ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.24, n.9, p.616-621, 2020
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v24n9p616-621

Performance of growing pigs subjected to lighting programs in climate-controlled environments

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ABSTRACT: The objective of this research was to evaluate the thermal comfort, physiological responses and performance of pigs in the growth phase, subjected to supplemental lighting programs in air-conditioned environments, in semiarid region of Pernambuco state, Brazil. Twenty-seven pigs (3/4 Duroc, ¼ Pietrain) were subjected to pens with no climate control, pens with forced ventilation and pens with adiabatic evaporative cooling, associated with 12 h of natural light, 12 h of natural light + 4 h of artificial light and 12 h of natural light + 6 h of artificial light. The experimental design was completely randomized, in a 3 x 3 factorial arrangement with three repetitions. Meteorological responses, physiological responses and performance variables of the animals were recorded. The evaporative cooling system attenuated the action of the stressors and ensured adequate thermal conditions for the animals. Respiratory rate and rectal temperature indicated that evaporative cooling ensured the maintenance of homeothermy. Weight gain and feed conversion were positively influenced for the animals exposed to evaporative cooling, but without significant effect of lighting programs.

Key words: animal environment, thermal stress, swine breeding, light supplementation

Desempenho de suínos em crescimento submetidos à programas de iluminação em ambientes climatizados

RESUMO: O objetivo desta pesquisa foi avaliar o conforto térmico, as respostas fisiológicas e o desempenho de porcos na fase de crescimento, submetidos a programas complementares de iluminação em ambientes climatizados, na região semiárida de Pernambuco, Brasil. Vinte e sete porcos (3/4 Duroc, ¼ Pietrain) foram submetidos a baias sem ar condicionado, baias com ventilação forçada e baias com resfriamento adiabático evaporativo, associadas a 12 h de luz natural, 12 h de luz natural + 4 h de luz artificial e 12 h de luz natural + 6 h de luz artificial. O delineamento experimental foi inteiramente casualizado, em arranjo fatorial 3 x 3, com três repetições. As respostas meteorológicas, fisiológicas e variáveis de desempenho dos animais foram registradas. O sistema de resfriamento evaporativo atenuou a ação dos agentes estressores e garantiu o alojamento térmico adequado para os animais. A frequência respiratória e a temperatura retal indicaram que o resfriamento evaporativo garantiu a manutenção da homeotermia. O ganho de peso e a conversão alimentar foram influenciados positivamente para os animais expostos ao resfriamento evaporativo, no entanto, sem efeito significativo dos programas de iluminação.

Palavras-chave: ambiência animal, estresse térmico, suinocultura, suplementação de luz

Editor responsible: Carlos Alberto Vieira de Azevedo
Ref. 216682 – Received 20 Nov, 2018 • Accepted 30 Jun, 2020 • Published 29 Jul, 2020

Introduction

Pigs are homeothermic animals, but have a limitation in the thermoregulation system, so the thermal environment is an extremely relevant factor in pig farming. In this context, in Brazil, one of the concerns of producers is the high air temperature, associated with high relative humidity, which compromises the transfer of energy through latent heat and the low capacity of natural air renewal in the facilities, typical of a country with essentially tropical climate (Santos et al., 2012).

Using climate control systems to mitigate the impact of stressors can minimize the negative effect of meteorological variables, promote animal welfare and, consequently, increase the production performance of pigs (Justino et al., 2015).

Some management practices to counterbalance the effects of daily thermal stress suffered by animals go beyond the adjustment of the microclimate inside the production facilities, comprising the use of supplemental lighting (Amaral et al., 2014).

This is a usual practice in poultry rearing systems, with satisfactory results, and its principle is to stimulate food intake at times of mild temperature (night time), when the micrometeorological conditions inside the housing environment facilitate the dissipation of energy from food, reducing the harmful effects of thermal and caloric stresses (Ferreira et al., 2015).

Therefore, the objective was to evaluate the thermal comfort, physiological responses and performance of pigs in the growth phase, subjected to supplemental lighting programs in air-conditioned environments, in the semi-arid region of Pernambuco state, Brazil.

Material and Methods

The study was carried out at the Swine Experimentation Bioterium of the Serra Talhada Academic Unit of the Federal Rural University of Pernambuco (UFRPE), located in the Sertão Mesoregion of Pernambuco, Brazil (07º 59’ 31” S longitude; 38º 17’ 54” W latitude and 444 m altitude). According to Köppen’s climate classification, the climate of the region is characterized as BShw', hot and dry semi-arid. The annual averages of rainfall, temperature and relative humidity in the region are 642.1 mm, 24.8 °C and 62.5%, respectively (Silva et al., 2015).

