Agronomy Research **15**(3), 629–638, 2017

Evaluation of the surface temperature of laying hens in different thermal environments during the initial stage of age based on thermographic images

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Abstract. The initial stage of laying hens requires important care in relation to the thermal environment, in view of the good development of the birds, the obtaining of good quality pullets and, consequently, the adequate laying rate of adult birds.
The aim of the present study was to study, through thermographic images, the variation of the superficial temperature of laying birds of the Lohmann LSL Lite line, from one to forty-two days of age, submitted to different thermal environments. For this experiment, 864 layer chicks were distributed homogeneously in four climatic chambers. The characterization of the different environments was as follows: thermal comfort conditions (32.8 °C–20.2 °C), two cold stress levels (28.0 °C–17.9 °C and 25.5 °C–17.3 °C) and one level of heat stress (37.4 °C–23.3 °C). The black globe temperature and humidity index (BGHI) was also calculated during the trials. The data were evaluated through the Tukey test, adopting the level of 5% of probability. Via infrared thermography the temperatures of head, body and shank of the laying birds were recorded. The results showed effect ($P < 0.05$) of the temperature of each environment on the surface temperature of the birds. Along with the rise of the ambient temperature, an increase in the surface temperature (head and shank) was found.
Under the recommended comfort treatment, the performance of laying birds during the early-stage, related to the superficial temperature of the birds shows the best values with temperature ranges of 32.8 °C–20.2 °C and BGHI values between 82.3 ± 1.3 and 66.4 ± 1.3.

Key words: environmental conditions, surface temperature, poultry, layer chicks, images analysis, infrared thermography.

INTRODUCTION

The thermal environment during the initial stage of laying hens should be well managed since temperature stress can affect the animal's metabolism, being an important factor in the production efficiency. During the initial stage, the greatest weight variations and the development of organs and all tissues occur. The complete and adequate formation of the organs should occur until five or six weeks of age, and during this period the physiological system is still in development both anatomically and functionally (Albino et al., 2014).

In the current intensive breeding system, the environment has a direct influence on the comfort and animal welfare conditions, affecting the maintenance of the thermal balance inside the facilities and the expression of their natural behaviour, influencing the productive performance of the laying birds (Mashaly et al., 2009; Cândido et al., 2015). The best productivity of the animal is achieved when maintained in a thermoneutral environment, i.e. when the feed energy content is not diverted to compensate for thermal deviations (CIGR, 2002).

The body surface of the birds is characterized by the presence of a layer of feathers, which are more important in the regulation of thermal equilibrium especially when the birds are exposed to cold. During periods of thermal stress, the extremities of birds without feathers, such as the comb, the dewlap and the feet, are usually vasodilated (Richards, 1971; Hillman et al., 1982).

Animal well-being is the full state of physical and mental health, in which the animal is in harmony with the environment where it lives, and a change in the animal's comfort state can be detected through its superficial temperature (Camerini et al., 2016). Nascimento et al. (2014), evaluating the thermal comfort of broiler chickens in two aviaries with different HVAC systems, found that, under conditions of thermal comfort, the superficial temperatures of the birds are strongly associated with the superficial temperatures of the installation.

Relating the thermal well-being to the evaluation of the comfort or stress state of the animals, it is essential to develop measurement techniques easily applicable and non-invasive. Highlighting infrared thermography is a safe and non-invasive thermal profile visualization that can indicate if the animal is under thermal stress (Cilulko et al., 2013). The technique allows a real-time evaluation of the thermal requirements of the animals in order to decide possible adjustments for the best productivity. Infrared cameras measure the amount of IR thermal energy emitted by the surfaces and convert it to surface temperature, producing thermal images that generate a detailed analysis of the temperature (Nascimento et al., 2011).

In order to achieve a better productive performance in poultry breeding, the concern between the interaction of the animal with the environment and the relative energy cost of the physiological adjustments becomes relevant. In this sense, this research was conducted with the objective to correlate the superficial temperature variation of light laying hens, from one to forty-two days of age, with different breeding environments, through thermographic images.

