce (IEA, 2012) and 20.4% of Brazilian total produce.

The city of Bastos is characterized by tropical climate with well-defined dry winters. According to Salgado and Nääs (2010), the region within the state of São Paulo is prone to daily high temperatures. Even though the issue is rather seasonal with variable duration, its effects on poultry rearing are economically relevant since they may affect production, egg quality and death rates increase (Jácome *et al.*, 2007; Trindade *et al.*, 2007). Thermal discomfort in laying hens triggers a variety of consequences closely linked to a fall in diet consumption, decrease in growth rate, high water intake, acceleration of heart beating, changes in feed conversion, loss in egg production and high incidences of soft eggshells (Tinôco, 2001; Silva *et al.*, 2005; Jácome *et al.*, 2007). Due to the region severe hot climate, especially in the summer, poultry breeders in the Bastos region installed climatization systems in the poultry houses so that the thermal stress effects on production would decrease. However, climatized poultry houses in the region are rare, perhaps due to the breeders' belief that the system operation costs are higher than the production economical gains. The amount of benefits brought about by climatization in poultry production may contribute towards the breeders' decision to invest in climatization systems.

The current research presumes that the internal environment control of laying hens poultry house would provide a better production performance in poultry and better economic earnings. So as to verify the above hypothesis, the current research analyzed three commercial poultry houses with different climatization systems and compared the internal thermal environment, egg production and quality, and death rates of laying hens among the different poultry houses and at the different areas of the same poultry house. Differences were calculated for economic profits based on the difference in electricity consumption used by the climatization systems

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and on the laying hens productivity differences among the poultry houses.

Materials and methods

The experiment was undertaken in three commercial egg production houses, each with a different climatization system. The rearing system in all poultry houses consisted of vertical cages with laying hens of the Dekalb White strain. The poultry houses were on the same farm, in the municipality of Bastos, SP, Brazil, at 21°56'001"S and 50°44'527"W, altitude 441 m asl.

The poultry houses were evaluated during three 21-day production cycles, between January and March 2012. The period comprised months with intense heat in the region and thus the possible positive effects of the climatization systems on death rates and production were verified. The three poultry houses were labeled A1, A2 and A3. A1 had an adiabatic evaporation climatization system with 12

exhausts installed on the east side and a pad-cooling device on the west side, providing a negative pressure ventilation system. A2 had a natural ventilation system provided by an opening on the north and south sides and a nebulization system over the laying hens. A3, the only one with a ventilation dome, had a natural ventilation system provided by openings on the north and south sides. It was not possible to monitor same-age laying hens in all the poultry houses since the farm had commercial aims. At the beginning of the experiment, there were 55,160 37-week-old laying hens in A1; 37,530 22-week-old laying hens in A2; 33,270 71-week-old laying hens in A3. The great difference in laying hens quantity in A1 was due to the installed climatization system and its dimensions, which were 125 m × 10.5 m, allowing installing three batteries of six cages at the time. The other sheds were smaller (110 m × 9 m) and had two batteries of five cages. The cages in all sheds were identical, being made of wire and having dimensions of 50 cm × 60 cm × 53 cm (width × depth × height), and housed groups of 9 to 10 birds, giving a density 333-300 cm² bird⁻¹ at the beginning of the housing lots. All poultry houses were built on steel structures with asbestos-cement tiles from east to west. The east and west sides were of sheet metal and the north and south sides were blue curtains. Because of the climate system A1, side curtains remained closed and the lighting was fully provided by compact fluorescent lamps. The other sheds they adopted mixed lighting (natural and compact fluorescent lamps) and the curtains were only partially closed overnight. In the poultry house A1 thermal environment and production were evaluated longitudinally distributed among three sectors, *i.e.* in the direction of cooling pad for the fans. In the other sheds, the thermal environment was assessed between distributed across three lines, taking advantage of the runners, and production distributed across four lines (sides of battery cages).

Three data loggers, Onset[®] Hobo U12-013, were installed in each poultry house to monitor the variables dry bulb temperature ($\pm 0.4^{\circ}\text{C}$), black globe temperature ($\pm 2.5\%$ absolute reading) and relative air humidity ($\pm 2.5\%$). Reports were taken every 30 min. Devices were installed in the corridors at different heights, namely, 2.5 m (high), 1.5 m (medium) and 0.8 m (low). The environmental variables were registered on a hot day for the three heights (0.8 m, 1.5 m and 2.5 m) to analyze the distribution of thermal environment within the poultry houses. Whereas 40 equidistant spots were selected at each height in A1, 30 equidistant spots were chosen for A2 and A3, using

Heat Stress Meter HT30 from EXTECH[®]. The device is furnished with a 3.5% precision for temperature; 5% for relative humidity and 3.5% for black globe temperature. Due to the time taken to cover the poultry house area and the time needed so that the apparatus would stabilize the measurements, data registry started at 10h00 and ended at 19h00, with

approximately 9 hours of data recording. The correction of time difference among the registers and the comparison of internal environments among the poultry house was performed by methodology following Gabriel Filho *et al.* (2011) to correct the variables of thermal environment at 14h00 as from environment data collected by the Hobos apparatuses in each

Table 1. Multiplication coefficients to normalize production between lots.

