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ENERGY BALANCE IN THE POULTRY-SHED SYSTEM AND ITS INFLUENCE ON BROILER PERFORMANCE

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ABSTRACT: The objective of this study was to determine the energy balance of the poultry-shed system and its effect on broiler performance during the production cycle. The experimental design was completely random with sub-divided blocks. The blocks were composed of five different types of sheds and the sub-blocks of the evaluation times (00:00 h to 23:00 h), allowing an analysis of variance and a comparison between means with the Tukey test. There were no significant differences between the mean values of the exchanges of sensible, latent and total heat between the poultry sheds but the differences for the evaluation times were significant ($P<0.05$). There was no significant difference between sheds 1 and 4 for broiler productive performance regarding weight gain, feed consumption and feed conversion. Bird performance was significant ($P<0.05$) for the remaining poultry sheds. The productive indexes remained below the ranges considered ideal for broilers and values in the final weeks were characterized by the poor installation efficiency in controlling temperature variations and, consequently, the energy balance in the system, which adversely affected bird productive performance.

KEYWORDS: broiler industry, thermal comfort, thermography

BALANÇO DE ENERGIA NO SISTEMA AVE-GALPÃO E SUA INFLUÊNCIA NO DESEMPENHO DE FRANGOS DE CORTE

RESUMO: Objetivou-se com este estudo a determinação do balanço de energia no sistema ave--galpão e seu efeito no desempenho de frangos de corte, durante o ciclo de produção. O delineamento experimental adotado foi o inteiramente ao acaso, no esquema de parcelas subdivididas, tendo-se nas parcelas cinco galpões, com tipologias distintas e, nas subparcelas, os horários de avaliação (00:00 h às 23:00 h), o que permitiu a análise de variância e a comparação entre médias, pelo teste de Tukey. Os valores médios das trocas de calor sensível, latente e totais não apresentaram diferença significativa entre os galpões estudados, mas quanto aos horários o efeito foi significativo ($P<0,05$). O desempenho produtivo das aves não apresentou diferença significativa nos galpões 1 e 4 para as variáveis ganho de peso, mortalidade, consumo de ração e conversão alimentar. Para os demais galpões, evidenciou-se efeito significativo ($P<0,05$) na performance dos animais. Nota-se que os índices produtivos se mantiveram abaixo das faixas tidas como ideais para a avicultura de corte, e os valores das últimas semanas são caracterizados pela baixa eficiência das instalações em controlar a variação da temperatura, e com isso, o balanço de energia no sistema, o que afetou negativamente o desempenho produtivo das aves.

PALAVRAS-CHAVE: avicultura de corte, conforto térmico, termografia.

INTRODUCTION

Brazilian poultry farming is considered an outstanding agricultural activity in the world due to low production costs and the quality of the final product. However, this production faces a big challenge, thermal stress, principally at the hottest times of the year.

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Birds act like a living thermodynamic system, which continually exchanges energy with the environment. In this process, the stressor agents produce internal variations in the animal with a direct influence on the energy flow between the external environment and the birds, which can lead to physiological adjustments to maintain homeothermy (ABREU & ABREU, 2011).

The effect of high atmospheric temperatures on birds can cause serious problems associated with thermal comfort and animal welfare, compromising their productive performance due to a reduction in feed consumption and more energy expenditure to maintain body temperature, adversely affecting zootechnical indexes (DAGHIR, 2009).

Heat can be dissipated into the environment through sensible exchanges (conduction, convection and radiation), which occur with the temperature difference between the surface of the animal and the environment. This can also happen through latent exchanges, characterized by the transfer of energy by evaporation by the respiratory system, provoked by a process of tachypnea, an important mechanism of thermal exchanges between the animal and the production environment (YAHAV, 2009).

Energy exchanges in birds are controlled by an alteration of blood flow on the body surface, and a perceptive change in the animal's state of comfort can be identified from the surface temperature, where an increase in this temperature can serve as a physiological response of the birds to unsuitable housing conditions. Therefore, the infrared thermograph is an important tool for evaluating the variation in the body surface temperature of birds (NASCIMENTO et al., 2011).

Infrared cameras measure the quantity of energy emitted by the target surface and convert this into surface temperature, producing thermal images obtained from an infrared thermovisor. This measuring instrument has been used to measure the surface temperature of broiler chickens in studies of sensible heat loss (YAHAV, 2009). This technique is modern, safe, non-invasive and non-destructive and does not interfere with the animals' routine. The quantification is very relevant for determining the thermal balance as well as heat losses during the cycle.