MATERIALS AND METHODS

Characterization of the facilities used during the initial phase

The experiment was developed in four climatic chambers with the following dimensions: 3.20 m long x 2.44 m wide x 2.38 m high, located in the experimental area of the Centre for Research in Ambience and Engineering of Agroindustrial Systems (AMBIAGRO), within the Department of Agricultural Engineering of the Federal University of Viçosa, in Viçosa, Minas Gerais, Brazil. Each climate chamber is equipped with a 2,000 W electric resistance air heater, a hot / cold split air conditioner of rating 3,500 W and an air humidifier with a capacity of 4.5 l and a mist rate of 300 mLh^{-1}. The heater and humidifier are operated by means of an MT-531R Plus electronic controller, temperature and humidity, which has the following specifications: control temperature ranging from -10 °C to 70 °C with a resolution of 0.1 °C, control humidity ranging from 20% to 85%.

The installation has also two AMB axial fans (model FD08025 S1M; DC 12 V, 0.15 A), for the renewal of the air inside the climatic chambers during the whole experimental period.

In each of the four climatic chambers used in this work four different thermal environments were established, constituting four treatments: one of the temperature ranges was considered as the comfort range recommended in the literature (TCL = Comfort Temperature by Literature) (Management Guide Lohmann LSL LITE, n.d.), the others represented two levels of cold stress, mild cold (MiC) and moderate cold (MoC) and one level of heat stress, moderate heat (MoH). Considering that the thermal requirement of the birds varies with the age, an attempt was made to represent this requirement in each week of life of the layer chicks during the experimental period. The variation of the weekly temperature occurred until the fifth week, and the sixth week remained with a temperature similar to that of the fifth week.

Table 1 shows the different temperatures applied during the experimental phase.

Table 1. Air temperature in the internal environment of the climatic chambers, in °C, depending on the treatment and age of the layer chicks

Thermal environment	Temperature (°C)				
	1–7days	8–14days	15–21 days	22–28 days	29–42 days
Moderate heat (MoH)	38	31	29	26	22
Literature approach (TCL)	31-35	28	26	23	19
Mild Cold (MiC)	28	25	23	20	17
Moderate Cold (MoC)	25	22	20	17	17

Management Guide Lohmann LSL LITE (n.d.); Albino et al. (2014); Ferreira (2016).

The relative air humidity was monitored and values maintained throughout the experimental period and in all treatments around 60%, in a range between 55 and 65%, since it is considered an adequate value for poultry production, regardless of the age of the birds (Tinôco, 2001; Ferreira, 2016).

Instruments and measurements used in the characterization of environments

From the first day of experiment the values of air temperature, relative humidity (RH) and black globe temperature (BGT) were recorded every 5 minutes, 24 hours per day, throughout the experimental period.

To measure air temperature and RH, HOBO® T / RH dataloggers, Model U14-001 (-20 °C to + 70 °C), with an accuracy of 0.7 °C for temperature and ± 3% over range of 20% to 80% for RH, were used. In order to obtain the BGT, a black globe was installed inside each climatic chamber, within which a Testo temperature sensor, model 174, with a resolution of 0.1 °C, measuring range from -30 to 70 °C and accuracy of ± 0.5 °C was installed. The sensors were placed at the height of the birds, in the centre of each climatic chamber. Based on the records, the Black Globe Humidity and Temperature Index (BGHI) was calculated by means of the Eq. 1 (Buffington et al., 1981). BGHI is used as reference in many experimental trials carried out in similar conditions in poultry sector in Brazil (Cella et al., 2001; Medeiros et al., 2005; Jacome et al., 2007). It is an accurate indicator of animal comfort and production, preferred to THI under heat-stressing environmental conditions with animals exposed to incident solar radiation, in real breeding situations.

$$BGHI = BGT + DPT\ (0.36) + 41.5 \quad (1)$$

where: BGHI = Black Globe Humidity and Temperature Index; BGT = Black Globe Temperature, in °C; DPT = Dew Point Temperature, in °C.

Management of laying birds during the initial phase

The experiment was carried out with laying birds from one to forty-two days of age, considered the initial stage for laying birds. During the experimental phase, 864 lightweight laying hens of the Lohmann LSL Lite line were housed in cages, distributed homogeneously in four climatic chambers (four treatments), totalling 216 birds per treatment (Fig. 1). The cages were 0.50 m² in surface (0.50 m wide x 1.00 m long) and 0.50 m high, being six units per chamber.