	Experiment weeks								
	1	2	3	4	5	6	7	8	9
A1	1.06	1.06	1.06	1.06	1.07	1.07	1.08	1.08	1.08
A2	1.41	1.23	1.18	1.10	1.09	1.08	1.08	1.08	1.06
A3	1.23	1.25	1.26	1.27	1.29	1.31	1.33	1.34	1.37

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation.

Table 2. Comparison of internal environment of the three laying hens houses.

	Temperature	Relative humidity	Black globe temperature
A1	25.40 ^c	81.50 ^a	25.67 ^b
A2	26.30 ^a	70.26 ^b	27.59 ^b
A3	26.83 ^b	70.66 ^b	27.19 ^a

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation. ^{a,b,c}Different letters on the same column indicate significant difference by Kruskal Wallis test at 5%.

Table 3. Variation of Black Globe and Humidity Index in the poultry houses at 14h00.

	A1		
	Sector 1	Sector 2	Sector 3
High	72.47 \pm 2.43 ^{Cb}	76.92 \pm 2.24 ^B	79.10 \pm 1.71 ^A
Medium	72.24 \pm 1.86 ^{Cb}	75.86 \pm 2.18 ^B	78.21 \pm 1.01 ^A
Low	75.40 \pm 1.12 ^{Ba}	77.55 \pm 1.54 ^A	79.22 \pm 0.82 ^A
	A2		
	Line 1	Line 2	Line 3
High	81.38 \pm 0.42 ^{Aa}	79.03 \pm 0.27 ^{Ba}	80.95 \pm 0.39 ^{Aa}
Medium	80.56 \pm 0.43 ^{Ab}	79.15 \pm 0.36 ^{Ba}	80.49 \pm 0.89 ^{Aa}
Low	77.49 \pm 0.37 ^{Ac}	76.40 \pm 0.75 ^{Bb}	77.77 \pm 0.39 ^{Ab}
	A3		
	Line 1	Line 2	Line 3
High	81.93 \pm 1.58 ^{Aa}	79.28 \pm 0.83 ^B	76.29 \pm 0.33 ^{Cb}
Medium	77.82 \pm 1.71 ^{Bb}	79.69 \pm 1.73 ^A	80.76 \pm 0.36 ^{Aa}
Low	81.89 \pm 1.31 ^{Aa}	78.50 \pm 0.45 ^B	77.49 \pm 0.20 ^{Bb}

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation; high, 2.5 m; medium, 1.5 m; low, 0.8 m. ^{a,b,c}Different letters in the lines indicate significant differences by Tukey's test at 5% in GTHI means among the sectors at the same height. ^{A,B,C}Different letters in the columns indicate significant differences by Tukey's test at 5% in GTHI means among heights of the same sector.

poultry house. Black Globe and Humidity Index (BGHI) was calculated from the collected variables by formula (Buffington *et al.*, 1981):

$$\text{BGHI} = \text{Tbg} + 0.36 \times \text{Tdp} - 330.08 \quad (\text{eq. 1})$$

where

Tbg, black globe temperature;

Tdp, dew point temperature, calculated by dry bulb temperature and relative humidity employing psychometric equations.

External environment was monitored by the meteorological station Hobo U30-ETH from Onset[®], installed on the Tupã UNESP campus, some 20 km from the poultry houses under analysis. So that the variables such as production, death rates and egg quality could be monitored, the poultry houses were divided into three longitudinal sectors in the case of A1 or transversal lines in the case of A2 and A3, at three heights, featuring low (0.8 m), medium (1.5 m) and high (2.5 m). Consequently, the variables could be compared within sectors, lines and heights of the poultry house. Thirty cages were chosen within each sector (or line), 10 for each height so that there would be 10 cages per sector. Each cage was labeled and a device was set to hold the eggs. There were thus 30 cages for each sector (or line) and 30 cages for each height to compare analyses among the regions of each poultry house. The number of eggs laid and the number of laying hens in each identified cage were registered daily for percentage of eggs placed by the laying hens in each cage. Total daily mortality rates in the poultry houses were monitored by taking into account the sectors (or lines) and the heights where dead laying hens were found and collected. Egg quality was analyzed for all eggs collected in the identified cages of each poultry house during the last three days of each production cycle. DET6000 from NABEL[®] measured the variables such as egg weight, shell resistance, shell thickness, albumen height, yolk color and Haugh unity.

Production and death rate data for each poultry house were compared and the influence of the different climatization systems was evaluated. The expected production curve provided by the Dekalb White strain management handbook was employed to compare production. When the laying hens' initial age in the experiment and the expected production curve of the Dekalb White strain were known (Granja Planalto, 2011), the production rates registered in the experiment were multiplied by the coefficients in Table 1 to normalize the rates of the three lots. Variables among the poultry houses could thus be compared. Egg quality was compared only between the sectors and

heights of the same poultry house so that the influence of heterogeneity of the thermal environment in each poultry house on the loss of egg quality could be verified. Production and death rates were also evaluated between the poultry house sectors and heights and comparison of the above factors was undertaken between the poultry houses.