The experiment was conducted between August and September 2017, totaling 45 days; the research was approved by the Committee on Ethics in the Use of Animals (CEUA/UFRPE), under protocol 23082.021090/2016-81.

The experimental design used was completely randomized, in a 3 x 3 factorial arrangement, with three replicates, in which the 27 animals used were randomly distributed in nine pens, three per pen, considered as replicates.

Pens with no climate control (NC), pens with forced ventilation (FV) and pens with adiabatic evaporative cooling system (EC) were evaluated, associated with 12 h of natural light (L12), 12 h of natural light + 4 h of artificial light (L16) and 12 h of natural light + 6 h of artificial light (L18). The climate control system was activated daily from 8 a.m. to 6 p.m., and the lighting programs from 18 to 22 h (L16) and from 23 to 5 h (L18), actuated by analog timers.

Twenty-seven pigs (3/4 Duroc, ¼ Pietrain) in the growth phase, with initial average weight of 30 ± 0.12 kg and final weight of 75.6 ± 0.95 kg, were housed in an experimental masonry shed, composed of 30 pens, with central corridor covered with 6 mm fiber cement roofing sheets. The pens were covered with ceramic tiles with one pitch, with 15° slope and concrete floor. Each pen was 6.0 m^2, with ceiling height of 2.2 m and 1.1-m-high containment walls, equipped with a semi-automatic feeder and a nipple drinker. The animals were randomly distributed in nine pens, three animals (males and females) per pen (2 m^2 $animal^{-1}$).

Climate control by forced ventilation was performed by means of axial fans with flow of 1200 m^3 h^{-1} at 1,780 rpm and diameter of 11”, which provided airflow at an average speed of 3.4 m s^{-1}.

The adiabatic evaporative cooling system consisted of evaporative air conditioners, which promote mist formation through the centrifugal effect of a central disc with an average flow rate of 7 L h^{-1}, using independent motors with blade rotation of 1,750 rpm and central disc rotation of 3,450 rpm, with average airflow speed of 2.5 m s^{-1}.

The supplemental lighting system was composed of soft/warm 15-W compact fluorescent lamps, installed in the geometric center of the pen at 1.83 m height from the floor and with 40 lx illuminance.

The nutritional management of the animals followed the concept of ideal protein, by development phase, meeting the nutritional requirements described by Rostagno (2017). Feed was provided at will, being distributed twice a day (morning and afternoon).

The meteorological variables, dry bulb temperature (Tdb, °C), relative humidity (RH, %) and black globe temperature (Tbg, °C) were recorded every hour, inside the pens and in the external environment, by HOBO U12-12 dataloggers installed in the geometric center of each pen at 1.0 m height from the floor and in the external environment, inside a meteorological shelter at 1.5 m height from the ground.

Wind speed measurements (Ws, m s^{-1}) were taken using a digital thermo-anemometer model AZ 8908, inside the pens at 1.0 m height from the floor and in the external environment at 2.0 m height from the ground. Tbg and Ws measurements were considered in the determination of black globe temperature index and humidity and radiant thermal load.

Thermal characterization of the studied environments was performed using data referring to the meteorological variables recorded inside the pens, in order to determine the comfort indices, by means of the radiant thermal load - RTL (W m^{-2}), proposed by Esmay (1982); temperature and humidity index - THI, proposed by Thom (1959); black globe temperature and humidity index - BGTHI, proposed by Buffington et al. (1981), and specific enthalpy - h (kJ kg^{-1} of dry air), proposed by Rodrigues et al. (2010).

The physiological variables respiratory rate (RR, mov min^{-1}), rectal temperature (RT, °C) and surface temperature (ST, °C) were recorded in all animals, at 0 and 12 h, once a week, along the entire experimental period, because these means are representative of the effect of supplemental lighting and the potential for attenuation of ambient temperature by the climate control systems.

RR measurements were performed by counting the number of movements of the flank region of the animals, at 1-min intervals. RT was measured with a digital thermometer for veterinary use, with scale from 20 and 50 °C and accuracy of ± 0.1 °C. Records of skin surface temperature were obtained using thermal images collected by a Flir E60 thermal camera.

The images were analyzed using the computer program FLIR QuickReport®, into which the values of emissivity (0.98), temperature and relative humidity obtained at the moment of image recording, and the standard distance between the animal and the camera (1.5 m) were entered.