The objective of this study was to determine the energy balance in poultry-shed system and its effect on broiler performance during the production cycle.

MATERIAL AND METHODS

The experiment was carried out in broiler rearing sheds in Granja Cajueiro and Integrados, located in the county of São Bento do Una, mesoregion of Agreste and microregion of the Vale do Ipojuca, State of Pernambuco. According to the climate classification of Thornthwaite and Mather (1955), the regional climate is DdA'a', characterized as megathermic semiarid, with a small or no water excess, an average annual rainfall of 630 mm, latitude of 08°31'16" S, longitude 36º33'33" O, and an altitude of 650 m. The highest temperatures occur between November and January and are higher than 30^{o}C. The average monthly temperature varies from 21 to 25^{o}C, with an annual mean temperature of 23^{o}C. The relative atmospheric humidity is 66%, with a mean wind speed of 3 m s^{-1}, which is more intense between October and December (SILVA et al., 2011).

Broiler chickens of the Cobb 500 line were used to evaluate the energy balance of the poultry-shed system. Five poultry sheds with distinct characteristics were chosen for this study (Figure 1).

FIGURE 1. Typological characteristics of the five selected sheds for this study.

Shed No.1 had a north-south orientation and measured 100.00 x 10.00 m, with a ceiling height of 2.60 m, closed laterally with a metal screen, a small wall of 0.27 m and a yellow polypropylene curtain, eaves of 0.70 m and a roof of clay tiles without a ceiling. The shed also had a heating system of wood-fired stoves and evaporative cooling with forced ventilation (axial fans and foggers), automatic feeding and nipple drinkers. The surroundings were partially planted with grass. Shed No.2 had an east-west orientation and measured 60.00 x 8.10 m, with a ceiling height of 1.90 m, closed laterally with a metal screen, a small wall of 0.34 m and a yellow curtain, eaves of 0.80 m and a roof of blackened clay tiles without a ceiling. The installation had a wood-fired central heating system without artificial climatization, automatic feeding and nipple drinkers. The shed No.3 had a north-south orientation and measured 76.00 x 8.00 m, a ceiling height of 1.85 m, closed laterally with a metal screen, a small wall of 0.40 m and a yellow curtain, eaves of 1.00 m and a roof of blackened clay tiles. The installation was equipped with a wood-fired central heating system without artificial climatization, tubular feeding pans and hanging drinkers. The surroundings were partially planted with grass. The shed No.4 had an east-west orientation and measured 100.00 x 10.00 m, with a ceiling height of 2.40 m, closed laterally with a metal screen, a small wall of 0.30 m and a blue polypropylene curtain, eaves of 0.90 m and a clay tile roof. The installation was equipped with a wood-fired central heating system and an evaporative cooling system (fan and foggers), automatic feeding pans and hanging drinkers. The shed No.5 had a north-south orientation and measured 57.80 x 8.00 m, with a ceiling height of 2.10 m, closed laterally with a metal screen, a small wall of 0.38 m and a yellow curtain, eaves of 0.60 m and a roof of blackened clay tiles. The installation was equipped with wood-fired stoves, without an artificial climatization system, tubular feeding pans and hanging drinkers. The surroundings were partially planted with grass and trees, providing natural shade on the external roof surface. The density of birds in all the poultry sheds was 10 birds m^{-2}.

The birds in the five poultry sheds were managed in a similar manner, with feed formulated according to the needs of the line and bird age; the bedding was rice straw (sheds 1 to 4) and rice straw and sugar cane bagasse (shed 5), which was turned over manually every night. The shed heating systems were used during the first two weeks of bird placing, with the lateral curtains completely closed; after this period the artificial climatization systems were activated from 8 a.m. and turned off at 7 p.m. in the sheds which had them.

The experiment was done during a seven week production cycle, from March to May 2012. Thermodynamic models, as described by NASCIMENTO (2010), were adopted, based on knowledge of the energy transfer for broilers in climate chambers.

Meteorological variable were registered by data loggers (HOBO U12-12 model), including dry bulb variable temperature (Tdb, °C), relative atmospheric humidity (RH, %) and black globe temperature (Tbg, °C), at 0.4 m above the floor and externally at 1.5 m above the floor, located in a meteorological shelter. Wind speed inside the installations was measured weekly using digital anemometers positioned near fans and openings along the sheds (entrance and exit). The meteorological data were registered every hour during the experimental period (49 days).