A B

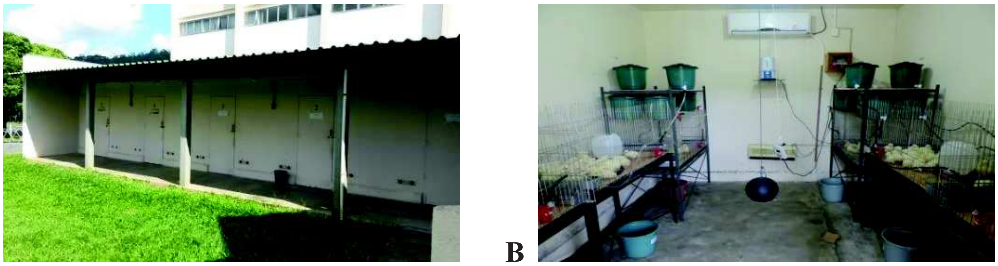

Figure 1. A) Outside view of the four climatic chambers; B) inside view of one climatic chamber.

From the first day to the end of the fourth week, each cage housed 36 chickens in order to guarantee a density of 140 cm^2 $bird^{-1}$. From the beginning of the fifth week until the end of the sixth week, the density was of 285 cm² $bird^{-1}$, which corresponds to 18 birds in each cage (Management Guide Lohmann LSL Lite, n.d.; Patterson & Siegel, 1998). This procedure was adopted to guarantee the density used by the poultry industry, under field conditions, for each of the different ages.

For the period from one to forty-two days water and feed were distributed ad libitum, and the work of filling up occurred twice a day (7 and 17 h), in order to keep the drinkers and feeders always supplied.

The experiment was conducted in a completely randomized experimental design, with four treatments (moderate heat, recommended comfort, mild cold and moderate cold), and in subplots with six replications. The data were evaluated through analysis of variance and the means compared using the Tukey test, adopting the level of 5% of probability. The results were interpreted statistically using the System Program for Statistical Analysis and Genetics – SAEG (2007).

Collection of data on physiological variables and productive performance of birds

Additionally, as used by Camerini et al. (2016), the superficial temperature of the head, body and shank were recorded using a ThermaCAM® b60 thermographic camera, FLIR Systems, Wilsonville, OR, USA, temperature range of -20 to 120 °C, ± 2%. Thermographic images of five random birds per cage were obtained, totalling 30 birds for each treatment. The images were processed using the software FLIR Quick Report, 1.2 SP2, FLIR Systems, Wilsonville, OR, USA, thus obtaining the average temperature of the selected areas of the head, body and shank of the birds. The coefficient of emissivity (ε) adopted was 0.95, as Nääs et al. (2010). In all the trials, the thermographic camera was positioned at a distance of 1.30 m from the bird on a side, to better focus and to photograph.

The birds were weighed weekly (BW, in grams). To evaluate the performance the following data were calculated: weight gain (WG, in grams); feed intake (FI), calculated as the difference between the feed provided and leftovers, during the experimental period; feed conversion (FC), consisting of the ratio between weight gain and feed intake.

RESULTS AND DISCUSSION

The values of the physiological and productive performance of birds from one to forty-two days of age in the different thermal environments are presented in Table 2. The conditions of comfort temperature (TCL) allow to obtain better productive performance in terms of weight gain and feed conversion, although the values (BW and FC) do not differ statistically in the four situations.

Table 2. Mean values of head, body and shank temperatures of the birds and accumulated values for body weight (BW) and feed conversion (FC) parameters in laying birds of the Lohmann LSL Lite line during the complete initial phase cycle (1 to 42 days of age), according to the different treatments (TR)

TR	Animal response				
	Head temperature (°C)	Body temperature (°C)	Shank temperature (°C)	BW (g.ave)	FC
MoH	43.42 ± 2.8	40.55 ± 4.8	43.48 ± 3.1	410.72 ± 4.8	2.96
TCL	42.03 ± 1.7	38.98 ± 4.2	42.28 ± 3.0	430.42 ± 3.8	2.81
MiC	41.18 ± 0.6	37.44 ± 2.9	40.73 ± 2.4	409.44 ± 5.2	2.98
MoC	38.73 ± 1.3	34.89 ± 3.3	38.22 ± 2.8	411.68 ± 6.4	3.18

Moderate heat (MoH), comfort recommended by the literature (TCL), mild cold (MiC) and moderate cold (MoC).