Smart Meter from IMS[®] for monitoring consumption of electricity by the climatization and lighting systems was installed to assess and compare the consumption of electricity spent by the different climatization systems. Lighting system functioning in A1 was different from that of the other poultry houses. In this case, the lamps were left on during the whole illumination period and thus the lighting circuits were monitored too. Moreover, the lighting and exhausts circuits were very distant in A1 and two Smart Meters were installed in the poultry house. Registers were taken every 30 min from 21st December 2011 to 24th March 2012.

To know the effect of the environment on production, egg quality and mortality a randomized design was used, in which the treatments were organized according to the 3×3 factorial design (height x sector). In assessing the consumption of electricity among poultry houses used a delineation used was randomized where treatments were the poultry houses

and repetitions day of production cycles. Data on the environment, consumption of electric power, egg production and quality were analyzed by parametric statistics and Tukey's comparative test at 5% probability. Data on mortality rates were analyzed by non-parametric statistics and Kruskal-Wallis mean comparative test at 5% probability was employed. Statistical analyses were performed by MINITAB 16[®].

Economic feasibility was estimated by calculating the Gross Operational Profit for each poultry house. Since differences between production costs were limited to electricity consumption of the different climatization and lighting systems, the following formula was employed:

$$\text{Gross Operational Profit} = \text{Income} - \text{Tax} - (\text{C}_{\text{ee climatization}} + \text{C}) \quad (\text{eq. 2})$$

where

C_{ee}, costs of electricity for the climatization system;

C, other production costs.

Since different numbers of laying hens were in the poultry houses, electricity consumption and Gross Operational Profit were calculated for groups of 1000 laying hens and, consequently, a comparison could be undertaken between the poultry houses.

This is an observational study comparing

Table 4. Percentage variation of normalized production in the interior of the poultry houses under analysis.

A1				
	Sector 1	Sector 2	Sector 3	
High	1.15±0.33	1.13±0.54	1.14±0.36	
Medium	1.11±0.33	1.08±0.33	1.15±0.62	
Low	1.11±0.31	1.08±0.33	1.12±0.52	
A2				
	Line 1	Line 2	Line 3	Line 4
High	1.00±0.40 ^B	1.02±0.44 ^{AB}	1.11±0.48 ^{Aa}	1.01±0.43 ^B
Medium	1.07±0.45	1.01±0.42	1.01±0.44 ^{ab}	1.05±0.47
Low	1.06±0.42	1.01±0.41	1.08±0.46 ^b	1.07±0.44
A3				
	Line 1	Line 2	Line 3	Line 4
High	1.13±0.40 ^{ABa}	1.03±0.35 ^A _{Ba}	0.96±0.37 ^{Bb}	1.05±0.39 ^{ABa}
Medium	1.05±0.37 ^{ABab}	1.04±0.88 ^{ABa}	1.09±0.45 ^{Aa}	1.01±0.36 ^{Ba}
Low	0.97±0.29 ^{Ab}	0.83±0.34 ^{Bb}	0.83±0.34 ^{Bc}	0.88±0.30 ^{Ab}

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation; high, 2.5 m; medium, 1.5 m; low, 0.8 m. ^{a,b,c}Different letters in the lines indicate significant differences by Tukey's at 5% probability in production means among the sectors or lines of the same height. ^{A,B,C}Different letters in the columns indicate significant differences by Tukey's test at 5% probability in production means among the heights of the same sector or line.

non-invasive in which the treatments were not randomly assigned to experimental units. The aim was to monitor the variables of interest and compare them to actual production conditions. Within each poultry house (climate system), data were recorded in regions bounded by the height of the shed and sectors or line that allowed comparing the variables of interest between regions within the same poultry house, detailing how each variable better behaved inside each poultry house.

Among the climate systems applied to analysis of variance (ANOVA) followed by Tukey test at 5% probability to analyze the differences between the variables of the thermal environment and the corrected normalized average production of the entire plant, and between regions within each poultry house.

Results and discussion

External climatic variables during the experimental period were monitored by the meteorological station on the UNESP Tupã campus. Figure 1 shows the behaviour of climatic variables during the period. According to Jácóme *et al.* (2007), temperature range for laying hens may vary between 15°C and 28°C, whereas relative air humidity may vary between 40% and 80%. Vale *et al.* (2008) reported that local wind speed above 1.4 m s⁻¹ and dry bulb temperature above 24°C would cause high mortality rates in meat chickens.

Figure 1 shows that the sheds' external environment was within the literature-established thermo-neutrality zone during most of the time. Favourable environment affected positively all the evaluated laying hens lots and decreased the expected effects by the climatized systems installed in two poultry houses. Figure 1d shows that regular and well-distributed rainfall during the experimental period influenced relative air humidity and raised it above thermo-neutrality limits (Figure 1b) in days of more intense rainfall.