The development of the energy balance in the poultry-shed system was made using the total exchanges per unit of surface area, derived from the sum of the exchanges of sensible (radiation and convection) and latent (evaporation) heat, using equations proposed by TURNPENNY et al., (2000).

$$\dot{Q}s = \dot{Q}cc + \dot{Q}r \tag{1}$$

where,

$\dot{Q}s$ - exchange of sensible heat between the bird and the environment (W m^{-2});

$\dot{Q}cc$ - heat flow by convection (W m^{-2}),

$\dot{Q}r$ - heat flow by radiation (W m^{-2}).

$$\dot{Q}cc = \frac{\rho \cdot c_p}{R_{cc}} \cdot (Tc - Ta) \tag{2}$$

where,

$\dot{Q}cc$ - heat flow by convection (W m^{-2});

ρ - air density (kg.m^{-3}); c_p = specific heat of the air (J kg^{-1} $°C^{-1}$);

R_{cc} - resistance of the limiting layer to the transfer of heat by convection (m^2 °C W^{-1});

Tc – body surface temperature (°C);

Ta – air temperature (°C).

$$\dot{Q}r = \frac{\rho \cdot c_p}{R_r} \cdot (T_c - \overline{T}_r) \tag{3}$$

where,

$\dot{Q}r$ - flow of sensible heat by long wave radiation (W m^{-2});

ρ - air density (kg m^{-3});

c_p – specific heat of the air (J kg^{-1} K^{-1});

R_r – resistance of the limiting layer to the transfer of heat by radiation (m^2 K W^{-1});

Tc – mean body temperature of the birds (K),

$\overline{T}_r$ - mean radiant temperature (K).

The mean body temperature of the birds was calculated from equations proposed by NASCIMENTO (2010), according to the different weeks of rearing (Table 1).

TABLE 1. Models of multiple linear regressions for calculating the mean body temperature (Tc) of the birds during the production cycle.

Week	Model
1st	$T_c = 0.11 \; T_{wing} + 0.10 \; T_{head} + 0.15 \; T_{foot} + 0.56 \; T_{back} + 3.45$
2nd	$T_c = 0.07 \; T_{wing} + 0.10 \; T_{head} + 0.16 \; T_{foot} + 0.47 \; T_{back} + 7.5$
3rd	$T_c = 0.23 \; T_{wing} + 0.13 \; T_{head} + 0.60 \; T_{back}$
4th	$T_c = 0.27 \; T_{wing} + 0.16 \; T_{head} + 0.07 \; T_{foot} + 0.45 \; T_{back}$
5th	$T_c = 0.46 \; T_{wing} + 0.07 \; T_{foot} + 0.32 \; T_{back} + 0.2 \; T_{crest}$
6th and 7th	$T_c = 0.27 \; T_{wing} + 0.10 \; T_{head} + 0.05 \; T_{foot} + 0.50 \; T_{back} + 0.10 \; T_{crest}$

The body temperature was measured using a FLIR®, i60 model thermographic camera, which permitted determination of the variation in the surface temperature at various places on the birds and also a better understanding of the processes of energy transfer for determining the thermal balance (Figure 2).

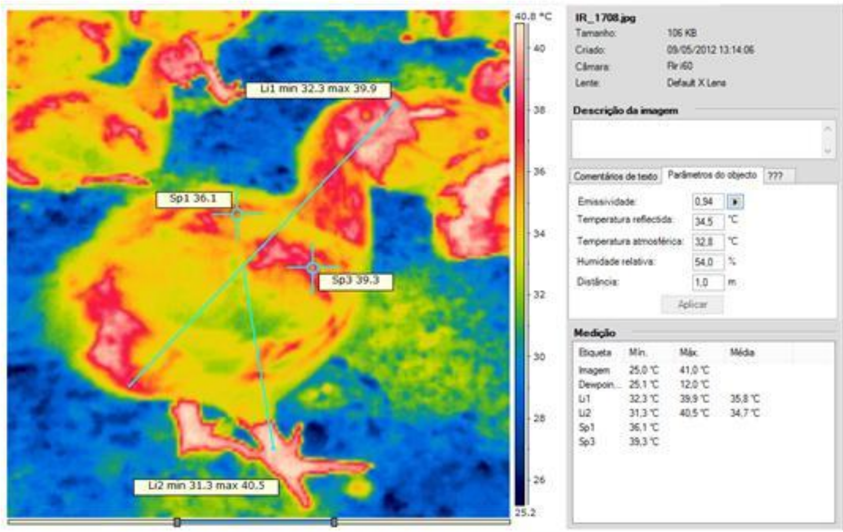

FIGURE 1. Thermal image of birds in the third week of the production cycle.