Animal performance was evaluated based on feed intake (FI; kg), feed conversion (FC, kg kg^{-1}) and weight gain (WG, kg). For determination and monitoring of WG, the animals were weighed every week on an electronic scale model LD1050, coupled to a containment structure.

Statistical analysis was performed using the program Statistical Analysis System (SAS, 2007) and the means were compared by Tukey test ($p \leq 0.05$).

Results and Discussion

There was a high local thermal amplitude, with value of 13.22 °C in the external environment, with minimum recorded at 5 h and maximum recorded at 13 h (Figure 1A). According to Oliveira et al. (2019b), the range tolerated by adult pigs is 8.0 °C. Santos et al. (2012) found a difference of 3.5 °C when reducing the thermal amplitude of a shed with pigs using forced ventilation associated with nebulization, compared to natural ventilation.

High amplitude can require more from the animals to adapt to daily thermal fluctuations, diverting energy from production to maintenance of homeothermy, which may result in negative impacts on their performance (Santos et al., 2012).

It is observed that, except for animals subjected to evaporative cooling, the animals were exposed to temperatures above the upper critical limit (UCL) of 27 °C (Santos et al., 2018), between 9 and 18 h, reaching extreme values (32.6 °C) at 14 h (Figure 1A).

The evaporative cooling system promoted reductions of 8.8 and 9.4 °C, compared to pens under forced ventilation and with no climate control, respectively (Figure 1A). Pereira et al. (2018) also observed lower temperature for environments equipped with evaporative cooling, when compared to systems of natural ventilation and forced ventilation, with positive effect on animal behavior and physiology.

The forced ventilation system, in some hourly intervals, was able to attenuate the temperature inside the pen, but at 16 h, the pens equipped with forced ventilation became hotter than those with no climate control, as a result of thermal storage in the surrounding condition of the facilities and the airflow promoted by the mechanical ventilation system (Figure 1A).

Figure 1B shows that the relative humidity remained within the tolerable limits from 60 to 70% (Tolon et al., 2010), in the external environment, in the pens with no climate control and in those with forced ventilation. The high values of relative humidity in pens with evaporative cooling occurred due to the high water vapor retention capacity in the air volume, made possible by the local psychrometric properties of the air, which consequently reduced air temperature, so that the isolated effect of moisture ultimately became null in a condition of thermal comfort for the animals.