The internal environment of each poultry house was compared by Kruskal Wallis test at 5% probability, as Table 2 demonstrates. The results in Table 2 showed that air temperature in the poultry house with tunnel-like ventilation and cooling by evaporation (A1) was significantly lower than that in the other poultry houses. Black globe temperature in the poultry house with only natural ventilation (A3) was significantly higher. Even if the external environment contributed towards the maintenance of the internal thermal environment within thermo-neutrality limits, the climatized poultry

house provided a more moderate thermal environment.

Figure 2 shows the Black Globe Temperature and Humidity Index (BGHI) variation for all the monitored poultry houses, at the three height levels, at 14h00. The graph of Figure 2 shows that there was a gradual heating in the direction of the shed's exhausts. According to Abreu and Abreu (2011), static pressure equilibrium is required throughout the entire poultry house and it should be related to the exhausts number and capacity. The exhausts outlets are also important to seal the laying hens poultry house when these are switched off. Deficient sealing will require a greater number of exhausts to achieve the required negative pressure. If such requirement is not met with, a lack of equilibrium ensues in the shed's internal temperature, coupled to other problems with uniformity of laying hens lots. Temperature rose, especially at the shed starting point, for cages placed at the bottom. It was verified that the area close to the exhausts in A1 with tunnel-type ventilation had a temperature above the upper limit of thermo-neutrality even though the external environment was within thermo-neutral patterns (BGHI >76; Jácóme *et al.*, 2007).

Figure 2b shows BGHI variation within the poultry house with natural ventilation and nebulization. The environmental temperature was higher throughout the shed extension when compared with that of the poultry house with

cooling by evaporation. Figure 2c shows thermal variation within the poultry house with only natural ventilation. Graphs demonstrate that the thermal environment varied in a north-south direction of the side openings. This fact, which characterized the ventilation flow of that particular day, was also reported in the poultry house with nebulization. The south side of this poultry house was prone to be hotter than the north side. Taking into account the three heights in all the poultry houses and dividing poultry house A1 into three sections lengthwise, and A2 and A3 into three lines in width, Table 3 shows the following differences with regard to the thermal environment within the interior of the poultry house.

The results on Table 3 show environment heating in the direction of the exhausts in A1. It was also perceived that, in the case of height, the cages in the lower part had the worst environmental conditions at the beginning of the poultry house, even though thermo-neutrality limits were observed. It has been verified that the high section of A2 was hotter and that the shed's central line had a more moderate temperature. A3 without any climatization system presented a randomized varied thermal environment. Since poultry house A3 had a chimney-effect ventilation dome, the latter might have influenced air circulation to such an extent that a temperature gradient pattern could not be observed within the heights and lines under analysis.

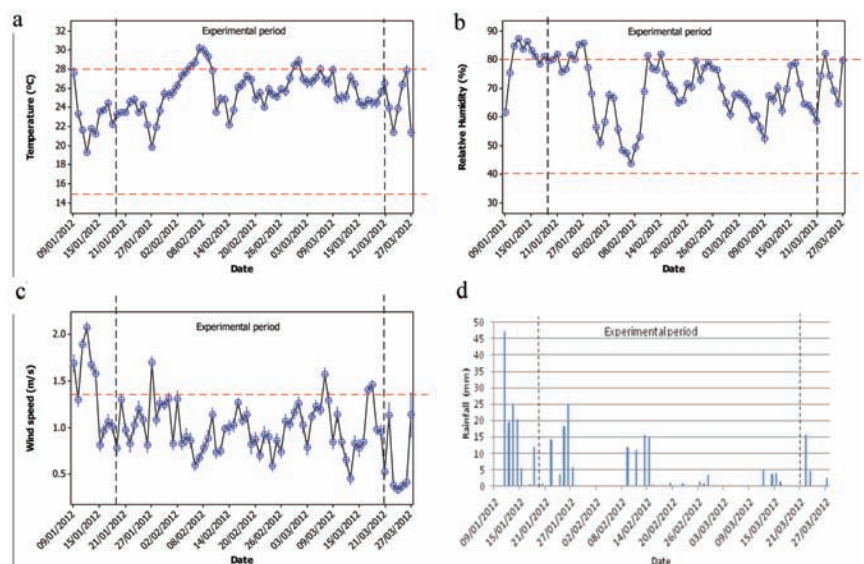


Figure 1. Variation of air temperature (a), relative humidity (b), wind speed (c), and daily rainfall (d) during the experimental period measured at the meteorological station.

A significant difference was reported in laying hens' production in the three poultry houses by Tukey's test at 5% probability. Laying hens in A1 with tunnel-type ventilation system and pad cooling had a 12.04% rise in production than estimates expected from Dekalb White laying hens strains. Whereas A2 with natural ventilation and nebulization system provided a 4.16% performance increase than expected, A3 without any climatization system showed a 1.65% fall in expected performance.