To calculate the latent exchange flow the empirical relationship of HUTCHINSON (1954) was used, determined by [eq. (4)]:

$$\dot{Q}_e = \left(-3{,}5 \cdot 10^{-3} \cdot e_a + 23\right) \cdot \left(T_n - 314\right) + 10 \tag{4}$$

where,

$\dot{Q}_e$ - total flow of heat by evaporation (W m^{-2});

e_a – environmental vapor pressure (kPa);

T_n - temperature of body nucleus, represented by the cloacal temperature (K).

For this rectal temperature, a regression model proposed by PONCIANO et al. (2012), was used using [eq. (5)]:

$$T_n = 35.03 + 0.15 \times T_a + 0.12 \times age \tag{5}$$

The zootechnical performance of the birds was calculated from the body weight, daily weight gain, feed conversion and the mortality rate. The feed consumption and live weight were registered weekly on field spreadsheets, which were compared to the reference data in the Cobb 500 line manual (COBB-VANTRESS INC., 2008).

A completely random experimental design was adopted (CRD); with subdivided blocks, with the blocks represented by the poultry sheds (1, 2, 3, 4 and 5) and the sub-blocks by the times for the exchanges of sensible, latent and total heat (00h00min to 23h00min). The statistical analyses were processed using the PROC GLM of the SAS Institute statistical program, version 9.0 (SAS, 2002). A totally random experimental design was used to analyze the zootechnical performance data, using the command PROC ANOVA of the SAS Institute app and comparing means with the Tukey test.

RESULTS AND DISCUSSION

The mean values of the sensible exchange (QS), latent exchange (QL) and total exchange (QT) of the poultry-shed system for the five types studied showed no significant differences. However, considering the times and the interaction (Shed*Hour), the effect was significant (P<0.05) (Table 2).

TABLE 2. Analysis of variance of the effects of the five poultry sheds and the average times of sensible (QS), latent (QL) and total (QT) exchanges and the interaction poultry shed x hour.

		Mean Squares		
F.V	DF	QS (W/m²)	QL (W/m²)	QT (W/m²)
Shed	4	1.21 ns	1.65 ns	1.13 ns
Residue (Shed)	24	148.37	37.22	148.32
Hour	23	213.51 **	599.34 **	143.04 **
Shed*Hour	92	1.45 **	3.23 **	1.23 **
Residue	690			
C.V (%)		14.26	7.01	11.11

In Table 3, it can be seen that the exchange of sensible heat was more evident in the time intervals of 00h00min, 03h00min, 06h00min, 18h00min and 21h00min, in the five poultry sheds, when the environmental temperatures were lower. The sensible exchanges by convection and radiation depend on a temperature differential between the bird's body surface and the environmental temperature: the greater this difference is, the more efficient these exchanges will be (NASCIMENTO et al., 2009).

TABLE 2. Mean values of the exchange of sensible heat (QS) for different times and poultry sheds during seven weeks of production.

Hours	QS (Wm^{-2})				
	1	2	3	4	5
00:00	172.73 a	224.13 a	202.91 a	210.18 a	235.07 a
03:00	176.33 a	229.72 a	209.21 a	211.93 a	252.61 a
06:00	149.58 ab	236.59 a	215.26 a	218.47 a	243.99 a
09:00	79.10 c	154.52 b	138.49 b	139.36 b	139.93 c
12:00	42.14 c	97.33 c	84.12 c	85.92 c	80.02 d
15:00	57.91 c	88.76 c	76.57 c	79.29 c	85.03 d
18:00	129.84 b	166.22 b	147.92 b	154.32 b	178.21 bc
21:00	156.33 ba	205.26 a	192.39 a	195.63 a	219.93 ab

Means with at least one similar small letter in the column do not differ among themselves at the 5% probability level according to the Tukeys test.