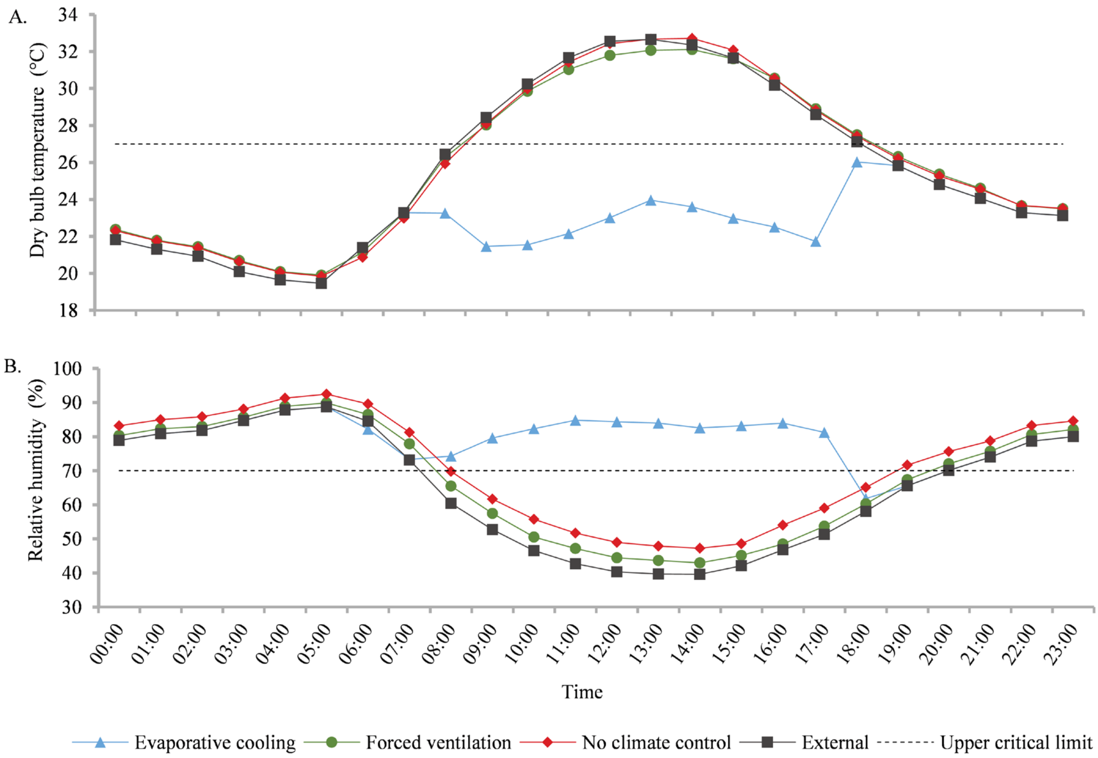


Figure 1. Average hourly variation of dry bulb temperature (A) and relative humidity (B) in the containment pens along the experimental period

The thermal characterization of the housing facilities through the comfort indices revealed a significant effect ($p \leq 0.05$) for radiant thermal load (RTL) in all treatments, and pens with forced ventilation had the worst thermal conditions in all hourly intervals, caused by the convective effect of hot air (Figure 2A). In the interval from 8 to 16 h, the lowest RTL occurred in the pens with evaporative cooling, which did not exceed the average of 472.6 W m^{-2}.

The temperature and humidity index (THI) and the black globe temperature and humidity index (BGTHI) showed similar average results, with significant effect between treatments at times of greatest thermal increment from 12 to 16 h (Figures 2B and C), with the lowest averages observed in pens with evaporative cooling, corresponding to 71.8 and 72.2 for THI and BGTHI, respectively, hence within the comfort range for pigs in growth phase (Oliveira et al., 2019a).

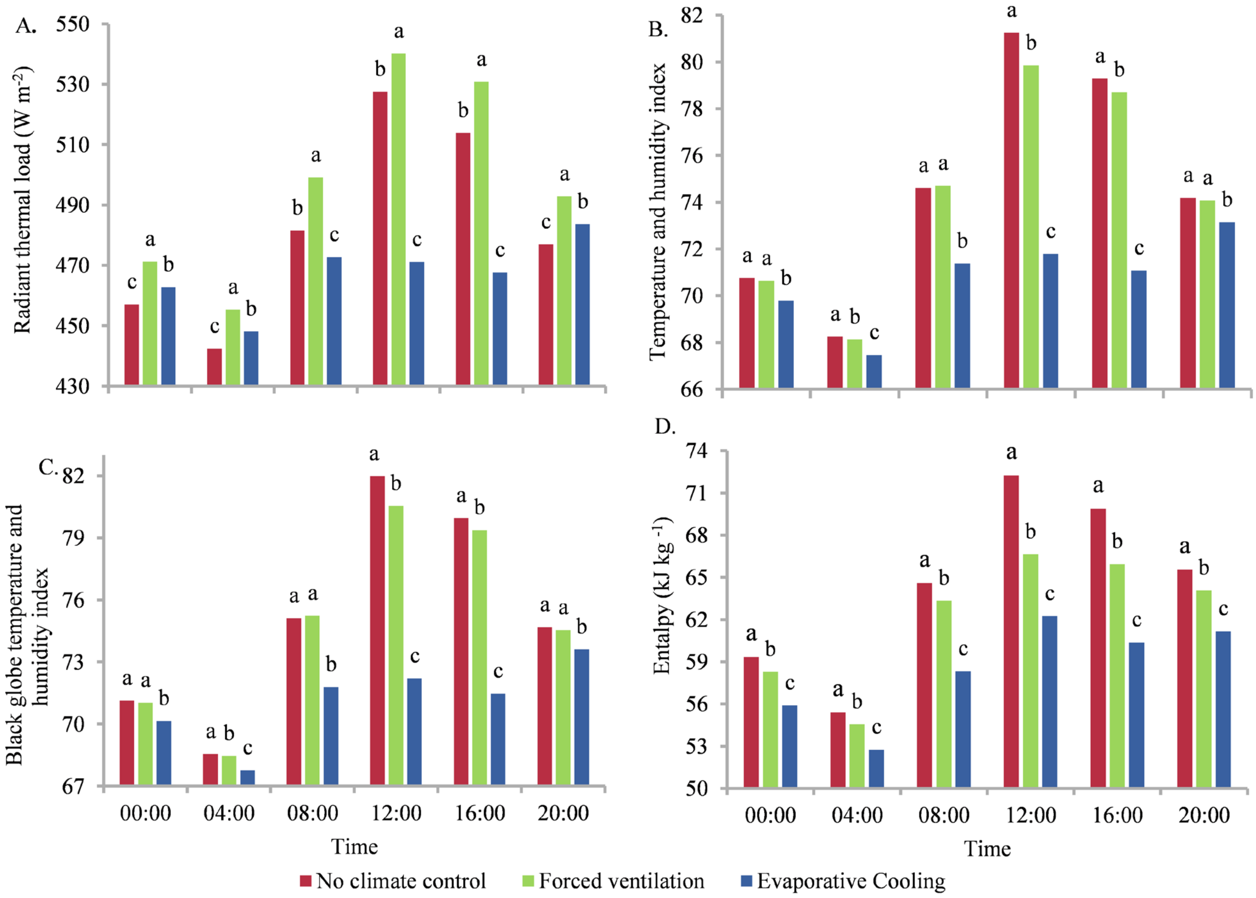
Enthalpy showed significant differences at all evaluation times and reached critical values at 12 h (Figure 2D) in pens with no climate control (72.2 kJ kg^{-1}), with forced ventilation (66.56 kJ kg^{-1}) and with evaporative cooling (62.25 kJ kg^{-1}). Oliveira et al. (2019b) point out that the effect of nebulization associated with mechanical ventilation attenuates the amount of energy present in the air volume, with emphasis on meeting the need for thermal comfort of pigs, when compared to forced ventilation (62.28 kJ kg^{-1}) and natural ventilation (72.87 kJ kg^{-1}).