Owing to differences in the thermal environment in the poultry houses, Table 4 shows normalized mean percentages in production among the inner sections of each poultry house, as well as better production homogeneity in the climatized poultry houses. A3 with no climatized apparatus demonstrates great production variability, with the worst performance provided by the cages placed at the lowest sections. Cages placed at line 3 in nebulization-provided A2 had a significantly better production performance than those of the other sectors. No difference in the laying hens' production performance was registered in A1 featuring tunnel-type ventilation. Tukey's statistical test showed the differences in egg quality at specific areas within the interior of each poultry house. Table 5 shows results in egg analysis for A1, revealing that there was a loss in egg weight from laying hens in low- and high-placed cages, according to their closeness to exhausts. Weight loss was caused by the hotter thermal environment close to the exhausts. Table 6 shows variability in egg quality in A2. No difference in egg quality was reported within the different areas under analysis. Table 7 shows egg quality variability in A3. Difference in egg weight was reported within the different lines in the low-placed cages. Eggshell quality in the central lines and at low height had a worse performance than that in other areas of the poultry house. Laying hens' death rates were calculated and rates among the poultry houses were compared by Kruskal-Wallis non-parametric test at 5% probability. Mortality rates in A1 were 39.5% less ($P < 0.05$) than that in A3 and 32.2% less ($P < 0.05$) than that in A2. No significant ($P > 0.05$) difference was reported in death rates in A2 and A3.

Since A1 provided better insulation from the external environment, mortality rates were lower, as Figure 3 shows. A positive and significant co-relationship ($P < 0.05$) was reported in the mortality rates of A2 and A3 with mean external temperature. Due to differences in the thermal environment within the poultry houses, mortality rates among these areas for each poultry house were compared by Kruskal-Wallis non-parametric test at 5% probability.

Figure 4 shows that low-placed cages had higher mortality rates than those of laying hens in the other cages and in all poultry houses. Results may be associated to deficient ventilation at this height. Variation in mortality rates was reported in A1 lengthwise (from the pad cooling to the exhausts). Figure 5 shows results for mortality rates within the same poultry house by Kruskal-Wallis non-parametric test at 5%. A lower mortality rates were registered in the cages close to the pad-cooling.

Register of electricity amounts were initially analyzed to verify the quality of electricity supply in each poultry house. According to Mosko *et al.* (2010), electricity consumption is a high factor in industrial production costs. Consequently, the rational use of engines and electricity must be taken into account when dealing with agricultural and cattle-raising sectors. Gains in energy efficiency should be dealt with as financial, environmental and social gains. Increase in the exhausts usage

time is a consequence of an increase in animal density so that heat stress could be avoided and, consequently, a rise in electricity consumption (Bueno and Rossi, 2006). Used electricity is highly relevant in calculating production costs. Eighty-one electricity interruptions for the exhausts and 14 interruptions for lighting in A1 were reported. Difference in electricity interruption in two different circuits in the same poultry house indicated that exhaust load was above the capacity of the installed circuit. Nineteen electricity interruptions were verified in the poultry house with ventilation and nebulization. On the other hand, fifty electricity interruptions were reported in the poultry house with natural ventilation. It may be surmised that electricity in the poultry house was being used in a non-sustainable way and caused an increase in electricity use, coupled to high tariffs and unnecessary additional costs.

Electric tension measured by nominal elec-

Table 5. Quality variation of eggs in A1 poultry house with tunnel ventilation and pad cooling.

	Sector 1	Sector 2	Sector 3
Weight of egg, g			
High	61.73±4.27 ^A	60.21±4.65 ^{AB}	58.74±4.30 ^B
Medium	62.81±4.69	59.85±3.94	60.38±4.28
Low	61.66±5.49 ^A	61.41±4.74 ^A	59.03±4.63 ^B
Height of albumen, mm			
High	7.09±1.28	6.99±1.24	7.09±1.11
Medium	7.15±1.22	7.17±1.36	7.03±1.17
Low	7.42±1.27	7.24±1.15	6.94±1.20
Yolk color			
High	5.55±0.58	5.45±0.48	5.53±0.58
Medium	5.46±0.66	5.38±0.59	5.34±0.72
Low	5.47±0.74	5.42±0.68	5.25±0.77
Haugh unit			
High	83.05±8.67	82.86±8.45	84.11±6.76
Medium	83.79±7.93	83.87±8.71	83.20±7.36
Low	84.54±9.67	84.41±6.94	83.38±7.94
Egg shell resistance, N			
High	41.58±9.21	41.18±8.04	42.07±6.86
Medium	42.46±7.65	41.77±8.63	39.52±7.74
Low	41.38±7.25 ^A	41.58±8.53 ^{AB}	38.83±9.12 ^B
Eggshell thickness, mm			
High	0.3977±0.0342	0.3978±0.0402	0.3962±0.0354
Medium	0.4053±0.0387	0.4006±0.0402	0.4009±0.0395
Low	0.3986±0.0381	0.4007±0.0369	0.4019±0.0448

High, 2.5 m; medium, 1.5 m; low, 0.8 m. ^{AB}Different letters in the lines indicate significant differences by Tukey's test at 5% probability in the means of the variable among the sectors of the same height.