The exposure to the heat causes thermal stress since it reduces the capacity of the birds to exchange sensible heat with the environment (UZUM & TOPLU, 2013). This reduction can be seen at 09h00min, 12h00min and 15h00min, where the latent exchanges shown in Table 4 were more significant.

TABLE 3. Mean values of the exchange of latent heat (QL) for different times and poultry sheds during the seven weeks of production.

Hours	QL (Wm^{-2})				
	1	2	3	4	5
00:00	30.97 de	29.94 d	25.60 c	27.08 c	23.67 e
03:00	30.52 e	28.28 d	26.92 c	28.52 c	24.1 e
06:00	35.26 cd	30.37 d	25.93	29.19 c	25.5 de
09:00	50.58 b	48.33 b	42.46 b	45.39 b	44.81 b
12:00	59.09 a	58.16 a	53.98 a	56.10 a	56.48 a
15:00	54.86 ba	54.59 a	56.22 a	55.88 a	56.0 a
18:00	39.67 c	36.58 c	40.84 b	39.96 b	37.88 c
21:00	34.25 de	32.66 cd	31.35 c	32.17 c	29.93 d

Means with at least one similar small letter in the column do not differ among themselves at the 5% probability level according to the Tukey test.

This is justified by the fact that the latent exchange is more evident when the birds experience high atmospheric temperatures. On analyzing the exchanges of sensible and latent heat for broilers at 42 days, NASCIMENTO & SILVA (2009) found that at high atmospheric temperatures the latent exchange was more expressive; this demonstrates the birds' attempts to maintain homeothermy by panting (respiratory evaporation). In this case, forced ventilation is recommended to minimize thermal stress due to the increase in energy dissipation by convection and evaporation (BARACHO et al., 2011).

It can be seen in Table 1 that the contribution of total exchanges was more intense at 00h00min, 03h00min, 06h00min, 18h00min and 21h00min, when the atmospheric temperatures are lower compared to other times, resulting in a milder microclimate, which was thermally comfortable for the birds. The studies by McKEE & HARRISON (2013) showed that the total heat production falls with increasing atmospheric temperature.

TABLE 4. Mean values of exchange of the total heat (QT) for different times and poultry sheds during the seven weeks of production.

Hours	QT (Wm^{-2})				
	1	2	3	4	5
00:00	203.71 a	254.06 a	228.50 a	237.26 a	258.73 ab
03:00	206.85 a	258.00 a	236.12 a	240.45 a	276.71 a
06:00	184.83 a	266.96 a	241.19 a	247.66 a	269.49 a
09:00	129.67 bc	202.85 b	180.96 cd	184.75 b	184.75 cd
12:00	101.22 c	155.48 c	138.10 de	142.02 c	136.5 e
15:00	112.77 c	143.36 c	132.79 e	135.17 c	141.03 ed
18:00	169.51 ba	202.80 b	188.76 bc	194.28 b	216.09 bc
21:00	190.98 a	237.91 a	223.75 abc	227.81 a	249.76 ab

Means with at least one similar small letter in the column do not differ among themselves at the 5% probability level according to the Tukeys test.

Figure 3 shows the variation in heat exchanges by sensible and latent means as a function of the atmospheric temperature. The latent exchanges were negative in the first week of the production cycle, which is explained by the fact that the prediction model of the cloacal temperature (PONCIANO et al., 2012) considers in its estimates, birds 14 days old, that is, the author believed that thermoneutrality would reside in a body nucleus temperature of 41ºC, which would indicate minimum exchanges of 10 W m^{-2}. At high temperatures, the latent exchange intensified, demonstrating the means which birds have of maintaining homeothermy by evaporation and respiration, while the sensible exchanges diminish with increasing temperature. This variation in the energy flow during the entire production cycle occurs because of the maturing of the thermoregulatory mechanisms developed after the second week of life, and in this case, the birds are more tolerant to the cold and more sensitive to the heat. This justifies the inversion of the sensible heat flow of the birds with high temperatures.