Except for the radiant thermal load, the pens with evaporative cooling presented comfort indices according to the requirement of pigs in the growth phase (Justino et al., 2015; Amaral et al., 2014), which indicates that it is the most efficient means of climate control in maintaining the thermal comfort of the animals.

The variables RR and RT at 0 h showed the lowest values in animals subjected to the evaporative cooling system associated with lighting for 18 h (Table 1), conditioned by the effect of climate control and rest time of the animals before the activation of the lighting in the 18 h light program, in which the lamps were turned on only at 23 h. Differently, ST showed the lowest value for the evaporative cooling system associated with lighting for 12 h. Similar results were obtained by Ferreira et al. (2015).

The lighting program with 16 h of light resulted in the prolongation of the day with no possibility of rest for the animals, because the lamps were turned on from 18 h and remained on until 22 h, that is, the animals remained active, which led to the highest values of the physiological variables studied. Amaral et al. (2014) also reported an increase in the RR of pigs subjected to a continuous program with 23 h of light, but a shed with no climate control.

The RR of animals exposed to evaporative cooling and 18 h of light was 36 mov min^{-1}, below that found by Oliveira et al. (2019a), corresponding to 45.9 mov min^{-1}, for pigs subjected to ambient temperature of 21 °C (Table 1). It is possible that at the time of measurement, the animals in pens with no climate control and with forced ventilation were still under the influence of the thermal stress suffered during the day, since this factor is proportional to stress intensity and duration, so the RR values were still high at the time of record.



Means followed by the same letter, within each time, are do not differ statistically from each other by Tukey test at $p \leq 0.05$

Figure 2. Mean values of radiant thermal load - RTL (A); temperature and humidity index - THI (B); black globe temperature and humidity index - BGTHI (C) and enthalpy - h (D), in the containment pens along the experimental period

Table 1. Mean values of respiratory rate (RR), rectal temperature (RT) and surface temperature (ST) in three lighting and climate control programs

Time (h)	Variables	Climate control		Lighting (hours) L12	L16	L18
0	Respiratory rate (mov min^{-1})	NC		55.0 a AB	62.0 a A	50.0 a B
		FV		44.0 b B	62.0 a A	53.0 a A
		EC		43.0 b B	57.0 b A	36.0 b C
	Rectal temperature (°C)	NC		39.0 a B	39.4 a A	39.2 a AB
		FV		38.8 a B	39.2 b A	38.2 b B
		EC		38.6 b A	38.9 b A	38.0 b B
	Surface temperature (°C)	NC		35.8 a A	34.4 b B	34.4 a B
		FV		34.0 b C	35.3 a A	34.1 a B
		EC		32.1 c B	33.6 c A	33.8 b A
12	Respiratory rate (mov min^{-1})	NC		63.0 a A	67.3 a A	63.6 a A
		FV		50.3 b A	61.0 b A	57.3 b A
		EC		47.3 b B	61.3 b A	43.6 c B
	Rectal temperature (°C)	NC		39.1 a A	39.2 a A	38.9 a A
		FV		38.9 b A	39.0 a AB	38.6 b B
		EC		38.7 b A	38.9 b A	38.5 b B
	Surface temperature (°C)	NC	37.3 a	37.7 a A	37.3 a A	36.9 a A
		FV	35.3 c	35.2 a A	35.7 a A	34.9 a A
		EC	36.3 b	35.8 a A	36.3 a A	36.9 a A