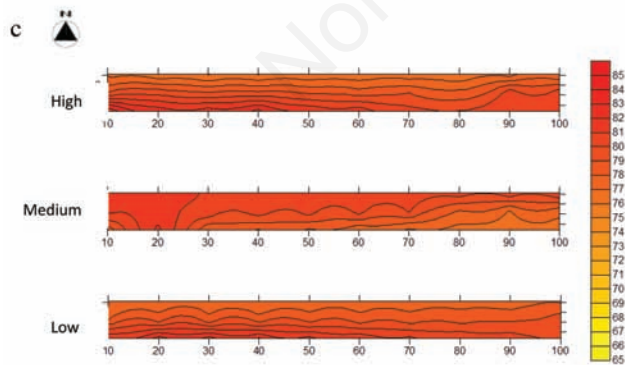
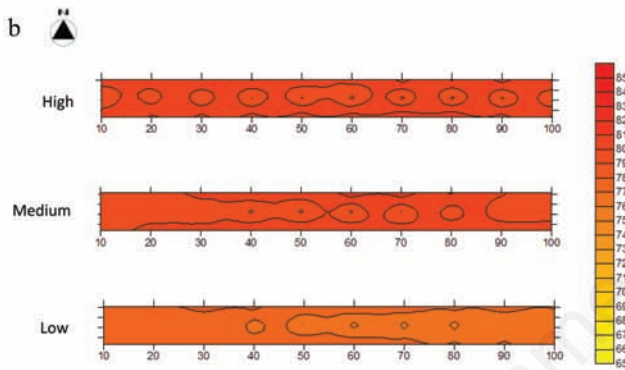
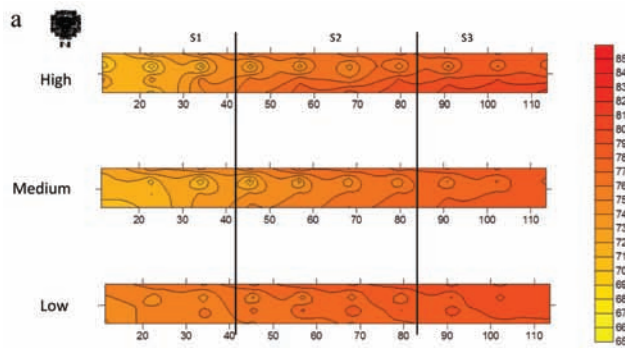


Figure 2. BGHI spatial variation for poultry houses with: a) tunnel-type ventilation system and cooling by evaporation; b) natural ventilation and nebulization system; c) natural ventilation system at 14h00.

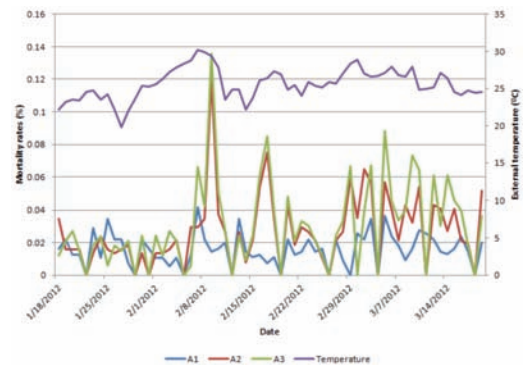


Figure 3. Mean daily external temperature variation and mortality rate in the three poultry houses under analysis. A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation.

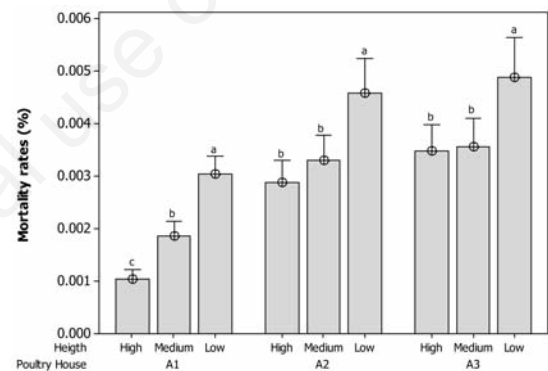


Figure 4. Mortality rates of laying hens at different heights in each poultry house. A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation. Different letters indicate significant difference at 5% probability by Kruskal-Wallis non-parametric test.