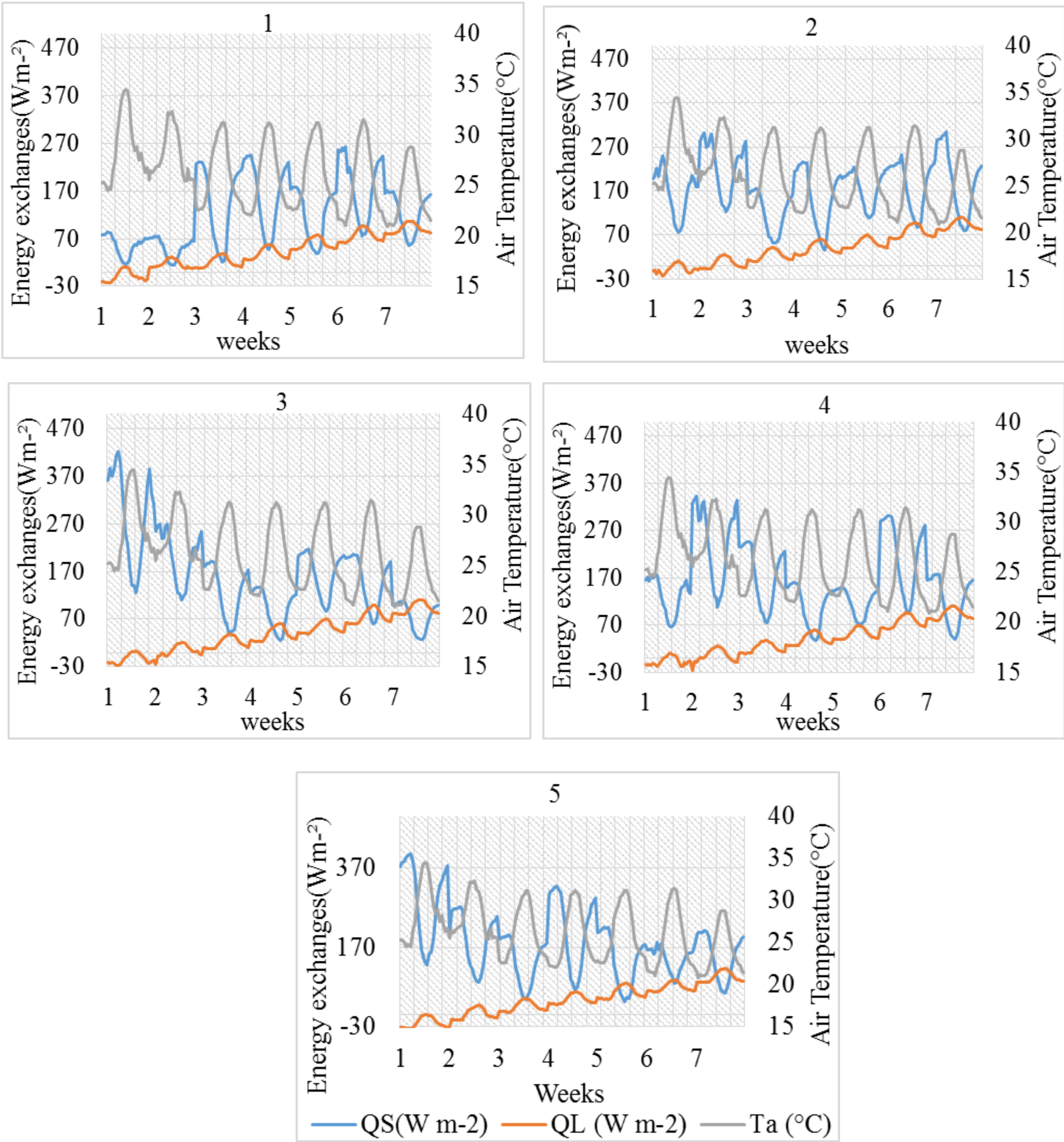

FIGURE 3. Weekly variation in hourly atmospheric temperature and heat exchanges for the poultry sheds analyzed.

In Figure 3, the distribution of the values between sensible, latent and total exchanges should be noted, in which even though the values of the latent exchange had increased in the final weeks of the production cycle, their values stayed below those which represent thermal stress conditions for the birds. According to SILVA et al., (2012), this condition is characterized when the values of latent exchange exceed those of sensible exchanges. This was only observed in shed No.3 in the last week of the production cycle, where the latent exchanges passed the sensible ones; any change in the latent exchanges in detriment to sensible exchanges reduces energy availability for bird development, intensifying energy use to maintain the body temperature.