Fig. 2 shows a thermographic image taken during trials and processed using the software FLIR Quick Report, 1.2 SP2.

Table 3 shows the average temperature values of thermographic images. In this work the average temperature of the body, head and shank of the birds were recorded, which differed ($P < 0.05$) for all treatments in relation to each evaluation day. Based on these results it is possible to highlight the strong effect that different temperatures exert on birds, thus modifying the physiological response to a given situation.

The observed values for the surface temperature were, in general, higher for the treatments moderate heat and recommended comfort, showing that there was increase of the surface temperature as the ambient temperature increased. Results are in line with research carried out by Nascimento et al. (2011). Evaluating the surface temperature of broilers from 7 to 35 days of age housed in climatic chambers and raised under three different temperatures (18 °C, 25 °C and 32 °C), the authors observed that the values of surface temperature increased significantly with air temperature rising.

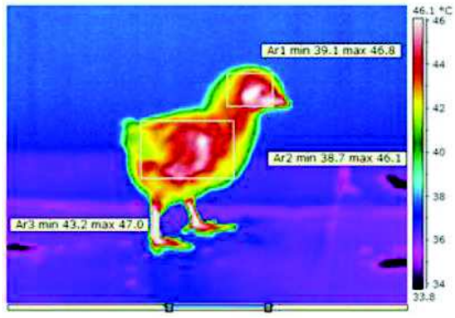

Figure 2. Example of thermographic image taken during trials.

The lower surface temperatures were found in mild and moderate cold stress treatments due to the peripheral vasoconstriction, in which as a way of preventing the loss of heat the bird reduces the blood circulation in order to conserve heat.

It can be observed that the lower values of superficial temperature of the head, body and shank occurred in mild cold treatments and moderate cold treatments. These treatments presented lower body weight and high feed conversion (Table 2), which occurred due to the increase in feed intake used primarily for the addition of calories to maintain homeothermia, not for a weight gain. As a matter of fact, there is a minimum of the metabolic heat production in the 'comfort range', out of which the energy intake increases, even if the temperature rises. At lower temperatures consumption is stimulated, constituting a mechanism of defence of the bird against possible variations of body temperature (Ferreira, 2016).

The temperature values found in the head and shank were higher than the body temperature. This behaviour was also observed by Camerini et al. (2016) which, evaluating the surface temperature of commercial laying birds under different climatic conditions (20 °C, 26 °C and 32 °C), observed that body, head and leg temperatures increased with the rising of air temperature and head temperature values were higher than body and shank temperatures.

This response is due to the fact that in the head region the high surface temperature, favoured by the membranous surface and rich vascular network, makes this area an important site of thermal exchange, where there is a sensitive heat flow from the animal to the environment (Camerini et al., 2016). Hillman et al. (1982) stated that during periods of thermal stress the extremities of birds without feathers, such as comb and dewlap or feet, are usually vasodilated causing greater heat loss. Also for Abreu et al. (2012), the regions without feathers have greater contribution in the exchanges between the corporeal surface and the surrounding environment.

Shinder et al. (2007) observed the effect of exposure of 3 and 4–day–old broilers at low temperatures and found that heat loss from the legs differed from the facial region, suggesting that the legs are a major organ for vasomotor responses, while the face is a more conservative vasoregulatory organ.

The lower temperature found in the body is due to the fact that the feathers contribute to the regulation of the thermal equilibrium. According to Melo et al. (2016), the bird parts covered with feathers favour some thermal insulation and make it difficult to exchange heat with the medium.

Table 3 shows an anomalous trend of temperatures at 36 days of age for all the examined situations. At the beginning of the fifth week the chickens were moved to give a proper surface per head (from 36 to 18 birds per cage). No other specific reasons have been found to explain this behaviour. Further trials could be useful to understand if the values found in the study are reliable and effectively related to managerial conditions or are due to some problems occurred during data collection.