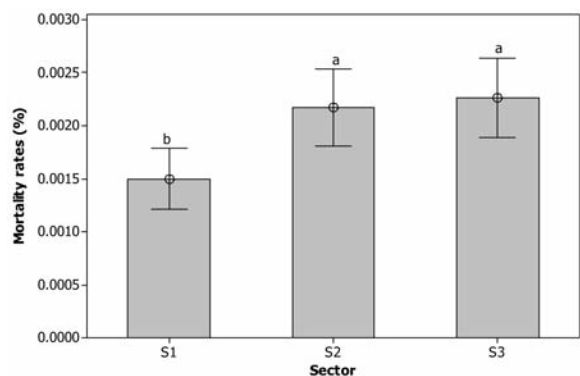


Figure 5. Laying hens' mortality rates in the different sectors of the poultry house with tunnel-like ventilation and pad-cooling. S1, sector 1, close to the pad-cooling; S2, sector 2, at the centre of the poultry house; S3, sector 3, close to the exhausts. Different letters indicate significant difference at 5% by Kruskal-Wallis non-parametric test.

tric tension registers was verified. According to Decree 55 of the Brazilian Electricity Agency (ANEEL), electricity tension provision may be classified as Adequate, Precarious and Critical. Table 8 shows the register percentage of the above-mentioned categories and the rate intervals to which each category belongs, according to ANEEL Decree 505/2001. All Critical-classified electric tension rates were the result of electricity interruptions. Exhaust's electric circuit of A1 had 0.3% of registers classified Precarious. It was later verified that the electricity transformer for this poultry house was undersized for the installed equipments and thus only 8 out of 12 exhausts in A1 were actually functioning. Daily and monthly electricity consumption in the three poultry houses under analysis, their respective extra costs caused by electricity consumption of the climatization system and the difference in lighting management in each poultry house were estimated. Table 9 gives the results of the above-mentioned estimates.

Taking into account that Brazilian Real (R\$) 0.23159 k W⁻¹ was the electric energy cost on March 2012 for Subgroup B2 (electricity for rural areas by the Vale Paranapanema Electricity Plant which provided power to farm under analysis) and that the poultry house with natural ventilation comprised a minimum installation for egg production in the region, the rate of electricity consumption in A3 for a group of 1000 laying hens was subtracted from that in A1 and A2. Consequently, the costs of poultry houses A1 and A2 were respectively R\$ 32.93 month⁻¹ and R\$ 0.49 month⁻¹ more than those of A3. Electricity consumption and operational costs of the climatization systems were calculated on the assumption that the other equipments and engines installed in the poultry house were similar with regard to potency and consumption. The three poultry houses evaluated in current experiment made possible the calculation of the economic feasibility of each, evidenced by the highest profits, based on the data analyzed in the assay. The poultry house with the tunnel-like ventilation provided the best internal insulation system from the external environment. However, insulation had a month operational cost of R\$ 34.09 per 1000 laying hens in contrast to R\$ 1.65 and R\$ 1.16 respectively for poultry house A2 with nebulization and poultry house A3 without any type of climatization. Egg production in A1 was 12.04% higher than the expected production percentage for the laying hens strain, whereas production rate in A2 remained at 4.16% higher than expected and that in A3 it was 1.65% lower than that estimated by the laying hens strain handbook.

Table 7. Egg quality variation in A3 poultry house with natural ventilation.

	Line 1	Line 2	Line 3	Line 4
Weight of egg, g				
High	63.50±6.71	63.11±5.77	61.10±3.82	63.81±5.51
Medium	65.20±5.55	63.27±8.07	64.08±5.29	62.79±4.41
Low	65.54±4.69 ^A	65.85±4.98 ^{AB}	62.24±4.88 ^B	61.98±9.58 ^B
Height of albumen, mm				
High	6.89±1.25	7.41±1.41	7.03±1.23	7.31±1.21
Medium	6.96±1.38	7.06±1.25	7.33±1.41	7.17±1.25
Low	6.76±1.18	7.29±1.29	7.30±1.34	7.05±1.38
Yolk color				
High	5.68±0.594	5.78±0.511	5.59±0.63	5.59±0.81
Medium	5.56±0.562	5.62±0.566	5.56±0.87	5.56±0.61
Low	5.69±0.548	5.69±0.717	5.73±0.66	5.57±0.79
Haugh unit				
High	81.14±9.07	84.86±8.39	82.75±8.68	83.98±7.35
Medium	81.04±9.22	82.11±8.68	82.61±12.46	83.33±7.35
Low	79.64±8.96	83.10±8.71	84.04±8.61	82.79±11.47
Eggshell resistance, N				
High	33.74±11.18	33.44±12.36	33.83±10.49 ^b	33.34±9.41
Medium	34.13±11.18	36.77±9.61	36.97±9.02 ^{ab}	34.81±9.31
Low	37.07±11.67	36.58±11.08	39.72±10.10 ^a	35.89±10.89
Thickness of eggshell, mm				
High	0.400±0.047	0.397±0.053 ^b	0.401±0.045	0.395±0.046
Medium	0.404±0.036	0.404±0.049 ^{ab}	0.403±0.050	0.398±0.042
Low	0.411±0.043	0.426±0.090 ^a	0.406±0.059	0.403±0.038

High, 2.5 m; medium, 1.5 m; low, 0.8 m. ^{AB}Different letters in the lines indicate significant differences by Tukey's test at 5% probability in the means of variable among columns of the same height. ^{ab}Different letters in the columns indicate significant differences by Tukey's test at 5% probability in means of variable among the lines of the same column.

Table 8. Electricity percentages classified in categories defined by ANEEL Decree 505/2001.