NC - Pens with no climate control; FV - Pens with forced ventilation; EC - Pens with adiabatic evaporative cooling system (EC); L12 - 12 h of natural light; L16 - 12 h of natural light + 4 h of artificial light; L18 - 12 h of natural light + 6 h of artificial light; Means followed by same lowercase letters in the column (climate control) and uppercase letters in the row (lighting programs) do not differ statistically by Tukey test ($p \leq 0.05$)

The RT of the animals housed in the pen with no climate control and with 16 h of light showed higher average (39.4 °C), being equal to the limit of homeothermy for pigs (Santos et al., 2018). The lowest mean RT (38.0 °C) was observed in animals housed in the pen with evaporative cooling and 18 h of light, with significant difference between those subjected to pens with no climate control, which did not differ from the animals exposed to pens with forced ventilation (Table 1).

All the means for skin surface temperature of the animals (ST) at 0 h showed difference ($p \leq 0.05$) for the factors climate control and lighting programs. The highest mean ST (35.8 °C) was found in animals housed in pens with no climate control and the lowest value (32.1 °C) in animals subjected to evaporative cooling and 12 h of light (Table 1).

For the time of 12 h, the effect of climate control was more evident in the alteration of physiological variables than that of the lighting program. It was verified that animals subjected to evaporative cooling had lower values of RR ($p \leq 0.05$) associated with the 12 and 18 h light programs. The lowest RR occurred for evaporative cooling associated with 18 h of light. ST was lower in animals exposed to forced ventilation, but without significant effect for lighting programs (Table 1).

Weight gain (WG, kg) and feed intake (FI, kg) showed significant interactions ($p \leq 0.05$), but feed conversion (FC, kg kg^{-1}) was only affected by climate control (Table 2).

The effect of climate control on WG, associated with the lighting programs, showed that, in the program with 12 h of light, the animals in pens with evaporative cooling differed statistically ($p \leq 0.05$) from those in the others, but they did not differ from each other.

In the 16-hour lighting program, the animals housed in pens with no climate control and with forced ventilation showed no significant difference; however, the animals under no climate control differed ($p \leq 0.05$) from those under evaporative cooling.

Table 2. Mean values of weight gain (WG), feed intake (FI) and feed conversion (FC) in three lighting and climate control programs

Variables	Climate control		Lighting (hours) 12	16	18
Weight gain (kg)	NC		20.8 b AB	18.9 b B	23.1 a A
	FV		23.8 b A	22.6 ab A	25.6 a A
	EC		27.6 a A	24.2 a AB	23.3 a B
Feed intake (kg)	NC		44.1 b B	42.2 b B	51.2 b A
	FV		53.7 a AB	51.2 a B	56.4 a A
	EC		54.0 a A	48.8 a B	42.4 c C
Feed conversion (kg kg^{-1})	NC	2.1 a	2.1 a A	2.2 a A	2.2 a A
	FV	2.2 a	2.3 a A	2.2 a A	2.2 a A
	EC	1.9 b	2.0 a A	2.0 a A	1.9 a A

NC - Pens with no climate control; FV - Pens with forced ventilation; EC - Pens with adiabatic evaporative cooling system (EC); L12 - 12 h of natural light; L16 - 12 h of natural light + 4 h of artificial light; L18 - 12 h of natural light + 6 h of artificial light; Means followed by same lowercase letters in the column (climate control) and uppercase letters in the row (lighting programs) do not differ statistically by Tukey test ($p \leq 0.05$)

For the lighting programs considering the climate control factor, it was observed that the WG of animals under no climate control showed difference ($p \leq 0.05$) only between those which received 18 and 16 h of light, with no difference when exposed to forced ventilation. Animals subjected to pens with evaporative cooling showed difference ($p \leq 0.05$) for WG only between the animals subjected to the programs with 12 and 18 h of light.

The highest average of WG was recorded in animals exposed to evaporative cooling with no lighting supplementation, which was 46% higher than that in animals under no climate control and with 16 h of light. Conversely, a study conducted by Simitzis et al. (2013) indicates that the animals exposed to the longest lighting period showed greater weight gain.