Table 3. Mean values of head temperature, body temperature and shank temperature for laying birds of the Lohmann LSL Lite line, 1 to 42 days of age, for the respective combinations of days and thermal environments

Days of age	Head temperature (ºC)			
	MoH	TCL	MiC	MoC
8	48.65^{a}	43.46^{b}	41.94^{c}	39.61^{d}
15	43.89^{a}	43.71^{a}	41.70^{b}	40.01^{c}
22	43.57^{a}	41.19^{b}	40.44^{b}	37.37^{c}
29	42.25^{a}	41.87^{a}	40.32^{b}	36.70^{c}
36	40.39^{a}	40.03^{a}	41.17^{a}	39.83^{b}
42	41.79^{a}	41.94^{a}	41.54^{a}	38.84^{b}
Days of age	Body temperature (ºC)			
	MoH	TCL	MiC	MoC
8	48.28^{a}	42.72^{b}	41.21^{c}	38.67^{d}
15	43.02^{a}	43.09^{a}	40.69^{b}	38.69^{c}
22	41.81^{a}	39.45^{b}	37.66^{c}	34.16^{d}
29	38.52^{a}	37.80^{a}	34.91^{b}	31.61^{c}
36	35.09^{a}	34.69^{a}	35.22^{a}	35.15^{a}
42	36.60^{a}	36.15^{a}	34.99^{a}	31.06^{b}
Days of age	Shank temperature (ºC)			
	MoH	TCL	MiC	MoC
8	49.00^{a}	42.97^{b}	40.66^{b}	36.82^{c}
15	44.72^{a}	45.48^{a}	43.30^{ab}	40.93^{b}
22	43.55^{a}	41.62^{a}	41.18^{ab}	37.99^{b}
29	40.67^{a}	40.42^{a}	36.03^{b}	33.57^{b}
36	40.57^{a}	40.51^{a}	41.24^{a}	41.23^{a}
42	42.39^{a}	42.73^{a}	41.99^{ab}	38.83^{b}

Moderate heat (MoH), literature approach (TCL), mild cold (MiC) and moderate cold (MoC). The averages followed by at least one letter in the row do not differ, at the 5% probability level by the Tukey test.

The values of temperature and relative humidity of the ambient air, and respective values of BGHI, related to laying birds from one to forty-two days of age, for each treatment are presented in Table 4.

Concerning the BGHI, this index was taken as reference and widely used in studies carried out in Brazil in poultry sector. The main studies refer to broilers (Cella et al., 2001; Medeiros et al., 2005) and some reference values were given only for broilers in different breeding phases. This study applies BGHI to laying hens, trying to give a first contribute to define comfort BGHI values for laying hens during the initial stage of breeding.

Finally, it is observed that the mean values of temperature and relative air humidity remained close to the values proposed for each thermal environment, indicating an adequate control of the environment inside the climatic chambers.

Table 4. Average and standard deviations of the values of air temperature (Tair), relative air humidity (RH) and black globe temperature and humidity index (BGHI) for each climatic condition evaluated in the period from 1 to 42 days