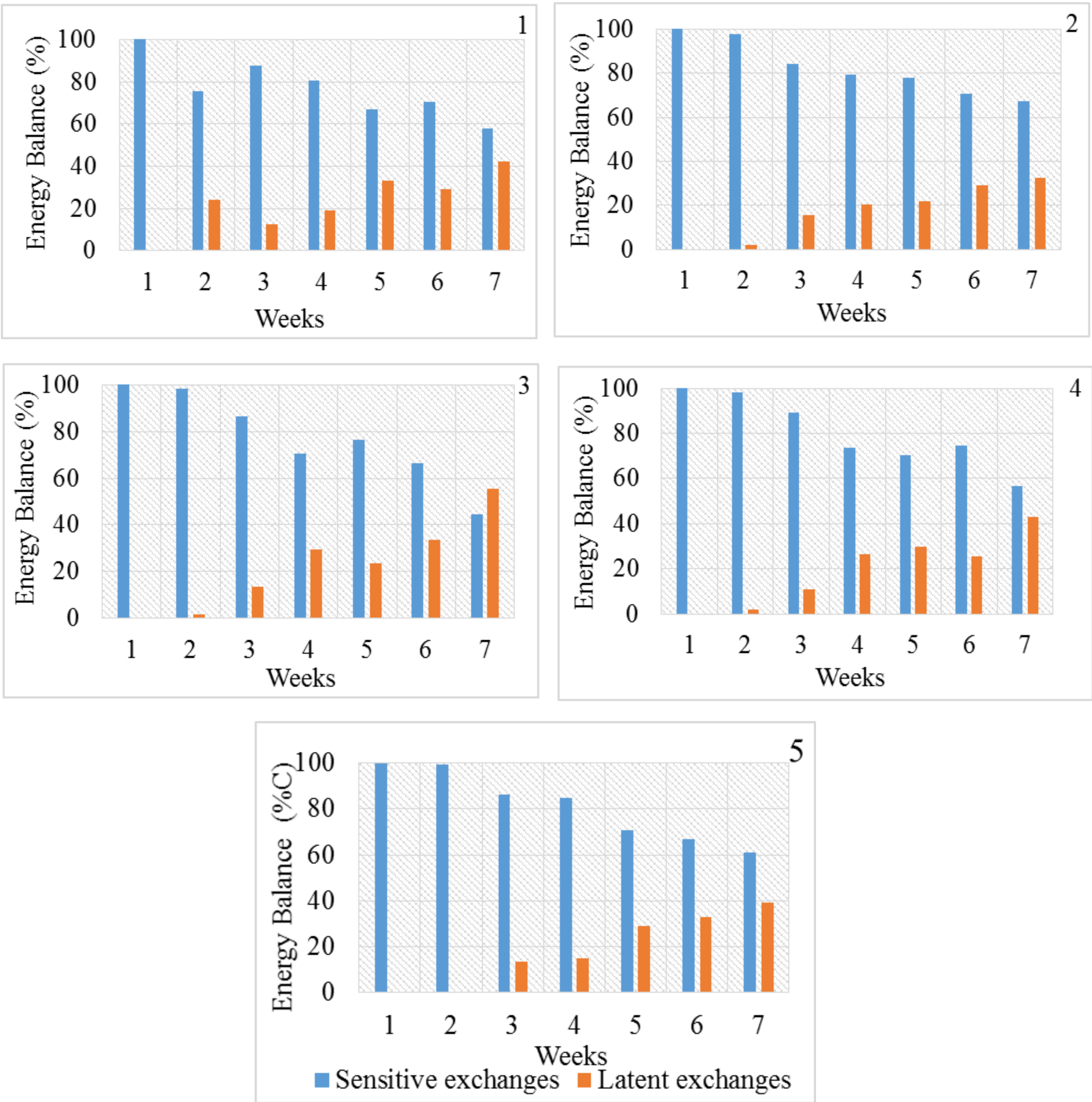

FIGURE 4. Percentage contribution of thermal exchanges for the energy balance in the five poultry sheds analyzed.

The response of the sensible exchanges demonstrated thermal stress after the fifth week for the five poultry sheds (Figure 4). The heat flow by sensible means was more expressive, above 80% from the first to the fourth week, while the heat exchanges by latent means only reached values equal to 30% of the total exchanges in the fourth (poultry sheds 1 and 4), third (poultry shed 2), sixth (poultry shed 3) and the fifth week of the production cycle (poultry shed 5). The birds increase their heat dissipation during this period by evaporation due to their greater sensibility to atmospheric temperature, which varies with the age.