The means of FI show that when considering the climate control factor associated with the 12 and 16 h lighting programs, a statistical difference ($p \leq 0.05$) was observed between animals in the pen with no climate control and the others. The FI of the animals exposed to 18 h of light differed significantly ($p \leq 0.05$) between all treatments, with the highest average for animals housed in the pens with forced ventilation. This result is in accordance with those obtained by Madeira et al. (2006), who observed higher feed intake by animals subjected to forced ventilation, compared to natural ventilation and ventilation associated with nebulization (Table 2).

In relation to the lighting programs, in pens with no climate control, there was a difference ($p \leq 0.05$) between the FI means of the animals subjected to the 18 hour lighting program compared to the others.

For animals in the pen with forced ventilation, the FI showed difference ($p \leq 0.05$) between those exposed to 16 and 18 h of light, while those subjected to evaporative cooling showed difference ($p \leq 0.05$) between all lighting programs, with the highest average in animals that did not receive light supplementation (Table 2).

Therefore, it is verified that the animals subjected to forced ventilation consumed more feed, confirming the results found by Oliveira et al. (2019b), when assessing climate control systems for growing pigs.

Brustolini & Fontes (2014) state that under temperature conditions above the upper critical temperature (UCT), the effects on pig weight gain is a factor of great relevance because, at each centigrade degree of increment there is a 55 g reduction in feed intake.

Animals exposed to evaporative cooling showed better response compared to those in pens with forced ventilation and with no climate control. Oliveira et al. (2019a) also observed worse feed conversion of growing pigs under heat stress, being 13.6% higher compared to that of animals kept under thermal comfort. This was not evidenced by Berton et al. (2015), who found that, although better WG and FI were obtained in animals under thermal comfort, FC was worse compared to those kept at high temperatures.

Evaporative cooling promoted better WG and FC, and light supplementation is dispensable considering the evaluated variables. It is also possible to highlight that, although the animals housed in pens equipped with forced ventilation consumed more feed, the nutritional content of the diet was probably used by their body to dissipate heat, aiming at the maintenance of homeothermy, which resulted in lower weight gain compared to animals subjected to evaporative cooling, consequently influencing the observed feed conversion levels.

Conclusions

1. Evaporative cooling system attenuated air temperature and ensured adequate thermal conditions for pigs.

2. Respiratory rate and rectal temperature indicated that evaporative cooling ensured the maintenance of homeothermy in the pigs.

3. Weight gain and feed conversion were positively influenced in pigs exposed to evaporative cooling, but with no effect of lighting programs.

Acknowledgments

The present work was carried out with support from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Financing Code 001.

Literature Cited

Amaral, P. I. S.; Ferreira, R. A.; Pires, A. V.; Fonseca, L. S.; Gonçalves, S. A.; Souza, G. H. C. Desempenho, comportamento e respostas fisiológicas de suínos em terminação submetidos a diferentes programas de luz. Journal of Animal Behaviour and Biometeorology, v.2, p.54-59, 2014. https://doi.org/10.14269/2318-1265.v02n02a05

Berton, M. P.; Dourado, R. C.; Lima, F. B. F.; Rodrigues, A. B. B.; Ferrari, F. B.; Vieira, L. D. C.; Souza, P. A.; Borba, H. Growing-finishing performance and carcass yield of pigs reared in a climate-controlled and uncontrolled environment. Internationa Journal of Biometeorology, v.59, p.955-960, 2015. https://doi.org/10.1007/s00484-014-0908-3

Brustolini, A. P. L.; Fontes, D. Fatores que afetam a exigência nutricional de suínos na terminação. 1.ed. Brasília: Coordenação Técnica da Integral Soluções em Produção Animal, 2014. 680p.

Buffington, D. E.; Collasso-Arocho, A.; Canton, G. H.; Pit, D. Black globe-humidity index (BGHI) as comfort equation for dairy cows. Transactions of the American Society of Agricultural Engineers, v.24, p.711-714, 1981. https://doi.org/10.13031/2013.34325

Esmay, M. L. Principles of animal environment. Westport: Avi, 1982. 325p.