Thermal environment	T_{air} (°C)	UR(%)	BGHI
		(1 – 7 days)	
Moderate heat (MoH)	37.4 ± 0.9	55.5 ± 8.2	87.7 ± 1.5
Literature approach (TCL)	32.8 ± 1.3	56.5 ± 7.6	82.3 ±1.3
Mild Cold (MiC)	28.0 ± 0.3	62.4 ± 3.5	76.3 ± 0.5
Moderate Cold (MoC)	25.5 ± 0.2	57.6 ± 3.5	72.6 ± 0.5
	(8–14 days)		
Moderate heat (MoH)	31.1 ± 1.3	64.1 ± 5.1	80.7 ± 0.6
Literature approach (TCL)	28.2 ± 0.5	62.6 ± 3.4	76.9 ± 0.8
Mild Cold (MiC)	25.3 ± 0.6	55.8 ± 10.1	71.9 ± 1.4
Moderate Cold (MoC)	22.1 ± 0.6	64.9 ± 6.5	69.1 ± 1.2
	(15–21 days)		
Moderate heat (MoH)	29.2 ± 0.7	61.1 ± 6.2	77.5 ± 1.1
Literature approach (TCL)	26.1 ± 0.5	60.4 ± 3.4	72.7 ± 0.9
Mild Cold (MiC)	23.1 ±0.5	61.9 ± 11.2	70.9 ± 1.4
Moderate Cold (MoC)	20.1± 0.8	64.1 ± 4.8	66.3 ± 1.1
	(22–28 days)		
Moderate heat (MoH)	26.0 ± 0.6	65.3 ± 8.1	73.8 ± 1.0
Literature approach (TCL)	23.4± 0.7	62.8 ± 4.7	70.9 ± 1.2
Mild Cold (MiC)	20.3 ± 0.5	60.3 ±7.2	66.8 ± 0.8
Moderate Cold (MoC)	17.9 ± 0.5	64.6 ± 5.9	63.7 ± 0.6
	(29–42 days)		
Moderate heat (MoH)	23.3 ± 1.4	65.6 ± 5.5	70.2 ± 2.4
Literature approach (TCL)	20.2 ± 1.1	65.7 ± 4.7	66.4 ± 1.3
Mild Cold (MiC)	17.9 ± 1.2	65.5 ± 5.9	64.1 ± 0.2
Moderate Cold (MoC)	17.3 ± 0.2	64.2 ± 4.3	62.6 ± 0.2

Moderate heat (MoH), literature approach (TCL), mild cold (MiC) and moderate cold (MoC).

CONCLUSIONS

The research allows to draw some conclusions, which can be useful in further studies on laying hens kept in different thermal conditions.

The use of infrared thermographic imaging has effectively allowed to identify the distribution of the surface temperature of birds occurring at different environmental temperatures. Variations of the surface temperature between the different treatments and higher surface temperatures for the regions without feathers such as the head and shanks of the layer chicks have been detected. Further studies in different breeding conditions should be useful to confirm the values found in these trials.

The performance of layer chicks during the initial phase (from one to forty-two days of age) is better in the comfort treatment as recommended in the literature, with a temperature range of 32.8–20.2 °C and BGHI values between 82.3 ± 1.3 and 66.4 ± 1.3, compared to treatments of moderate heat stress and mild and moderate cold stress. These results confirm that the microclimatic conditions recommended in literature provide acceptable thermal comfort and well-being to birds of this age.

ACKNOWLEDGEMENTS. To CAPES, CNPq, FAPEMIG and the LOHMANN do Brasil.

REFERENCES

Abreu, P.G., Abreu, V.M., Coldebella, A., Hassemer, M.J. & Tomazelli, I.L. 2012. Morphologic measures as a function of the weight and broiler age by means of images. *Rev. Bras. Eng. Agríc. Ambient.* **16**, 795–801 (in Portuguese).

Albino, L.F.T., Carvalho, B.R., Maia, R.C. & Barros, V.R.S.M. 2014. *Laying hens: breeding and feeding*. Viçosa, Aprenda Fácil, 376 pp. (in Portuguese).

Buffington, D. E., Colazo-Arocho, A. & Canton, G. H. 1981. Black globe humidity index (BGHI) as comfort equation for dairy cows. *Trans. ASAE* **24**, 711–714.

Camerini, N.L., Silva, R.C., Nascimento, J.W.B., Oliveira, D.L. & Souza, B.B. 2016. Surface temperature variation of laying hens created in two creation systems using Thermography. *Agropecuária Científica no Semiárido* **12**, 145–152 (in Portuguese).

Cândido, M.G.L., Teles Junior, C.G.S., Tinôco, I.F.F., Arcila, J.C.P., Queiroz, P.P., Oliveira, K.P., França, L.G.F., Coelho, D.J.R. & Barbari, M. 2015. Evaluation of the feeding behavior of broilers in different thermal environments via image analysis. In: *Precision Livestock Farming '15*, 15-18 September, Milan, Italy, pp. 202-207.