	Category		
	Adequate 0.98*TN≤TL≤1.03*TN	Precarious 0.95*TN≤TL<0.98*TN or 1.03*TN<TL≤1.05*TN	Critical TL<0.95*TN or TL>1.05*TN
A1/Lighting	99.7%	0.0%	0.3%
A1/Exhausts	97.9%	0.3%	1.8%
A2	99.6%	0.0%	0.4%
A3	98.9%	0.0%	1.1%

TN, nominal electric tension; TL, electric tension measured by calibrated instruments; A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation.

Since mean production percentage of Dekalb White strain was 82.67% (mean obtained from the performance table during the producing period, according to the strain's management handbook) for laying hens' producing life between 18 and 80 weeks, Table 10 shows income of poultry houses under analysis. Taxes and production costs of the eggs were subtracted from the Gross Operational Profit to calculate income. Table 11 shows the financial result for each poultry house for each group of 1000 laying hens, indicating that poultry house A1 provided the highest Gross Operational profit. The poultry house with tunnel-like ventilation system and pad cooling had the best thermal insulation that provided high productivity gains and housed 50% more laying hens in the best thermal conditions. Poultry

house A2 controlled better the thermal environment than A3 and, consequently a greater profit was obtained from this poultry house.

Although it is impossible to compare egg quality between the poultry houses, loss of egg quality, especially in weight and eggshell, has been verified in very hot environments inside of the poultry houses. It was expected that egg produced in A1 were better when compared to those produced in the other poultry houses. Lower mortality rates for laying hens in poultry house A1 had also been observed. Such an index was highly important and significant for the calculation of financial results. The decrease in the number of laying hens due to death is not shown in Table 11. A moderate thermal environment was reported throughout the poultry house with tunnel-like ventilation

and pad cooling. These factors contributed towards an increase in production, improvement in egg quality and decrease in laying hens mortality rates, as envisaged by assay by Faria *et al.* (2001), Barbosa Filho *et al.* (2006), Pereira *et al.* (2007) and Trindade *et al.* (2007). High performance of the poultry house with tunnel-like ventilation system (negative pressure) has also been registered by Abreu and Abreu (2011) in so far as the poultry house was totally sealed and adequately climatized. Although the evaluated poultry house had several variations in its internal environment that would indicate system faults, climatization by tunnel ventilation and pad cooling provided financial gains 5.5% and 11.8% higher than poultry houses with nebulization or without any type of climatization, respectively.

Table 9. Consumption and daily and monthly electricity costs by the different climatization systems and light management of the poultry houses under analysis.

	Electricity consumption,		Costs of daily electricity consumption, R\$	Costs of weekly electricity consumption, R\$	Costs of monthly electricity consumption (for every 1000 laying hens), R\$
	kW/day	kW/month			
A1	270.69	8120.73	62.69	1880.68	34.09
A2	8.95	268.35	2.72	62.15	1.65
A3	5.39	161.64	1.25	37.43	1.16

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation.

Table 10. Income for each poultry house based on the estimated production percentage, taking into account the production profit by the most adequate thermal environment provided by the climatization systems under analysis.

	Expected production percentage – management handbook, %	Estimated production percentage in current assay, %	30-dozen-boxes for each group of 1000 laying hens, R\$	Average price per box of egg (30 dz) in 2011, R\$ ^a	Income of each poultry house for each group of 1000 laying hens, R\$
A1	82.67	92.62	2.57	50.57	129.96
A2	82.67	86.11	2.39	50.57	120.86
A3	82.67	81.31	2.26	50.57	114.29

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation. ^aMean price for 30 dozens of eggs in 2011 was calculated from a series of prices registered at the Institute of Agricultural Economy (IEA) set by wholesale producers of white extra eggs.

Table 11. Gross Operational Profit from each poultry house based on the daily income calculated and on monthly electricity costs for each climatization system, for each group of 1000 laying hens.

	Income per day, R\$	Income per week, R\$	Monthly costs of electricity used for climatization, R\$	Gross Operational Profit per week + taxes + other costs + expenses, R\$
A1	129.96	3898.80	34.09	3864.71
A2	120.86	3625.80	1.65	3624.15
A3	114.29	3428.70	1.16	3427.54

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation.

A1, poultry house with tunnel-like ventilation and evaporation cooling; A2, poultry house with natural ventilation and nebulization; A3, poultry house with only natural ventilation. ^aMean price for 30 dozens of eggs in 2011 was calculated from a series of prices registered at the Institute of Agricultural Economy (IEA) set by wholesale producers of white extra eggs.

Conclusions

Differences in environments in the same poultry house were relevant in all the poultry houses and demonstrated mistakes in the climatization system project and undersize of the apparatuses. Egg production and quality losses were reported due to heat. This fact reinforces the need for climatization in laying hens poultry houses in hot regions. The poultry house with tunnel ventilation and pad cooling provided the best thermal insulation from the external environment, with consequent better financial results. The results of poultry house with nebulization was better than the poultry house without climatization.

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