It can be seen in Table 6 that there was no significant difference between poultry shed 1 and 4 for weight gain, mortality; feed consumption and feed conversion, including poultry shed 3 for this last variable. The difference was significant at the 5% probability level for the remaining poultry sheds.

TABLE 5. Mean values of the productive variables, weight gain (WG), mortality (TM), feed consumption (FC) and feed conversion (CA) for the five poultry sheds evaluated.

Shed	WG Weekly (kg)	TM Weekly (%)	FC Weekly (kg)	CA
1	0.375 a	5.773 c	0.746 a	1.932 b
2	0.327 ab	8.468 b	0.689 ab	2.051 ab
3	0.282 b	9.758 a	0.604 b	1.975 b
4	0.369 a	5.614 c	0.732 a	1.961 b
5	0.316 ab	8.113 b	0.684 ab	2.152 a

Means with at least one similar small letter in the column do not differ among themselves at the 5% probability level according to the Tukeys test.

During the birds' productive cycle, the highest mortality rates were observed in poultry sheds 2, 3 and 5, with values of 8.47; 9.76 and 8.11%, respectively. These values were higher than those cited by Cobb-Vantress (2008), which were around 5% for the line evaluated. The lowest mortality rate observed in this study was in poultry sheds 1 and 4, which, different from the other poultry sheds, had a system of environmental thermal conditioning (fans associated with foggers).

Feed consumption by the birds in the five poultry sheds studied was higher than that reported by ANTUNES et al., (2012), which was 2,818 g, when evaluating the performance of female broilers of the Cobb 500 line. DAMASCENO et al., (2010), working with two ventilation systems (poultry shed equipped with tunnel ventilation (negative pressure) and a system of evaporative cooling of porous, wet material and fogging) verified mean FC values of 2,392 and 2,384 g, respectively, for the birds.

According to Cobb -Vantress (2008), the feed conversion (CA) for broilers of the Cobb 500 line is 1.70, thus below the value found in this study, where the lowest value observed was in poultry shed 1 (1.93) and the highest in poultry shed 5 (2.15). Similar values for CA were found by PASSINI et al., (2013), who evaluated the influence of external roof painting and the productive performance of 19 to 49-day old broilers reared in Northeast Brazil. ROCHA et al., (2010) evaluated poultry sheds covered by asbestos cement tiles, with three thermal conditioning systems, correlating them with the productive indexes and finding values of 1.97 and 2.07, respectively.

In general, it can be observed that the values observed for the productive indexes were below those bands considered ideal for the broiler industry, as observed in Figure 5, which shows the variation in the weekly weight gain compared to the Cobb-Vantress (2008) reference standard.

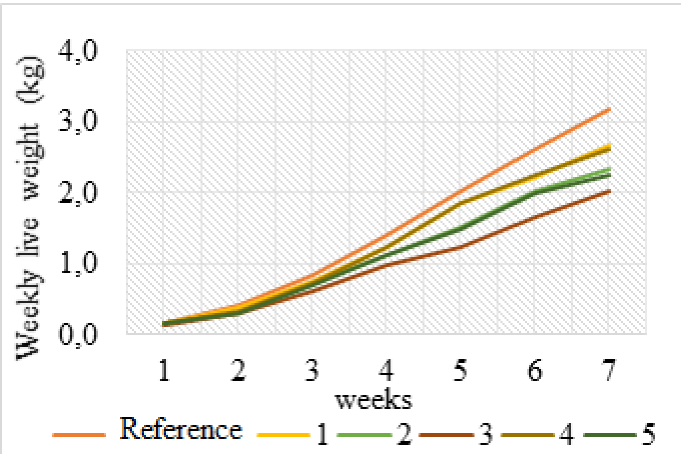

FIGURE 5. Variation in weight gain during the production cycle.

The weekly live weight in all the poultry sheds was below that recommended for the line (COBB-VANTRESS INC., 2008). The values of the final weeks are characterized by the low efficiency of the installation in controlling the variation in temperature and consequently, the energy balance of the interior of the poultry shed, thus directly affecting its productive performance.

CONCLUSIONS

It was possible to verify the critical conditions of the installations from the energy balance, which did not satisfy the thermal needs of the broiler chickens during the production cycle, thus adversely affecting bird performance. Thus, it is considered that sheds 1 and 4 showed better energy balance, based on productive reports.

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