Cella, P.S., Donzele, J.L., Oliveira, R. F.M., Albino, L.F.T., Ferreira, A.S., Gomes, P.C., Valerio, S.R. & Apolonio, L.R. 2001. Lysine levels keeping amino acid relationships for 1-21 days broiler chickens, in different thermal environments. *R. Bras. Zootec*. **33**, 433-439 (in Portuguese).

CIGR. 2002. *Climatization of Animal Houses - Heat and moisture production at animal and house levels*. 4th Report of Working Group of International Commission of Agricultural Engineering, Section II. Editors: Pedersen, S. & Sällvik, K., 46 pp.

Cilulko, J., Janiszewski, P., Bogdaszewski, M. & Szczylskagie, E. 2013. Infrared thermal imaging in studies of wild animals. *Eur. J. Wildlife Res.* **59**, 17–23.

Ferreira, R.A. 2016. *Greater production with better environment for poultry, pigs and cattle*. Learn Easy, Viçosa, 296 pp (in Portuguese).

Hillman, P.E., Scott, N.R. & Van Thienhoven, A. 1982. Vasomotion in chicken foot: dual innervation of arteriovenous anastomoses. *Animal Journal Physiology* **242**, 582–590.

Jácome, I.M.T.D., Furtado, D.A., Leal, A.F., Silva, J.H. & Moura, J.F. 2007. Evaluation of thermal comfort indexes for laying-hen houses in the northeast of Brazil. *Rev. Bras. Eng. Agríc. Ambient.* **11**, 527-531 (in Portuguese).

Lohmann LSL-Lite (n.d.). Management guide. www.hylinena.com/UserDocs/ products/Lohmann:LSL-Lite.pdf. Accessed 11.8.2016.

Mashaly, M.M., Hendricks, G.L., Kalama, M.A., Gehad, A.E., Abbas, A.O. & Patterson, P.H. 2004. Effect of heat stress on production parameters and immune responses of commercial laying hens. *Poult. Sci*. **83**, 889–894.

Medeiros, C.M., Baêta, F.C., Oliveira, R., Tinôco, I.F.F., Albino, L.F.T. & Cecon, P.R. 2005. Effects of air temperature, relative humidity and velocity on broilers. *Engenharia na Agricultura* **13**, 277-286 (in Portuguese).

Melo, A.S., Fernandes, R.T.V., Marinho, J.B.M., Arruda, A.M.V., Figueirêdo, L.C. & Fernandes, R.T.V. 2016. Relationship between temperature and nutrition on laying performance. *Pubvet*. **10**, 855–860 (in Portuguese).

Nascimento, G.R., Nääs, I.A., Baracho, M.S., Pereira, D.F. & Neves, D.P. 2014. Infrared thermography in the estimation of thermal comfort of broilers. *Rev. Bras. Eng. Agríc. Ambient.* **18**, 658– 663 (in Portuguese).

Nascimento, G.R., Nääs, I.A., Pereira, D.F., Baracho, M.S. & Garcia, R.2011. Assessment of broiler surface temperature variation when exposed to different air temperatures. *Braz. J. Poultry Sci.* **13** 259–263 (in Portuguese).

Nääs, I.D.A., Romanini, C.E.B., Neves, D.P., Nascimento, G.R.D. & Vercellino, R.D.A. (2010). Broiler surface temperature distribution of 42 day old chickens. *Sci. Agric.* **67** 497–502.

Patterson, P.H. & Siegel, H.S. 1998. Impact of cage density on pullet performance and blood parameters of stress. *Poultry Sci.* **77**, 32–40.

Richards, S.A. 1971. The significance of changes in the temperature of the skin and body core of the chicken in the regulation of heat loss. *J. Physiol.* **216**, 1–10.

Shinder, D., Rusal, M., Tanny, J., Druyan, S. & Yahav, S. 2007. Thermoregulatory responses of chicks (Gallus domesticus) to low ambient temperatures at an early age. *Poultry Sci.* **86**, 2200–2209.

Tinôco, I.F.F. 2001. Industrial aviculture: new concepts of materials, conceptions and constructive techniques available for Brazilian poultry houses. *Braz. J. Poultry Sci.* **3,** 1–26 (in Portuguese).