Ferreira, R. A.; Fassani, E. J.; Ribeiro, B. P. V. B.; Oliveira, R. F. de; Cantarelli, V. de S.; Abreu, M. T. de. Programas de luz para suínos em crescimento. Archives of Veterinary Science, v.20, p.65-70, 2015. https://doi.org/10.5380/avs.v20i3.39679

Justino, E.; Nääs, I. A.; Carvalho, T. M. R.; Salgado, D. A. Efeito do resfriamento evaporativo e do balanço eletrolítico sobre a lactação de porcas em condições de verão tropical. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, v.67, p.455-464, 2015. https://doi.org/10.1590/1678-6478

Madeira, J. G. P.; Figueiredo, A. V.; Azevedo, D. M. M. R.; Costa, A. P. Utilização de nebulização e ventilação forçada em maternidades de suínos. Revista Brasileira de Saúde e Produção Animal, v.8, p.51-58, 2006.

Oliveira, R. F.; Moreira, R. H. R.; Ribeiro, B. P. V. B.; Resende, M.; Chaves, R. F.; Gionbelli, M. P.; Ferreira, R. A. Acute heat stress compromises the physiology of growing pigs. Archivos de Zootecnia, v.68, p.300-302, 2019a. https://doi.org/10.21071/az.v68i262.4150

Oliveira, Z. B.; Bottega, E. L.; Oliveira, M. B.; Silva, C. M.; Tondolo, T. Análise do conforto térmico no estado do Rio Grande do Sul utilizando técnicas geoestatísticas e dados das normais climatológicas. Revista Engenharia na Agricultura, v.27, p.195-203, 2019b. https://doi.org/10.13083/reveng.v27i3.935

Pereira, T. L.; Titto, E. A. L.; Conte, S.; Devillers, N.; Sommavilla, R.; Diesel, T.; Dalla Costa, F. A.; Guay, F.; Friendship, R.; Crowe, T.; Faucitano, L. Application of a ventilation fan-misting bank on pigs kept in a stationary trailer before unloading: Effects on trailer microclimate, and pig behaviour and physiological response. Livestock Science, v.216, p.67-74, 2018. https://doi.org/10.1016/j.livsci.2018.07.013

Rodrigues, V. C.; Silva, I. J. O. da; Vieira, F. C.; Nascimento, S. T. A correct enthalpy relationship as thermal comfort índex for livestock. International Journal of Biometeorology, v.55, p.455-459, 2010. https://doi.org/10.1007/s00484-010-0344-y

Rostagno, H. S. Tabelas brasileiras para aves e suínos: Composição de alimentos e exigências nutricionais. 4.ed. Viçosa: UFV, 2017. 488p.

Santos, J. H. T.; Tinôco, I. de F. F. da; Costa, C. A. Avaliação diferentes sistemas de ventilação em terminação de suínos, para as condições do Centro-oeste brasileiro. Engenharia na Agricultura, v.20, p.201-209, 2012. https://doi.org/10.13083/1414-3984.v20n03a01

Santos, T. C. dos; Carvalho, C. da C. S.; Silva, G. C. da; Soares, T. E.; Moreira, S. de J. M.; Cecon, P. R. Influência do ambiente térmico no comportamento e desempenho zootécnico de suínos. Revista de Ciências Agroveterinárias, v.17, p.241-253, 2018. https://doi.org/10.5965/223811711722018241

SAS - Statistical Analysis System. SAS companion for the microsoft windows environment - version 8. Cary: SAS Institute, 2007. 672p.

Silva, T. G. F. da; Primo, J. T A.; Moura, M. S. B. de; Silva, S. M. S. e; Morais, J. E. F. de; Pereira, P. de C.; Souza, C. A. A. de. Soil water dynamics and evapotranspiration of forage cactus clones under rainfed conditions. Pesquisa Agropecuária Brasileira, v.50, p.515-525, 2015. https://doi.org/10.1590/S0100-204X2015000700001

Simitzis, P. A E.; Veis, D.; Demiris, N.; Charismiadou, M. A.; Ayoutanti, A.; Deligeorgis, E. G. The effects of the light regimen imposed during lactation on the performance and behaviour of sows and their litters. Applied Animal Behaviour Science, v.144, p.116-120, 2013. https://doi.org/10.1016/j.applanim.2013.01.014

Thom, E. C. The discomfort index. Weatherwise, v.12, p.57-59, 1959. https://doi.org/10.1080/00431672.1959.9926960

Tolon, Y. B.; Baracho, M. S.; Nääs, I. de A.; Rojas, M.; Moura, D. J. de. Ambiências térmica, aérea e acústica para reprodutores suínos. Engenharia Agrícola, v.30, p.1-13, 2010. https://doi.org/10.1590/S0100-69162010000100001